Heat transfer equations pdf

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Conduction as heat transfer occurs if there is a temperature gradient in a solid or stationary liquid medium. With conductive energy transfers from more energetic to less energetic molecules when adjacent molecules collide. Heat flows in the direction of falling temperatures because higher temperatures are associated with higher molecular energy. Conductive heat transfer can be expressed with Fourier's law q = (k / s) A dT = U A dT (1) where q = heat transfer (W, J/s, Btu/hr) k = Thermal conductivity of materials (W/m K or W/m oC, Btu/(hr oF ft2/ft)) s = material thickness (m, ft) A = heat transfer range (m2, ft2) U = k / s = Heat transfer coefficient (W/(m2K), Btu/(ft2 h oF) dT = t1 - t2 = temperature gradient - difference - over material (oC, oF) Calculate Overall Heat transfer coefficient - U-value Example - Conductive heat transfer A flat wall is constructed of solid iron with thermal conductivity 70 W/moC. The thickness of the wall is 50 mm and the surface length and width is 1 m by 1 m. The temperature is 150 oC on one side of the surface and 80 oC on the other. The conductive heat transfer through the wall can be calculated q = [(70 W/m oC) / (0,05 m)] [(1 m) (1 m)] [(150 oC) - (80 oC)] = 98000 (W) = 98 (kW) Leading heat transfer calculator. This calculator can be used to calculate conductive heat transfer through a wall. The calculator is generic and can be used for both metric and imperial units as long as the use of devices is consistent. Calculate overall heat transfer including convection k - thermal conductivity (W/(mK), Btu/(hr oF ft2/ft)) A - range (m2, ft2) t1 - temperature 1 (oC, oF) t2 - temperature 2 (oC, oF) s - material thickness (m, ft) Conductive heat transfer through a Flat surface or Wall with Bearings in Series The heat carried through a wall with bearings in thermal contact can be calculated as q = dT A / ((s1 / k1) + (s2 / k2) + ... + (s n / kn)) (2) where dT = t1 - t2 = temperature difference between the inlet and the outer wall (oC, oF) Note that heat resistance due to surface convection and radiation is not included in this equation. Convection and radiation in general have a major impact on the overall heat transfer coefficients. Example - Conductive Heat Transfer through an Oven Wall An oven wall of 1 m2 consists of 1.2 cm thick stainless steel inner layer covered with 5 cm outside the insulation layer of the insulation board. The steel's internal surface temperature is 800 K and the outer surface temperature of the insulation board is 350 K. The thermal conductivity of stainless steel is 19 W/(m K) and the thermal conductivity of the insulation board is 0.7 W/(m K). The conductive heat transport through the layered wall can be calculated as q = [(800 K) - (350 K)] (1 m2) / ([(0.012 m) / (19 W/(m K))] + [(0.0 5 m) / (0.7 W/(((((0.7 W/((((0.7 W/((((0.7 W/(((((0.7 W/((((0.7 W/((((0.7 W/((((0.7 W).(0.7 W)(0.7 W).(0.7 W).(0.7 W)(0.7 W).(0.7 W/((0.7 W/((((0.7 W/((((0.7 W/((((0.7 W/((((0.7 W/((((0.7 W/((((0.7 W/((((0.7 W/((((0.7 W/((((0.7 ((0.7 W/((((0.7 W/((((0.7 W/((((0.7 W/((((0.7 W/((((0.7 W/((0.05 M) / (0.7 W/(((((((0.7 W) 0.7 W/(((0.05 M) / (0.7 W/m K)))) = 6245 (W) = 6.25 kW Thermal conductivity metals Thermal conductivity Perlite insulation Thermal conductivity Units Btu/(h ft2 Btu/(h ft2 oF/in) Btu/(s ft2 oF/ft) Btu in)/(ft² h h MW/(m2 K/m) kW/(m2 K/m) W/(m2 K/m) W/(m2 K/m) W/(m2 K/cm) W/(cm2 oC/cm) W/(in2 oF/in) kJ/(h m m 2 K/m) J/(s m2 oC/m) kcal/(h m2 oC/m) cal/(s cm2 oC/cm) 1 W/(m K) = 1 W/(m oC) = 0.8598 4 kcal/(h m oC) = 0,5779 Btu/(ft h oF) = 0,048 Btu/(i h oF) = 6,935 (Btu in)/(ft² h °F) Thermal conductivity units Converter Tag Search en: conduction heat transfer temperatures: conducción de la temperatura de transferencia de calorde: Leitungswärmeübertragungstemperatur 6-24-98 Heat transfer There are three basic ways in which heat is transmitted. In liquids, heat is often transmitted by convection, where the movement of the liquid itself carries heat from one place to another. Another way of transferring heat is through conduction, which does not involve any movement of a substance, but rather is a transfer of energy within a substance (or between substances that come into contact). The third way to transfer energy is through radiation, which involves absorbing or giving off electromagnetic waves. Convection Heat transfer in fluids is generally done via convection. Convection currents are set in the liquid because the warmer part of the liquid is not as dense as the cooler part, so there is an upward strong force on the warmer liquid, causing it to rise while the cooler, denser, liquid drops. Birds and gliders use upward convection currents to rise, and we also rely on convection to remove soil-level pollution. Forced convection, where the liquid does not flow on its own but is pushed, is often used for heating (e.g. forced-air ovens) or cooling (e.g. fans, car cooling systems). Conduction When heat is transmitted via conduction, the substance itself does not flow; rather, heat is transmitted internally, by vibrations of atoms and molecules. Electrons can also carry heat, which is why metals are generally very good conductors of heat. Metals have many free electrons, which move around randomly; these can transfer heat from one part of the metal to another. The equation that controls heat conduction along any length (or thickness) L and cross-sectional area A, at a time t is: k is the thermal conductivity, a constant depending only on the material, and with units of J / (s m C). Copper, a good thermal conductor, which is why some pots and pans have copper bases, have a thermal conductivity of 390 J / (s m C). Styrofoam, on the other hand, a good insulator, has a thermal conductivity of 0.01 J / (s m C). Example Keep in mind what happens when a layer of ice builds up in a freezer. When this happens, the freezer is much less effective at keeping food frozen. During normal operation, a freezer keeps food frozen by transferring heat through the aluminium walls of the freezer. The inside of the freezer is kept at -10 C; this temperature is maintained by having the other side of the aluminium at a temperature of -25 C. The aluminum is 1.5 mm thick, and the thermal conductivity of aluminium is 240 J / (s m C). With a temperature difference of 15 , the amount of heat by aluminum per second per square meter can be calculated from the conductivity equation: This is a fairly large heat-transfer rate. But what if 5 mm of ice builds up inside the freezer? Now the heat must be transferred from the freezer, at -10 C, through 5 mm ice, then through 1.5 mm aluminum, to the outside of aluminum at -25 C. The heat transfer rate must be the same through the ice and aluminum; this allows the temperature at the ice-aluminum interface to be calculated. Setting heat-transfer rates equally provides: The thermal conductivity of ice is 2.2 J/ (s m C). Loose for T gives: Now, instead of heat transmitted through aluminum with a temperature difference of 15 , the difference is only 0.041 . This results in a heat transfer rate of: With an ice layer covering the walls, the heat transfer rate is reduced by a factor of more than 300! It's no wonder that the freezer has to work much harder to keep food cold. Radiation The third way to transfer heat, in addition to convection and conduction, is through radiation, in which energy is transmitted in the form of electromagnetic waves. We'll talk about electromagnetic waves in much more detail in py106; an electromagnetic wave is basically an oscillating electric and magnetic field that travels through space at the speed of light. Do not worry if that definition goes over your head, because you are already familiar with many types of electromagnetic waves, such as radio waves, microwaveovens, the light we see, X-rays and ultraviolet rays. The only difference between the different varieties is the frequency and wavelength of the wave. Please note that the radiation we are talking about here, in terms of heat transfer, is not the same as the dangerous radiation associated with atomic bombs, etc. This radiation comes in the form of very high energy electromagnetic waves, as well as nuclear particles. The radiation associated with heat transfer is completely electromagnetic waves, with a relatively low (and therefore relatively safe) energy. Everything around us takes in energy from radiation, and gives it away in the form of radiation. When everything is at the same temperature, the amount of energy received is equal to the amount emitted. Since there is no net change in energy, there are no temperature changes. When things are at different temperatures, however, the warmer objects refer to more energy in terms of radiation than they take in; the reverse applies to the colder objects. The amount of energy an object radiates depends strongly on temperature. For an object with a temperature T (in Kelvin) and a surface A, the energy radiated at a time t given by the Stefan-Boltzmann Act of Radiation: The constant e is known as emissivity, and it is a measure of the fraction of the incident radiation energy absorbed and radiated by the object. This largely depends on how shiny it is. If an object reflects a lot of energy, it will absorb (and very little; if it reflects very little energy, it will absorb and radiate quite efficiently. Black objects, for example, generally absorb radiation very well, and would have envoys near 1. This is the maximum possible value for emissivity, and an object with e =1 is called a perfect blackbody, note that the emissivity of an object depends on the wavelength of radiation. A shiny object can reflect a lot of visible light, but it can be a good absorber (and therefore emitter) of radiation of a different wavelength, such as ultraviolet or infrared light. Note that the emissivity of an object is a measure not only of how well it absorbs radiation, but also how well it radiates energy. This means a black object that absorbs most of the radiation it is exposed to will also radiate energy away at a higher rate than a shiny object with low emissivity. The Stefan-Boltzmann Act tells you how much energy is radiated from an object at temperature T. It can also be used to calculate how much energy is absorbed by an object in an environment where everything around it is at a certain temperature : The net energy change is simply the difference between the radiated energy and the absorbed energy. This can be expressed as a force by sharing energy over time. The net effect of an object of temperature T is thus: Heat transfer in general We have looked at the three types of heat transfer. Management and convection rely on temperature differences; radiation also does, but with radiation the absolute temperature is important. In some cases a method of heat transfer can dominate over the other two, but often heat transfer occurs via two, or even all three, processes simultaneously. A stove and oven are perfect examples of the different types of heat transfer. If you boil water in a pot on the stove, heat is carried from the hot burner through the base of the pot to the water. Heat can also be carried out along the handle of the pot, which is why you have to be careful about picking the pot up, and why most pots don't have metal handles. In the water in the pot, convection currents are set up, which helps to heat the water evenly. However, if something is cooked in the oven, heat from the glowing elements in the oven is transferred to the food via radiation. Thermodynamics Thermodynamics is the study of systems that involve energy in the form of heat and work. A good example of a thermodynamic system is gas limited by a piston in a cylinder. If the gas is heated, it will expand, do work on the piston; this is an example of how a thermodynamic system can do work. Thermal equilibrium is an important concept in thermodynamics. When two systems are in thermal equilibrium, there is no net heat transfer between them. This occurs when the systems are at the same temperature. In other words, systems at the same temperature will be in thermal equilibrium with each other. First Law of Thermodynamics changes in the energy to heat added to a system and the work of a system. The first law is simply a preservation of energy equation: The internal energy symbol U. Q is positive if heat is added to the system, and negative if heat is removed; W is positive if work is done by the system, and negative if work is done on the system. We've talked about how heat can be transferred, so you probably have a good idea of what Q means in the first team. What does it mean for the system to do work? Work is simply a force multiplied by the distance moved in the direction of the force. A good example of a thermodynamic system that can do work is the gas limited by a piston in a cylinder, as shown in the diagram. If the gas heats up, it will expand and drive the piston up, thereby doing work on the piston. If the piston is pressed down, on the other hand, the piston does work on the gas and the gas does negative work on the piston. This is an example of how the work is carried out by a thermodynamic system. An example of numbers can make this clearer. An example of work done Think of a gas in a cylinder at room temperature (T = 293 K), with a volume of 0.065 m3. The gas is limited by a piston with a weight of 100 N and an area of 0,65 m2. The pressure above the piston is atmospheric pressure. a) What pressure does the gas have? This can be determined from a free-body diagram of the piston. The weight of the piston acts down, and the atmosphere exerts a downward force as well, coming from force = pressure x area. These two forces are balanced by the upward force that comes from the gas pressure. The piston is in equilibrium, so the forces balance. Therefore: Dissolve for the pressure of the gas provides: The pressure in the gas is not much greater than atmospheric pressure, just enough to support the weight of the piston. (b) The gas heats up, expands it and pushes the piston upwards. If the volume absorbed by the gas is doubled, how much work has the gas done? One assumption to make here is that the pressure is constant. Once the gas has expanded, the pressure will certainly be the same as before because the same freebody chart applies. As long as the expansion takes place slowly, it is reasonable to assume that the pressure is constant. If the volume has doubled, then, and the pressure has remained the same, the ideal gas law tells us that the temperature must have doubled as well. The work done by the gas can be determined by working out the force applied by the gas and calculating the distance. However, the force applied by the gas is the pressure times of the range, so: W = F s = P A s and the area multiplied by the distance is a volume, namely the volume change of the gas. So, at constant pressure, work is only pressure multiplied by the change in volume: This is positive because the force and distance moved are in the same direction, so this is work performed by the gas. Pressure-volume graph That has been discussed, a gas encased by a piston in a cylinder can make at the piston, the work, the pressure multiplied by the change in volume. If the volume does not change, no work is done. If the pressure remains constant while the volume changes, the work done is easy to calculate. On the other hand, if pressure and volume are both changed it is somewhat more difficult to calculate the work done. As an aid in calculating the work performed, it is a good idea to draw a pressure-volume graph (printed on the y-axis and volume on the x-axis). If a system moves from one point on the graph to another and a line is drawn to connect the points, the work is carried out the area under this line. We'll go through some different thermodynamic processes and see how this works. Types of thermodynamic processes There are a number of different thermodynamic processes that can change the pressure and/or volume and/or temperature of a system. To simplify things, think about what happens when something is kept constant. The different processes are then categorized as follows : Isobaric - the pressure is kept constant. An example of an isobaric system is a gas, which is slowly heated or cooled, limited by a piston in a cylinder. The work performed by the system in an isobaric process is simply the pressure multiplied by the change in volume, and the P-V graph looks like: Isochoric - the volume is kept constant. An example of this system is a gas in a box with solid walls. The work performed is zero in an isocheric process, and the P-V graph looks like: Isothermal - the temperature is kept constant. A gas bounded by a piston in a cylinder is again an example of this, only this time the gas is not heated or cooled, but the piston is slowly moved so that the gas expands or is compressed. The temperature is maintained at a constant value by the system being in contact with a reservoir with constant temperature (the thermodynamic definition of a reservoir is something large enough that it can transfer heat to or out of a system without changing the temperature). If the volume increases while the temperature is constant, the pressure must decrease, and if the volume decreases the pressure must increase. Adiabatic - in an adiabatic process, no heat is added or removed from the system. The isothermal and adiabatic processes should be examined in a little more detail. Isothermic processes In an isothermal process, the temperature remains constant, so the pressure and volume are in verse proportion to each other. The P-V graph for an isothermal process looks like this: The work performed by the system is still the area below the P-V curve, but since this is not a straight line calculation is a bit tricky, and really can only be properly done using calculus. The internal energy of an ideal gas is proportional to the temperature, so if the temperature is held firmly the internal energy does not change. The first law, which deals with changes in internal energy, thus becomes 0 = Q - W, so Q = W. If the system works, the energy comes from heat entering the system from the reservoir, if work is carried out on the system, heat flows out of the system to the reservoir. Adiabatic processes In an adiabatic process, no heat is added or removed from a system. The first law of thermodynamics is thus reduced to say that the change in the internal energy of a system undergoing an adiabatic change is equal to -W. Since the internal energy is in direct proportion to temperature, the work becomes: An example of an adiabatic process is a gas that expands so quickly that no heat can be transferred. The expansion is working, and the temperature is dropping. This is exactly what happens to a carbon dioxide fire extinguisher, with the gas coming out at high pressure and cooling that expands at atmospheric pressure. Specific heat capacity of an ideal gas With liquids and solids that are changing temperature, the heat associated with a temperature change is given by the equation: A similar equation holds for an ideal gas, just instead of writing the equation in terms of the mass of the gas it is written in terms of the number of moles of gas, and using a capital C for the heating capacity, with units of J / (mol K): For an ideal gas capacity depends on the type of thermodynamic process the gas experiences. In general, two different heating capacities are given for a gas, the heating capacity at constant pressure (Cp) and the heating capacity at constant volume (Cv). The value at constant pressure is larger than the value at constant volume because at constant pressure not all of the heat goes into changing the temperature; some go to doing work. On the other hand, at constant volume no work is done, so all heat goes into changing the temperature. In other words, it takes less heat to produce a given temperature change with constant volume than at constant pressure, so Cv < Cp. It's a qualitative statement about the two different heat capacities, but it's very easy to examine them quantitatively. The first law says: We also know that PV = nRT, and at constant pressure the work done is: Note that this applies to a monatomic ideal gas. For all gases, however, the following is true: Another important number is the relationship between the two specific heats, which are represented by the Greek letter gamma (g). For a monatomic ideal gas this ratio is: Back to the lecture schedule website website

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