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When describing heat transfer problems, students often make the mistake of interchangeably using the terms heat and temperature. In fact, there is a clear difference between them. Temperature is a measure of the amount of energy that substance molecules have. This is a relative measure of how hot or cold the substance is and can be used to predict the direction of heat transfer. The temperature symbol is T. Common scales for temperature measurement are temperature scales Fahrenheit, Rankine, Celsius and Kelvin. Heat is energy during transportation. Energy transfer as heat occurs at the molecular level due to temperature difference. Heat can be transferred through solids and liquids through conduction, through fluid convection and through empty space by radiation. The heat symbol is Q. Common units for heat measurement are the British heat unit (Btu) in the English system of units and calories in the SI system (International Unit System). Heat and workDistinction should also be performed between the energy concepts of heat and work. Both represent energy in transition. The work is the transmission of energy resulting from the force acting remotely. Heat is the energy transmitted due to the temperature difference. Neither heat nor work are thermodynamic properties of the system. Heat can be transferred to or from the system and work can be done on or by the system, but the system cannot contain or store heat or work. Heat to the system and work from the system are considered positive amounts. When there is a temperature difference over the border, the second law of thermodynamics indicates that the natural flow of energy is from a warmer body to a colder body. The second law of thermodynamics denies the possibility of ever completely converting to work all the heat supplied to the system operating in the cycle. The Second Law of Thermodynamics, described by Max Planck in 1903, states: It is not possible to build an engine that will operate in a complete cycle and will not cause any other effect except weight gain and cooling of the tank. The second law says that if you draw heat from the tank to increase weight, the weight reduction will not generate enough heat to return the tank to its original temperature, and eventually the cycle will stop. If two blocks of metal at different temperatures are thermally insulated from their surroundings and are connected to each other, heat will flow from warmer to colder. Eventually, the two blocks reach the same temperature and the heat transfer stops. Power was not lost, but instead some of the energy was transferred from one block to another. Heat transfer modes are always transmitted when there is a temperature difference between two bodies. There are three basic ways of heat transfer: heat transfer by the action of atoms or molecules of the material to which the heat is transmitted. Convection involves heat transfer by mixing and moving macroscopic parts of the fluid. Radiation or radiant heat transfer involves the transfer of heat by electromagnetic radiation, which arises as a result of body temperature. Three ways of heat transfer will be described in more detail in the following chapters of this module. Heat flowMeasured heat is represented by the symbol . Common units for heat transfer rate Q ˜are Btu/hour. Sometimes it is important to determine the rate of heat transfer per unit area, or the heat flow that has the symbol . The units for heat flow are Btu/hr-ft2 Q ˜. The heat flow can be determined by dividing the heat transfer rate by the area through which the heat is transmitted. Q ˜//= Q ⁊ A (2-1)where:Q ⁊/ = heat flow (Btu/hr-ft2)Q ˜= bit rate (Btu/hour)A = area (ft2)Thermal conductivityThe property of a solid material is measured by a property called thermal conductivity (k) measured in Btu/hr-ft-oF. This is the degree of ability of the substance to transfer heat through the solid through the conduction. The thermal conductivity of most liquids and solids varies with temperature. For fumes, it depends on the pressure. Log Mean Temperature DifferenceIn heat exchanger applications, input and output temperatures are commonly specified based on the liquid in the pipes. The temperature change that occurs through the heat exchanger from the entrance to the exit is not linear. The exact temperature change between the two liquids in the heat exchanger is best represented by the average temperature difference log (LMTD or ΔTlm), defined in equation 2-2.ΔT 1m = (ΔT2 - ΔT1) / ln(ΔT2 /ΔT1) (2-2-T1) 2)where:ΔT2 = greater temperature difference between two streams of liquid either at the entrance or outlet to the heat exchangerΔT1 = a smaller temperature difference between two streams of liquids either at the entrance, or output to the heat exchangerConvective heat transfer coefficientConvective heat transfer coefficient (h), defines partially, heat transfer due to convection. The convective heat transfer coefficient is sometimes referred to as the film coefficient and represents the thermal resistance of a relatively stagnant layer of liquid between the heat transfer surface and the fluid medium. Common units used to measure the convective heat transfer coefficient are Btu/hr - ft2 - oF.Total heat transfer coefficientIn the case of combined heat transfer, it is common practice to combine the total heat transfer rate (Q), the total cross-sectional heat transfer area (Ao) and the total temperature difference (ΔThis) using the total heat transfer coefficient (Uo). Total heat the coefficient combines the heat transfer coefficient of two heat exchanger fluids and the thermal conductivity of heat exchanger pipes. Uo is specific to the heat exchanger and liquid that are used in the heat exchanger. Q ˜= Uo Ao ΔT0 (2-3)where:Q ≂ heat transfer rate (Btu/hr)Uo = total heat transfer coefficient (Btu/hour - ft2 - by F)Ao = total cross-section area for heat transfer (ft2)ΔThis = total temperature difference (oF)Bulk liquid temperature (Tb), referred to as bulk temperature, varies depending on the details of the situation. For flow adjacent to a hot or cold surface, Tb is the temperature of the liquid that is far from the surface, for example, the center of the flow channel. For cooking or condensation, TB is equal to the saturation temperature. Important information in this chapter is summarized below.•Heat is energy transmitted due to temperature difference.•Temperature is a measure of the amount of molecular energy contained in the substance.•Work is the transfer of energy resulting from a force acting remotely.•The second law of thermodynamics means that that heat is not transferred from the cold to a warmer body without any external energy source.•The conduction involves the transfer of heat by interaction of atoms or molecules of the material to which heat is transmitted.•Convection involves the transfer of heat by mixing and moving macrosecous parts of the liquid.•Radiation or radiant heat transfer, involves the transfer of heat by electromagnetic radiation that arises as a result of body temperature.•Heat flow is the transfer of heat per unit area.•Thermal conductivity is a measure of a substance's ability to transfer heat over itself.•Log the average temperature difference is ΔT, which most accurately represents ΔT for heat exchanger.•The local heat transfer coefficient represents the degree of ability to transfer heat through the stagnant film layer.•The total heat transfer coefficient is a measure of the heat exchanger's ability to transfer heat from one liquid to another.•Volume temperature is the temperature of the liquid , which best represents most of the liquid that is not physically connected to the heat transfer points. Chapter 2: Heat transfer managementConsumable involves heat transfer by interactions between adjacent material molecules. Heat transfer by the line depends on the driving force of the temperature difference and the resistance to heat transfer. Heat transfer resistance depends on the nature and dimensions of the heat transfer medium. All problems with heat transfer include temperature difference, geometry and physical properties of the object being studied. When transferring heat during wiring the object being studied is usually fixed. Problems with convection include fluid media. Problems with radiation heat transfer include solid or liquid surfaces separated by gas, steam or vacuum. There are several ways to correlate the geometry, physical properties, and temperature difference of an object with the rate at which heat is transmitted over an object. When transferring heat to the wiring, the most common means of correlation is the Fourier Act of Conduction. The law, in its equation form, is most often used in its rectangular or cylindrical form (tubes and cylinders), both of which are listed below. Rectangular: Q ≂ k A (ΔT/Δx) (2-4)Cylindrical: Q ≂ k A (ΔT/Δr) (2-5)where:Q ≂ heat transfer rate (Btu/hour)A = cross-sectional heat transfer area (ft2)Δ <3> <9>x = plate thickness (ft)Δr = cylindrical wall thickness (ft)ΔT = temperature difference (°F)k = thermal conductivity of the plate (Btu/ft-hr-F)The use of equations 2-4 and 2-5 in determining the amount of heat transmitted by the line is shown in the following examples. Line-Rectangular coordinatesSampling:1000 Btu/hour is carried out through the part of the insulating material shown in Figure 1, which measures 1 ft2 in cross-section. The thickness is 1 in. and the thermal conductivity is 0.12 Btu / hr-ft-° F. Calculate the temperature difference between the material. Figure 1: Guide via board solution: Using equation 2-4:Q ≂ kA (ΔT/Δx)Solution for ΔT:ΔT = Q (Δx/kA)ΔT = (1000 (btu/hour) (1/1/1/2 1/112ft) /(o.12 Btu/hr-ft-°F) (1ft2)ΔT = 694°FExample:Concrete floor with conductivity of 0.8 Btu /hr-ft-F measures 30 ft by 40 ft with a thickness of 4 inches. The floor has a surface temperature of 70 ° F and the temperature below it is 60 ° F. What is the heat flow and heat transfer rate across the floor? Solution: Using equations 2-1 and 2-4:Q ⁊/ = Q ⁊A = k (ΔT/Δx) = (0.8 Btu/hr-ft-°F) (10°F/0.333ft) =24 Btu/hr-ft2Using 2 2-ft2 3:Q ≂ kA (ΔT/Δx) = Q ⁊/ AQ níci= (24 Btu/hr-ft2)(1200 ft2)Q ≂ 28 800 Btu/hrIt is possible to compare heat transfer with current current in electrical circuits. The heat transfer rate can be considered a current flow and a combination of thermal conductivity, material thickness and surface as resistance to this flow. The temperature difference is a potential or driving function for heat fluctuation, resulting in the Fourier equation being written in a form similar to Ohm's Law of Electrical Circuit Theory. If the term thermal resistance Δx/k is written as a term of resistance, where resistance is reciprocal thermal conductivity divided by material thickness, the result is a conduction equation similar to electrical systems or networks. The electrical analogy can be used to solve complex problems related to both series and thermal resistances. The student is referred to in Figure 2, showing the equivalent resistance of the circuit. A typical problem with the wiring in its similar electrical form is given in the following example, where the electrical Fourier equation can be written as follows. Q ⁊/ = ΔT / Rth (2-6)where:Q ⁊/ = Heat flow (/A) (Btu/hr-ft2)ΔT = Temperature difference (oF)のRth = thermal resistance (Δx/k) (hr-ft2 – oF/Btu)Figure 2: Equivalent resistanceElectric analogue mixture:The composite protective wall consists of a copper plate of 1 in, 1/8 inches. asbestos layer, and 2 in. layer of fiberglass. The thermal conductivity of materials in Btu/hr-ft-o F units is as follows: kCu = 240, kasb = 0.048 and kfib = 0.022. The total temperature difference on the wall is 500 ° F. Calculate the thermal resistance of each wall layer and the rate at which heat transfer per unit area (heat flow) is calculated through the composite structure. Solution:Rcu = Δxcu / kcu = 1in (1ft/12in)/240 Btu/hr-ft-°F = 0.000347 hr-ft2-°F/BtuRasb = Δxasb / kasb= 0.125 (1ft/12in) / 0.048 Btu/hr-ft-°F= 0.2170 hr-ft2-°F/BtuRfib = Δxfib / kfib= 2in (1ft/1 0.022 Btu/hr-ft-°F= 7.5758 hr-ft2-°F/BtuQ ⁊ A = (T1-T0) / (Rcu+Rasb+Rfib)= 500°F/(0.000347 + 0.2170 +7.5758) hr-ft2-°F/Btu= 64.2 Btu/hr-ft2Conducting cylindrical coordinatesConduction cylindrical coordinatesConduction of thunder through a rectangular body is the most direct application of the Fourier Act. Heat transfer through the pipe or wall of the heat exchanger pipe is more difficult to evaluate. Over the cylindrical wall, the area of heat transfer is constantly increasing or shrinking. Figure 3 is a cross-sectional view of a pipe made of homogeneous material. Figure 3: The surface area of the cross-section of the cylindrical pipeA flat area (A) for heat transfer by pipe (neglect of the ends of the pipe) is directly proportional to the radius (r) of the pipe and the length (L) of the pipe. A = 2 π r LA radius increases from the inner wall to the outer wall, the area of heat transfer increases. The development of the equation evaluating heat transfer by an object with cylindrical geometry begins with the Fourier equation 2-5.Q ˜= kA (ΔT/Δr)From the above discussion it can be seen that no simple expression for the area is accurate. Neither the face of the inner surface nor the surface of the outer surface can be used in the equation. For a problem related to cylindrical geometry, it is necessary to define the average cross-sectional area of the log (Alm). Alm = Aouter – Ainner/ ln (Aouter / Ainner) (2-7)Replacing the expression 2πrL for the area in equation 2-7 allows you to calculate the average area of the protocol from the inner and outer radius, without first calculating the inner and outer regions. Alm = 2 π router L - 2 π rinner L / Ln (2 π router L / 2 π rinner L) = 2 π L (router - rinner / Ln router / The expression for the medium log area can be inserted into equation 2-5, which allows us to calculate the heat transfer rate for cylindrical geometry. Q ≂ k A lm (ΔT/Δr) = k [2 π L (r0-ri / ln ro / ri)] (To-Ti/r0-ri)Q ≂ 2 π to L (ΔT)/ ln (ro (ro (ro / ri) (2-8)where:L = pipe length (ft)ri = inner radius of the pipe (ft)ro = radius of the outer tube (ft)Example: The 35 ft stainless steel pipe has an internal diameter of 0.92 ft and an outer diameter of 1.08 ft. The temperature of the inner surface of the pipe is 122o F and the temperature of the outer surface is 118o F. Thermal conductivity of stainless steel is 108 Btu / hr-ft-o F.Calculate the rate of heat transfer through the pipe. Calculate the heat flow on the outer surface of the pipe. Solution:Q ̃= 2 π to L (Th - Tc) / ln (ro/ri) = 6.28 (108 Btu/hr-ft-°F) (35 ft) (35 ft) (35 ft) 1 22°F - 118°F) / ln (0.54 ft/0.46 ft) = 5.92 x 105 Btu/hrQ ̃/ = Q ̃/ A = Q / 2 π ro L = 5.92 x 105 Btu/hour / 2 (3.14) (0.54 ft) (35 ft) =4985 Btu/hr-ft2Sample:The length of a 10ft tube with an internal radius of 1in and an external radius of 1.25in has an external surface temperature of 250°F. Heat transfer is 30,000 Btu/hour. Find the internal surface temperature. Suppose k = 25 Btu/hr-ft-°F.Solution:Q ̃= 2 π l (Th – Tc) / ln (r0/ ri)Solution for Th:Th = [Q ̃ln (ro / ri) / 2 π k L] + Tc = [(30,000 Btu (at 30,000 Btu/hour) (at 30,000 Btu/hour) (at 30,000 Btu/hour) (at 30,000 Btu/hour) (at 30,000 Btu/hour) (at 30,000 Bt (at 30,000 Btu/hour) (at 30,000 Btu/hour) (at 30,000 Btu/hour) (at 30,000 Btu/hour) (at 30,000 Btu/hour) (at 211.25in /2 (3.14) (25 Btu/hr-ft-F)(10ft)] + 250°F = 254°FThe heat transfer order over the cylindrical wall can be extended to include a composite body composed of several concentric cylindrical layers, As shown in Figure 4.Figure 4: Composite cylindrical layersExample:Thick-walled nuclear cooling pipe (ks = 12,5 Btu/hr-ft-F) with 10 inches. inner diameter (ID) and 12 inches. the outer diameter (OD) is covered by 3 in. asbestos insulation (ka = 0,14 Btu/hr-ft-o F), as shown in Figure 5. If the temperature of the inner wall of the pipe is maintained at 550 ° F, calculate the heat loss to the length of the trace. The outside temperature is 100°F.Figure 5: ProblemSolution pipe insulation: Q̇ / L = 2 π (Tin – To) / {[ln (r2 / r1) / ks] + [ln (r3 / r2) / ka]} Q̇ / L = 2 π (550°F - 100°F) / {[ln (6 in/ 5 in.) / 12.5 Btu/hr-ft-°F] + [ln (9 in. / 6.) / 0.14 Btu/hr-ft-°F]} Q̇ / L = 971 Btu/hr-ft-°F Important information in this chapter is summarized below.• Heat transfer line is the transfer of thermal energy by interactions between adjacent material molecules.• Heat transfer lines are the interactions between adjacent material molecules.• Heat transfer lines are the interactions between adjacent material molecules.• Heat transfer lines • Fourier's conduction law can be used to solve problems with rectangular and cylindrical coordinates.• Heat flow (Q) is the heat transfer rate (Q) divided by an area (A).• Heat conduction problems can be solved using equivalent resistance patterns analogous to electrical circuit problems. Chapter 3: Convection Heat involves heat transfer by moving and mixing macroscopic parts of the fluid (that is, fluid flow beyond a fixed boundary). The term natural convection is used when this movement and mixing is caused by changes in density resulting from temperature differences inside the liquid. The term forced convection is used when this movement and mixing is caused by an external force such as a pump. Heat transfer from the hot water radiator to the room is an example of heat transfer by natural convection. An example of forced convection is the transfer of heat from the surface of the heat exchanger to the bulk of the liquid pumped by the heat exchanger. Heat transfer by convection is more difficult to analyze than heat transfer by conduction, because no heat transfer media property, such as thermal conductivity, can be defined to describe the mechanism. Heat transfer by convection varies from situation to situation (on fluid flow conditions) and is often associated with liquid flow mode. In practice, the analysis of heat transfer by convection is treated empirically (by direct observation). Convection heat transfer is treated empirically due to factors affecting stagnant film thickness:• Liquid speed• Liquid viscosity• Heat flow• Surface roughness• Flow type (single-phase/two-phase)Convection involves heat transfer between the surface at a given temperature (Ts) and liquid at a flat temperature (Tb). The exact definition of the flue temperature (TB) varies depending on the details of the situation. For flow adjacent to a hot or cold surface, Tb is the temperature of the liquid far from the surface. For cooking or condensation, Tb is the temperature of saturation of the liquid. For flow in the pipe, Tb is the average temperature measured on a specific cross-section of the pipe. The basic relationship for convection heat transfer takes the same form as for heat transfer by line:Q ̃= h A ΔT (2-9), where:Q ̃= heat transfer rate (Btu/hr)h = convective heat transfer coefficient (Btu/hr-ft2 -°F)A = heat transfer area (ft2)ΔT = temperature difference (°F)Convective heat transfer coefficient (h) depends on the physical properties of the liquid and the physical situation. The convective heat transfer coefficient for laminar flow is usually relatively low compared to the convective heat transfer coefficient for turbulent flow. This is due to the turbulent flow rate, which has a thinner layer of stagnant liquid film on the surface of heat transfer. The h values were measured and given in the table for commonly occurring liquids and flow situations occurring during heat transfer by convection. Example: A 22-foot uninsulated steam line passes through the room. The outer diameter of the steam pipe is 18 inches and the temperature of the outer surface is 280 oF. Convective the air transmission coefficient is 18 Btu/hr-ft2 – oF. The rate of heat transfer from the pipe to the room is calculated if the room temperature is 72oF.Solution: Q ̃= h A ΔT=h (2 π r L) ΔT=(18 Btu/hr-ft2-oF) (2 (2 (2(18 Btu/hr-ft2-oF) (2 (2 (2(18 Btu/hr-ft2-oF) oF) (2 (2 (2 (2 (2 (2 (2 (2 (2(23.14)(0.75 ft) (22ft) (280oF - 72oF)=3.88 x 105 Btu/hr Applications involving convective heat transfer takes place in pipes, pipes, or similar cylindrical equipment. In such circumstances, the heat transfer area normally specified in the convection equation (Q ̃= h A ΔT) varies according to the temperature passing through the cylinder. In addition, the temperature difference existing between the inner and outer pipes, as well as the temperature differences along the pipe, requires the use of some average temperature values in order to analyze the problem. This average temperature difference is called the average temperature difference log (LMTD) described above. This is the temperature difference at one end of the heat exchanger minus the temperature difference at the other end of the heat exchanger, divided by the natural logarithm of the ratio of the two temperature differences. The above definition for LMTD includes two important assumptions: (1) liquid-specific heat does not differ significantly with temperature, and (2) convection heat transfer coefficients are relatively constant throughout the heat exchanger. Total heat transfer coefficientMy heat transfer processes that we encounter in nuclear facilities include a combination of conduction and convection. For example, heat transfer in a steam generator involves convection from the bulk of the reactor coolant to the surface of the steam generator's internal pipe, conduction through the pipe wall, and convection from the outer surface of the pipe to the secondary side liquid. In the case of combined heat transfer for the heat exchanger, there are two values for h. For liquid film inside pipes there is a convective coefficient of heat transfer (h) and a convective coefficient of heat transfer for liquid film outside the pipes. The thermal conductivity (k) and thickness (x) of the pipe wall must Δ taken into account. Instead, an additional term (Uo), called the total heat transfer coefficient, must be used. It is common practice to combine the total heat transfer rate ( ) with the cross-sectional heat transfer area (Ao) and the total heat transfer coefficient Q ̃(Uo). The relationship of the total heat transfer coefficient to the individual terms of conduction and convection is shown in Figure 6.Figure 6: Total heat transfer coefficientThe calling equation 2-3:Q ̃= Uo Ao Δ Child Uo is defined in Figure 6.An an example of this concept applied to cylindrical geometry is shown in Figure 7, which shows the typical situation of combined heat transfer. Figure 7: Combined heat transferUse in the figure representing the flow in the pipe, the transfer of heat by convection between temperatures T1 and T2; the heat transfer of the conduction takes place between temperatures T2 and T3; and heat transfer occurs by convection between temperatures T3 and T4. Therefore, these are three processes. Each has an associated heat transfer coefficient, a cross-sectional area for heat transfer and a temperature difference. The basic relationships for these three processes can be expressed using equations 2-5 and 2-9.Q ̃= h1 A1 (T1 - T2)Q ̃= (k / Δr) Alm (T2 - T3)Q ̃= h2 A2 (T3 - T4)ΔIt can be expressed as the sum of ΔT of the three individual process.ΔTo = (T1 - T2) + (T2 - T3) + (T3 - T4)If the basic relationship for each process is resolved for the related temperature difference and replaced by the expression for ΔThis above, the following relationship results.ΔTo = Q ̃[(1 / h1 A1) + (Δr / k Alm) + (1 / h2 A2)]This relationship can be adjusted by selecting the reference cross-sectional area Ao.ΔTo = (Q ̃/ Ao) [(Ao / h1 A1) + (ΔR Ao / k Alm) + (Ao / h2 A2)]Solution for Q ̃results in equation in the form Q ̃= Uo Ao ΔToQ ̃= [1 / [(Ao / h1 A1) + (Δr Ao / k Alm)+ (Ao / h2 A2)]] Ao ΔTo (2-10)where :Uo = 1 / [(Ao / h1 A1) + (ΔR Ao / k Alm)+ (Ao / h2 A2)]Equation 2-10 for the total coefficient of heat transfer in cylindrical geometry is quite difficult to work with. The equation may be simplified without loss of great accuracy if the tube analysed is thin-walled, i.e. if the tube being analysed is thin-walled. For a thin-walled pipe, the inner surface area (A1), the outer surface area (A2) and the average logo surface (A1m) are very close to being the same. Assuming that A1, A2, and A1m are equal to each other and also equal to Ao allows us to cancel all the conditions of the area in the denominator of equation 2-11.This results in a much simpler expression, which is similar to the one developed for the flat heat exchanger in Figure 6.Uo = 1 /[(1 /h1) + (Δr / k) + (1 / h2)]The process of heat transfer convection is strongly dependent on the properties of the liquid under considered. Accordingly, the convective heat transfer coefficient (h), the total coefficient (Uo) and other properties of the liquid may vary substantially for the liquid if there is a major temperature change during its journey through a convective heat transfer device. This is especially true if the properties of the liquid are strongly dependent on temperature. Under these circumstances, the temperature at which properties are searched must be a certain average value, not an input or output temperature value. For internal flow, the volume or average temperature value is obtained analytically using energy savings. For external flow, the average temperature of the film, which is average free current temperature and solid surface temperature. In any case, the average temperature value is used to obtain the properties of the liquid to be used in the heat transfer problem. The following example shows how to apply these principles by solving the problem of convective heat transfer, in which the temperature is calculated. ConvectionConvection heat transferExample:Flat wall is exposed to the environment. The wall is covered with a layer of insulation of 1 in. strong, the thermal conductivity of which is 0.8 Btu / hr-ft-° F. The wall temperature on the inside of the insulation is 600 ° F. The wall loses heat to the environment by convection on the surface of the insulation. The average value of the convection coefficient of heat transfer on the insulating surface is 950 Btu/hr-ft2 -°F. If the outer surface of the insulation does not exceed 105°F.Solution: a. Find the flow of the head (Q ̃//) through the insulation. Q ̃= k A (ΔT / Δx) Q ̃/ A = 0.8 (Btu / hr - ft - oF) [(600oF - 105oF) / (1in) (1ft / 12in)]Q ̃= 4752 Btu/(hr-ft2)b. Find the ambient temperature. Q ̃= h A (Cans - Tb)(Cans - TB) = Q ̃/ h ATb = Cans - Q ̃// hTb = 105oF - (4752 Btu/hr-hr-ft2)/950 Btu /hr-ft2-oF)Tb= 100oFReseachable information in this chapter is summarised belowConctional summary of heat transfer• Convection heat transfer is the transfer of heat energy mixing and movement of liquid or gas.• Whether convection is natural or forced, is determined by the fact that as the medium is set in motion.• If both convection heat transfer and wiring are the total heat transfer coefficient must be used to solve problems.• the heat transfer equation for convection heat transfer is• Q ̃= h A ΔTChapter 4: Radiant Heat TransferRadiant heat transfer involves heat transfer by electromagnetic radiation that arises as a result of body temperature. Most of the energy of this type is in the infrared area of the electromagnetic spectrum, although some of them are in the visible area. The term thermal radiation is often used to distinguish this form of electromagnetic radiation from other forms, such as radio waves, X-rays or gamma rays. Heat transfer from the fireplace through the room in the field of view is an example of radiant heat transfer. Radiant heat transfer does not need a medium such as air or metal to take place. Any material that has a temperature above absolute zero emits some radiant energy. When the sun covers the cloud, its heat and light diminish. This is one of the most famous examples of heat transfer by thermal radiation. Radiation of the black bodyThod, which emits the maximum amount of heat for its absolute temperature, is called the black body. The rate of transfer of radiant heat from the black body to the surrounding area can be expressed by the following = σ A T4 (2-12)where:Q ̃= heat transfer rate (Btu/hr)σ = Stefan-Boltzman constant (0,174 Btu/hr-ft2 -°R4)A = surface area (ft2)T = temperature (°R)Two black bodies radiating to each other have a clean heat flow between them. The net heat flow between them is determined by adjusting equation 2-12.Q ̃= σ A (T14 – T2 4), where:A = area of the first body (ft2)T1 = temperature of the first body (°R)T2 = temperature of the second body (°R)All bodies above absolute zero temperature emit some heat. The sun and the earth radiate warmth to each other. It seems to violate the second law of thermodynamics, which says that heat can not flow from a cold body to a hot body. The paradox is solved by the fact that each body must be in the direct field of view of the other in order to receive radiation from it. Therefore, whenever a cool body radiates heat to a hot body, the hot body must also radiate heat into the cool body. Since the hot body emits more heat (due to a higher temperature) than the cold body, the clean heat flow is from hot to cold, and the second law is still satisfied. EmisivityReal objects do not produce as much heat as a perfect black body. They emit less heat than the black body and are called gray bodies. To take into account the fact that the actual objects are gray bodies, equation 2-12 is adjusted to be the following shape. Q̇ = ε σ A T4where:ε = emissivity of the gray body (undimimidable)Emissivity is simply a factor by which we multiply the heat transfer of the black body, taking into account that the black body is an ideal case. Emissivity is a non-dimensional number and has a maximum value of 1,0.Radiation configuration factorRadiative heat transfer between two gray bodies can be calculated according to the equation below. Q ̃= fa fe σ A (T4 1 – T4 2),where:fa = is a form factor that depends on the spatial arrangement of both objects (undimimable)fe = is a factor of emissivity that depends on the emissivity of both objects (undimimidable)Two separate expressions fa and fe can be combined and given the symbol f. The thermal flow between two gray bodies can now be determined by the following equation:Q ̃= f σ A (T4 1 T4 2) (2-13)The symbol (f) is a non-dimensional factor sometimes called the radiation configuration factor that takes into account the emissivity of both bodies and their geometry. The radiation configuration factor is usually found in the textbook for the given situation. Once the configuration factor is obtained, the total net heat flow can be determined. Radiant heat flow should be included in the problem only if it is greater than 20% of the problem. Example:Calculate radiant heat between the floor (15ft x 15ft) of the furnace and the roof if both are located 10ft apart. The temperature of the floor and roof is 2000 °F and respectively. Suppose the floor and roof have black surfaces. Solution:A1 = A2 = (15 ft) (15 ft) = 225 ft2T1 = 2000 °F + 460 = 2460°RT2 = 600°F + 460 = 1060°RTables from the reference book, give:f1-2 = f2-1 = 0.31Q1-2 = σ A f (T1 4 - T24)= (0.174 Btu/hr-ft2 -oR4) (225 ft 2) (0.31) [(2460o R)4 – (1060o R)4]= 4.29 x 1014 Btu/hourThe summary information in this chapter is summarized below.• The radiation of the black body is the maximum amount of heat, which can be transferred from the ideal object.• Emissivity is the degree of deflection of the body from the ideal black body.• The radiation configuration factor takes into account the emitter and relative geometry of the two objects. Chapter 5: Heat exchangersMous transfer of thermal energy between liquids is one of the most important and frequently used processes in mechanical engineering. Heat transfer is usually carried out using a device known as a heat exchanger. Common applications of heat exchangers in the nuclear field include boilers, fan coolers, cooling water heat exchangers and capacitors. The basic design of the heat exchanger usually has two liquids of different temperatures separated by some conductive medium. The most common structure has one liquid flowing through metal pipes and the other fluid flowing around the pipes. On both sides of the tube, heat is transferred by convection. Heat is transferred through the wall of the pipe by a guide. Heat exchangers can be divided into several categories or classifications. In the most commonly used type of heat exchanger there are two liquids with different temperature flow in spaces separated by a tubular wall. They transfer heat through convection and conduction through the wall. This type is referred to as an ordinary heat exchanger, compared to the other two types classified as regenerators and cooling towers. A common heat exchanger is a single-phase or two-phase heat exchanger. In the single-phase heat exchanger, both liquids (cooled and heated) remain in the initial gaseous or liquid state. In two-phase heat exchangers, some of the liquids may change their phase during the heat exchange process. The steam generator and the main condenser of nuclear installations are two-phase, common classifications of the heat exchanger. Single-phase heat exchangers are usually tube and shell type; that is, the exchanger consists of a set of pipes in a container called a shell (Figure 8). At the ends of the heat exchanger, the liquid on the side of the pipe is separated from the liquid on the side of the shell by a tubular sheet. The design of the two-phase exchangers is essentially the same as that of single-phase exchangers. Figure 8: Typical pipes and shell heat exchangerParalel and anti flow patterns Although conventional heat exchangers can be very different in design and construction and can be single-phase or two-phase type, their modes of operation and efficiency are largely determined direction of flow of the liquid in the exchanger. The most common arrangement of flow paths within the heat exchanger are counterflow and parallel flow. A counter-flow heat exchanger is one in which the direction of flow of one of the working fluids is opposite to the direction of flow of the other liquid. In a parallel flow exchanger, both liquids in the heat exchanger flow in the same direction. Figure 9 represents the directions of fluid flow in parallel exchangers and counter-current exchangers. Under comparable conditions, more heat is transferred in the counter-current than in a parallel heat exchanger. Figure 9: Fluid flow directionThe temperature profiles of the two heat exchangers indicate two main disadvantages in the design of the parallel flow. First, a large temperature difference at the ends (Figure 10) causes a large heat stress. The opposite expansion and shrinkage of building materials due to different liquid temperatures can lead to possible material failure. Secondly, the temperature of the cold liquid protruding from the heat exchanger never exceeds the lowest temperature of the hot liquid. This relationship is a significant disadvantage if the purpose of the design is to increase the temperature of cold liquid. Figure 10: Temperature profiles of the heat exchanger Design of a parallel flow heat exchanger is advantageous if it is necessary to bring two liquids to almost the same temperature. The up-current heat exchanger has three significant advantages over the design of the parallel flow. First, a more uniform temperature difference between the two liquids minimizes heat stress throughout the exchanger. Secondly, the output temperature of the cold liquid can approach the highest temperature of the hot liquid (input temperature). Thirdly, a more uniform temperature difference creates a more uniform heat transfer rate throughout the heat exchanger. Whether parallel or counter-current, heat transfer within the heat exchanger involves both conduction and convection. One liquid (hot) convective transmits heat to the wall of the pipe, where the wiring runs through the pipe to the opposite wall. The heat is then convective transferred to the second liquid. Since this process takes place along the entire length of the exchanger, the temperature of the liquids that flow through the exchanger is not generally constant, but varies along the entire length, as shown in Figure 10. The rate of heat transfer varies along the entire length of the heat exchanger pipes, as its value depends on the temperature difference between hot and cold liquid in the displayed place. No regenerative heat exchangerAs of heat exchangers can be classified as regenerative or non-regenerative. Non-regenerative application is most common and includes two separate liquids. One liquid cools or heats the other without Fluid. Heat that is removed from a warmer liquid is usually rejected by the environment or other cooler (Figure 11). Figure 11: Non-regenerative heat exchangerRegenerational heat exchangerGenerative heat exchanger Regenerative heat exchanger usually uses liquid from another area of the same system for hot and cold liquids. An example of regenerative and non-regenerative heat exchangers operating in conjunction is commonly found in the reactor system cleaning system. The primary coolant to be cleaned is extracted from the primary system, passes through the regenerative heat exchanger, non-regenerative heat exchanger, demineralizer, back through the regenerative heat exchanger and returned to the primary systemIn the regenerative heat exchanger, water returning to the primary system is preheated with water entering the cleaning system. This achieves two objectives. The first of these devices is to minimize the thermal stress in the piping of the primary system due to the cold temperature of the purified coolant returned to the primary system. The second is to reduce the temperature of the water entering the cleaning system before reaching the non-regenerative heat exchanger, which allows the use of a smaller heat exchanger to reach the desired temperature for cleaning. The main advantage of the application of a regenerative heat exchanger is the preservation of system energy (that is, less loss of system energy due to liquid cooling). Figure 12: Regenerative heat exchangerThe heating towerTypical function of the cooling tower is to cool the water of the steam power plant with air, which is brought into direct contact with water. The water is mixed with steam, which disperses from condensate into the air. The formation of steam requires a significant removal of internal energy from the water; internal energy becomes latent heat of steam. Heat and mass exchange are combined in this process, which is a steady state of the process, such as heat exchange in a normal heat exchanger. Wooden cooling towers are sometimes used in nuclear installations and factories of various industries. They usually consist of large chambers freely filled with trays or similar wooden elements of construction. Water to be cooled is pumped to the top of the tower, where it is distributed by spray or wooden troughs. It then falls over the tower, splashing down from deck to deck. Part of it evaporates into the air that passes through the tower. The entfalps needed for evaporation are pumped out of the water and transferred to the air, which is heated while the water cools. The airflow is either horizontal due to wind currents (transverse currents) or vertically upstream in the upstream of falling water. The counter current is caused by the chimney effect of warm humid air in the tower or fans at the bottom (forced thrust) or on (induced flow) of the tower. Mechanical towing towers are more economical and smaller than natural convection towers with the same cooling capacity. Log Mean Temperature Difference Application To Heat Exchangers The average temperature difference of the log (LMTD or ΔTlm) must be evaluated before determining heat dissipation from the heat exchanger. The following example shows such a calculation. Example:The heat exchanger against liquid and liquid flow is used as part of an auxiliary system in a nuclear installation. The heat exchanger is used to heat cold liquid from 120°F to 310°F. Assuming that the hot liquid enters at 500 °F and leaves 400 °F, the LMTD for the exchanger shall be calculated. Solution:ΔT2 = 400°F - 120°F = 280°FΔT1 = 500°F - 310°F = 190°FΔTlm = (ΔT2 - ΔT1) / ln (190°FΔT2 / T1) = (280 °F - 190 °F/ ln (280 °F / 190 °F) = 232 °FThe cutting of the heat exchanger problem can be simple enough to represent the overall balance forward, or it can be so detailed, that requires an integral number. For example, a steam generator can be analyzed by the total energy balance from the supply water supply to the steam outlet, in which the amount of heat transmitted can be expressed simply as Q̇ = mΔh, where the mass flow of the secondary coolant and Δh is the changeentalpy of the liquid. The same steam generator can also be analyzed by the energy balance on the primary flow with the equation, Q̇ =ṁ cpΔT, where m ̃ cp and ΔT are the mass flow p, the specific thermal capacity and the temperature change of the primary coolant. The heat transfer rate of the steam generator can also be determined by comparing the temperatures on the primary and secondary side with the heat transfer characteristics of the steam generator using equation Q ̃= Uo Ao ΔTlm.Capacitors are also examples of components found in nuclear installations where the LMTD concept is needed to solve certain problems. When steam enters the capacitor, it gives up latent heat evaporation into circulating water and turns the phase into liquid. Since condensation occurs, it is advisable to indicate this latent heat of condensation. After the steam condenses, the filled liquid will continue to transfer heat to the circulating water system as it continues to drop to the bottom (hotwell) of the capacitor. This continued cooling is called hypothermia and is necessary to prevent kavitation in condensate pumps. Solving problems with the capacitor is solved in the same way as for steam generators, as shown in the following example. Total heat transfer coefficientWhen heat transfer is processed through heat exchanger pipes, the total heat transfer coefficient Uo is calculated. Earlier in this module, we looked at the method for Uo for both rectangular and cylindrical coordinates. Since the wall thickness of the condenser tube is so small and the cross-section area for heat transfer is quite constant, we can use equation 2-11 to calculate Uo.Uo = 1 / [(1 / h1) + (Δr / k) + (1 / h2)]Referring to the convection part of this manual, calculate the heat speed per tube track from the capacitor under the following conditions. ΔTlm = 232oF. The outer diameter of the copper condenser tube is 0.75 inches with a wall thickness of 0.1 inches. Suppose the internal convective heat transfer coefficient is 2000 Btu/hr-ft2 and the thermal conductivity of copper is 200 Btu/hr-ft2-oF. External convective heat transfer coefficient is 1500 Btu/hr-ft2 -°F.Solution: Uo = 1 / [(1 / h1) + (Δr / k) + (1 / h2)=1 / [(1 / 2000) + (0.1 in. / 200) + (1 ft. / 12 inches) + (1 / 1500)]= 827,6 Btu/hr-ft2 -°FQ ̃= Uo Ao ΔTlmQ ̃/ L = Uo Ao 000ΔTlm / L = Uo 2 π r ΔTlm = (827.6 Btu/hr-ft2 -°F) (2 π) (0.37 5 inches) (1 ft. / 12 inches.) (232 °F) = 37, 700 Btu/hr-ft2 -°PV nuclear device convective heat transfer is used to remove heat from the surface for heat transfer. The liquid used for cooling is usually in a compressed state (i.e. in a cooled liquid) at a pressure higher than the normal saturation pressure for a given temperature. Under certain conditions, a certain type of boil (usually boiling the core) may occur. Therefore, it is recommended to study the cooking process as it applies to the nuclear field when discussing convection heat transfer. More than one type of boiling can take place in a nuclear installation, especially if the coolant pressure is quickly lost. Discussing boiling processes, namely local and mass boiling, will help the student understand these processes and provide a clearer idea of why mass boiling (specifically film boiling) should be avoided in nuclear facilities. The most common type of local boiling, which occurs in nuclear facilities, is the cooking of nuclei. When the nucleate boils, steam bubbles form on the surface of the heat transfer, which are then torn off and transferred to the mainstream liquid. Such movement increases heat transfer, because the heat generated on the surface is transferred directly to the liquid stream. Once measured into the mainstream liquid, the bubbles collapse because the volume temperature of the liquid is not as high as the heat transfer surface temperature where the bubbles were formed. This heat transfer process is sometimes desirable because the energy generated on the heat transfer surface is quickly and efficiently taken away. As the temperature of the system increases or the pressure of the system decreases, the volume fluid can reach saturation conditions. At this time, the bubbles entering the coolant channel do not collapse. Bubbles will tend to merge to form larger steam bubbles. Phenomenon known as bulk cooking. Bulk cooking can ensure sufficient heat transfer provided that the steam bubbles are taken away from the heat transfer surface and the surface is constantly moistened with liquid water. When this can not occur the results of cooking the film. When the pressure of the system drops or the flow drops, the bubbles can not escape so quickly from the surface of the heat transfer. Similarly, if the temperature of the heat transfer surface increases, more bubbles are formed. As the temperature continues to rise, more bubbles are formed than can be effectively hijacked. Bubbles grow and associate and cover small areas of the heat transfer surface with steam film. This is known as a partial film of boiling. Since steam has a lower convective heat transfer coefficient than water, steam patches on the heat transfer surface act by isolating the surface, making heat transfer difficult. As the surface area for heat transfer covered with steam increases, the surface temperature increases dramatically, while the heat flow from the surface decreases. This unstable situation continues until the affected surface is covered with a stable blanket of steam, which prevents contact between the heat transfer surface and the liquid in the center of the flow channel. The condition after the formation of a stable steam blanket is referred to as cooking film. The process of switching from boiling nucleate to cooking film is graphically shown in Figure 13. The figure shows the effect of boiling on the relationship between the heat flow and the temperature difference between the heat transfer surface and the liquid that passes through it. In Figure 13, four regions are represented. The first and second areas show that as the heat flow increases, the temperature difference (surface to liquid) does not change much. Better heat transfer occurs when cooking nucleate than with natural convection. As the heat flow increases, the bubbles become so much that there is a partial cooking of the film (part of the surface covered with bubbles). This area is characterized by an increase in the temperature difference and a decrease in heat flow. Thus, the increase in the temperature difference causes the overall cooking of the film, in which the steam completely covers the surface of the heat transfer. In practice, if the heat flow increases, suddenly there is a transition from boiling nucleate to cooking film, and the temperature difference increases rapidly, as shown by the dashed line in the picture. The point of transition from boiling nucleate to boiling film is called the point of departure from the boiling of the nuclei, commonly written as DNB. The heat flow associated with DNB is commonly called critical heat flow (CHF). In many applications, CHF is an important parameter, for example, in a reactor, if the critical heat flow is exceeded and DNB occurs at any point in the core, the temperature difference required to transfer heat generated from the surface of the fuel rod to the reactor coolant increases considerably. If, as it could be, the temperature increase causes the fuel rod to exceed its design limits, a failure occurs. The amount of convection heat transfer can only be determined after the local heat transfer coefficient has been determined. This determination shall be based on available experimental data. After experimental data are correlated with dimensional analysis, it is common practice to write an equation for a curve that has been drawn through data and compare experimental results with those obtained by analytical means. When applying any empirical equation for forced convection to practical problems, it is important that the student remembers that the predicted values of the heat transfer coefficient are not accurate. The heat transfer coefficient values used by students can vary widely from student to student, depending on the source of the book the student used to obtain information. In turbulent and laminar flow, the accuracy of the heat transfer coefficient predicted from any available equation or graph shall not be better than 30 %. The rate of heat formation in the nuclear core is directly proportional to the rate of fuel fission and the thermal neutron present. On a flat thermodynamic basis, the same heat generation is also related to the temperature difference of the liquid throughout the core and the mass flow of the liquid passing through the core. The size of the reactor core is therefore dependent and limited by how much liquid can pass through the core to remove the heat energy produced. Many other factors influence the amount of heat generated at the reactor core, but its limit rate of generation is based on how much energy the coolant can safely carry. The rate of fission within a nuclear reactor is controlled by several factors. Fuel density, neutron flow and fuel type affect the rate of fission and thus the rate of heat generation. Here is the following equation, which shows how q ̃is related to these factors . The terms will be discussed in more detail in the nuclear science modules. Q ̃= heat generation rate (Btu/s)G = energy produced for fission (Btu/fission)N = number of fissile fuel cores/unit volume (atoms/cm3)σf = microscopic cross-section of fuel fission (cm2 (φ = neutron flux (n/cm2 φ-sec)Vf = fuel volume (cm3)The heat output produced by the reactor is directly related to the mass flow of the reactor coolant and the temperature difference throughout the core. The relationship between power, mass flow and temperature is given in equation 2-14.Q ̃= heat generation rate (Btu/hr)m ̃= mass flow (lbm/hour)cp = specific heat reactor cooling system (Btu/lbm-°F)ΔT = temperature difference between the core (°F)For most types of reactors (boiling water reactor excluded), the coolant temperature depends on the reactor power and coolant flow. If the flow rate is constant, the temperature will change directly with the power. If the power is constant, the temperature will vary inversely with the flow rate. Once the type and quantity of fuel is determined, the neutron flow distribution along the core is formed. Both radial and axial flow distributions must be determined. The radial distribution looks at the flow from the center of the core to the edges. The axial distribution looks at the flow from the bottom to the top of the core. As can be seen in equation 2-14, the rate of fission directly affects the rate of heat generation in the reactor core. The highest heat generation rate will be present in the core areas with the highest heat generation. The distribution of axial and radial flow affects many factors, including the number and type of control rods, the geometry and size of the nucleus, the concentration of the poisons of the fissile product and the properties of the reflector. Peak energy production areas within each distribution typically occur near the core center, as shown in Pictures 14 and 15, but may vary during transients or as core age. The above values represent neutron flow profiles regardless of the effects of the control rods. Once the control rods and reflectors are taken into account, the flow profiles become much flatter, although the peak still occurs near the center. The shape of the profiles can be determined by measuring the ratio of peak flow to the average flow in the distribution. This peak factor is referred to as the hot channel factor. A hot channel factor of 1.0 would mean a flat flow profile. Hot channel factors are calculated values used to take into account various uncertainties in the tolerances used in core production. Take, for example, a coolant channel with a minimum acceptable width and length, located near the fuel plate with the maximum acceptable fuel load. In this channel we would now have less water than in the average channel, receiving more heat than a normal coolant channel. For all given core power and flow values, this hypothetical channel would be closest to the heat limit. Therefore, all aspects of the design are based on the hot channel factor for each kernel. The hot channel factor of the nuclear heat flow (HFHCF) is the ratio of the maximum heat flow expected in any area to the average heat flow of the core. The hot channel factor of the rise of nuclear enthalpy is the ratio of total heat generation kW along the fuel rod with the highest total kW to the total kW of the average fuel rod. Thus, limiting the peak flow value in the core is directly related to the hot channel factor. However, when discussing flow profiles, core flow values are usually referred to as peaks rather than peaks. In nuclear reactors, fuel is usually distributed in individual components that sometimes resemble rods, pipes, or plates. The average power produced per unit of fuel component length can be broken down by the total thermal power of the core by the total length of all fuel components in the core. This quantity is called the average linear power density. Common units for measuring average linear power density are kW/ft. Calculate the average linear power density for the entire core if the 3400 MW reactor is operating at full power. The basic data are: each fuel rod is 12 ft long193 fuel assemblies in coreVerage linear power density = total heat output / total length of fuel rodVerage linear power density = 3.4 x 106 kW / [12 (264) (193)] (193)]

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