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But what do those bubbles tell you and what makes them the key indicator of perfect pasta water temperature? On Earth, water boils via natural convection. Image courtesy of Markus Schweiss via Wikipedia To simplify a bit, boiling is actually a very efficient heat transfer process and, in this case, boiling transfers the heat from the fire on your stove to the water that will cook your pasta. It seems straight-forward enough here on Earth: As you wait for your pot of water to boil, there is a complex process going on in there. First, the liquid on the bottom of the pot closest to the heat source starts to get hot; as it does, it rises. The rising hot water is replaced by the cooler, more dense water molecules. The water molecules in your pot continually exchange in this way, thanks to gravity, eventually warming the entire pot of liquid. This is known as natural convectionâ€"the movement of molecules through fluidâ€"which is a primary method of heat and mass transfer. Without buoyancy or convection, boiling fluids behave quite differently in space. Video courtesy of NASA But natural convection is not enough, as it does not yet provide those bubbles you need for your pasta. To get those bubbles, you have to wait long enough for the bottom of the pot to get hotter than the boiling point of the water. The bubbles rise, due to buoyancy, and then collapse as they reach the denser, relatively cooler water at the surface of the pot. This motion not only helps to move the water around more quickly think stirring , but the bubbles themselves transfer heat energy as well. This bubble formation is called nucleate boiling; a far more effective way to transfer heat than natural convection on its own. In fact, so effective that ultimately it leads to more complex boiling called transition boilingâ€"the highly turbulent bubble flow that indicates the water is now hot enough to cook your pasta. In space, however, bubbles behave differently. Without gravity, the effects of buoyancy and convection are absent. The warmer water cannot rise; instead it remains near the heat source, getting hotter and hotter. Meanwhile, the remaining water further away from the heat source stays relatively cool. As the heated fluid reaches its boiling point, the bubbles do not rise to the surface. Instead, the bubbles that do form coalesce into one large bubble that sits on the heated surface. Within the bubble lies precious heat energy, trapped! The result is a seemingly inefficient or at least very different, way to transfer heat. Blue regions indicate regions of low heat transfer. For example, automotive engineers are interested in designing compact, energy-efficient systems to cool off hot car engines, based on the heat transfer mechanics of boiling. In fact, your own refrigerator uses a coolant with a low boiling point and some associated pressure changes in order to keep your food cold inside. By transferring heat from the fridge air to the coolant to the point of boiling, heat ultimately dissipates from the bubbles and radiates out into the air in your home. In essence, although the air inside of your fridge may seem cold to you, it is actually warm enough to boil its coolant, which is the very heat transfer process responsible for keeping your food cold. The Boiling Experiment Facility or BXF , which launched on STS in February , will enable scientists to perform in-depth studies of the complexities involved in bubble formation as a result of heat transfer. For instance, what roles do surface tension and evaporation play during nucleate boiling when buoyancy and convection are not in the equation? What about the variations in the properties of the heating surface? By controlling for gravity while on the International Space Station, scientists can investigate the various elements of boiling, thus potentially driving improved cooling system designs. Improved efficiency in cooling technology can lead to positive impacts on the global economy and environment; two hot topics that have much to gain from boiling in space. Ruttley has authored publications ranging from hardware design to neurological science, and also holds a U.

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Heat Transfer in Phase Change Presented at the 28th National Heat Transfer Conference: Presented at the 28th National Heat Transfer Conference and of the Asme Heat Transfer Division [American Society of Mechanical Engineers Heat Transfer Division, I. S. Habib, L. S. Yao, J. Goodman, Calif.) National Heat Transfer Conference (San Diego.

Climate models[edit] Climate models study the radiant heat transfer by using quantitative methods to simulate the interactions of the atmosphere, oceans, land surface, and ice. Heat equation[edit] The heat equation is an important partial differential equation that describes the distribution of heat or variation in temperature in a given region over time. In some cases, exact solutions of the equation are available; [22] in other cases the equation must be solved numerically using computational methods. System analysis by the lumped capacitance model is a common approximation in transient conduction that may be used whenever heat conduction within an object is much faster than heat conduction across the boundary of the object. This is a method of approximation that reduces one aspect of the transient conduction systemâ€”that within the objectâ€”to an equivalent steady state system. That is, the method assumes that the temperature within the object is completely uniform, although its value may be changing in time. For small Biot numbers, the approximation of spatially uniform temperature within the object can be used: Heat-transfer principles may be used to preserve, increase, or decrease temperature in a wide variety of circumstances. Insulation, radiance and resistance[edit] Thermal insulators are materials specifically designed to reduce the flow of heat by limiting conduction, convection, or both. Thermal resistance is a heat property and the measurement by which an object or material resists to heat flow heat per time unit or thermal resistance to temperature difference. Radiance or spectral radiance are measures of the quantity of radiation that passes through or is emitted. Radiant barriers are materials that reflect radiation, and therefore reduce the flow of heat from radiation sources. Good insulators are not necessarily good radiant barriers, and vice versa. Metal, for instance, is an excellent reflector and a poor insulator. The effectiveness of a radiant barrier is indicated by its reflectivity, which is the fraction of radiation reflected. A material with a high reflectivity at a given wavelength has a low emissivity at that same wavelength , and vice versa. An ideal radiant barrier would have a reflectivity of 1, and would therefore reflect percent of incoming radiation. Vacuum flasks , or Dewars, are silvered to approach this ideal. In the vacuum of space, satellites use multi-layer insulation , which consists of many layers of aluminized shiny Mylar to greatly reduce radiation heat transfer and control satellite temperature. A heat engine is a system that performs the conversion of a flow of thermal energy heat to mechanical energy to perform mechanical work. A thermoelectric cooler is a solid state electronic device that pumps transfers heat from one side of the device to the other when electric current is passed through it. It is based on the Peltier effect. A thermal diode or thermal rectifier is a device that causes heat to flow preferentially in one direction. Heat exchangers[edit] A heat exchanger is used for more efficient heat transfer or to dissipate heat. Heat exchangers are widely used in refrigeration , air conditioning , space heating , power generation , and chemical processing. In parallel flow, both fluids move in the same direction while transferring heat; in counter flow, the fluids move in opposite directions; and in cross flow, the fluids move at right angles to each other. Common constructions for heat exchanger include shell and tube, double pipe , extruded finned pipe, spiral fin pipe, u-tube, and stacked plate. Examples of heat sinks are the heat exchangers used in refrigeration and air conditioning systems or the radiator in a car. A heat pipe is another heat-transfer device that combines thermal conductivity and phase transition to efficiently transfer heat between two solid interfaces. Architecture[edit] Efficient energy use is the goal to reduce the amount of energy required in heating or cooling. In architecture, condensation and air currents can cause cosmetic or structural damage. An energy audit can help to assess the implementation of recommended corrective procedures. For instance, insulation improvements, air sealing of structural leaks or the addition of energy-efficient windows and doors. Thermal transmittance is the rate of transfer of heat through a structure divided by the difference in temperature across the structure.

Well-insulated parts of a building have a low thermal transmittance, whereas poorly-insulated parts of a building have a high thermal transmittance. Thermostat is a device to monitor and control temperature. Anthropogenic heat An example application in climate engineering includes the creation of Biochar through the pyrolysis process. Thus, storing greenhouse gases in carbon reduces the radiative forcing capacity in the atmosphere, causing more long-wave infrared radiation out to Space. Climate engineering consists of carbon dioxide removal and solar radiation management. Since the amount of carbon dioxide determines the radiative balance of Earth atmosphere, carbon dioxide removal techniques can be applied to reduce the radiative forcing. Solar radiation management is the attempt to absorb less solar radiation to offset the effects of greenhouse gases. The ability of the atmosphere to capture and recycle energy emitted by the Earth surface is the defining characteristic of the greenhouse effect. The greenhouse effect is a process by which thermal radiation from a planetary surface is absorbed by atmospheric greenhouse gases, and is re-radiated in all directions. Since part of this re-radiation is back towards the surface and the lower atmosphere, it results in an elevation of the average surface temperature above what it would be in the absence of the gases. Heat transfer in the human body[edit] See also: Wet-bulb temperature The principles of heat transfer in engineering systems can be applied to the human body in order to determine how the body transfers heat. Heat is produced in the body by the continuous metabolism of nutrients which provides energy for the systems of the body. Therefore, excess heat must be dissipated from the body to keep it from overheating. When a person engages in elevated levels of physical activity, the body requires additional fuel which increases the metabolic rate and the rate of heat production. The body must then use additional methods to remove the additional heat produced in order to keep the internal temperature at a healthy level. Heat transfer by convection is driven by the movement of fluids over the surface of the body. This convective fluid can be either a liquid or a gas. For heat transfer from the outer surface of the body, the convection mechanism is dependent on the surface area of the body, the velocity of the air, and the temperature gradient between the surface of the skin and the ambient air. Heat transfer occurs more readily when the temperature of the surroundings is significantly less than the normal body temperature. Clothing can be considered an insulator which provides thermal resistance to heat flow over the covered portion of the body. This smaller temperature gradient between the surface temperature and the ambient temperature will cause a lower rate of heat transfer than if the skin were not covered. In order to ensure that one portion of the body is not significantly hotter than another portion, heat must be distributed evenly through the bodily tissues. Blood flowing through blood vessels acts as a convective fluid and helps to prevent any buildup of excess heat inside the tissues of the body. This flow of blood through the vessels can be modeled as pipe flow in an engineering system. The heat carried by the blood is determined by the temperature of the surrounding tissue, the diameter of the blood vessel, the thickness of the fluid , velocity of the flow, and the heat transfer coefficient of the blood. The velocity, blood vessel diameter, and the fluid thickness can all be related with the Reynolds Number , a dimensionless number used in fluid mechanics to characterize the flow of fluids. Latent heat loss, also known as evaporative heat loss, accounts for a large fraction of heat loss from the body. When the core temperature of the body increases, the body triggers sweat glands in the skin to bring additional moisture to the surface of the skin. The liquid is then transformed into vapor which removes heat from the surface of the body. The body continuously loses water by evaporation but the most significant amount of heat loss occurs during periods of increased physical activity.

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Ruler scale is in millimeters. Typically, a vacuum pump is used to remove the air from the empty heat pipe. The heat pipe is partially filled with a working fluid and then sealed. The working fluid mass is chosen so that the heat pipe contains both vapor and liquid over the operating temperature range. Below the operating temperature, the liquid is too cold and cannot vaporize into a gas. Above the operating temperature, all the liquid has turned to gas, and the environmental temperature is too high for any of the gas to condense. Whether too high or too low, thermal conduction is still possible through the walls of the heat pipe, but at a greatly reduced rate of thermal transfer. For the heat pipe to transfer heat, it must contain saturated liquid and its vapor gas phase. The saturated liquid vaporizes and travels to the condenser, where it is cooled and turned back to a saturated liquid. In a standard heat pipe, the condensed liquid is returned to the evaporator using a wick structure exerting a capillary action on the liquid phase of the working fluid. Wick structures used in heat pipes include sintered metal powder , screen, and grooved wicks, which have a series of grooves parallel to the pipe axis. When the condenser is located above the evaporator in a gravitational field, gravity can return the liquid. In this case, the heat pipe is a thermosiphon. Finally, rotating heat pipes use centrifugal forces to return liquid from the condenser to the evaporator. The advantage of heat pipes over many other heat-dissipation mechanisms is their great efficiency in transferring heat. Heat pipes are designed for very long term operation with no maintenance, so the heat pipe wall and wick must be compatible with the working fluid. For example, water in an aluminum envelope will develop large amounts of non-condensable gas over a few hours or days, preventing normal operation of the heat pipe. In a heat pipe life test, heat pipes are operated for long periods of time, and monitored for problems such as non-condensable gas generation, material transport, and corrosion. This is by far the most common type of heat pipe. Aluminum envelope with ammonia working fluid for Spacecraft Thermal Control. Superalloy envelope with alkali metal cesium, potassium, sodium working fluid for high temperature heat pipes, most commonly used for calibrating primary temperature measurement devices. There are two main applications for vapor chambers. First, they are used when high powers and heat fluxes are applied to a relatively small evaporator. After the vapor condenses on the condenser surfaces, capillary forces in the wick return the condensate to the evaporator. Note that most vapor chambers are insensitive to gravity, and will still operate when inverted, with the evaporator above the condenser. In this application, the vapor chamber acts as a heat flux transformer, cooling a high heat flux from an electronic chip or laser diode, and transforming it to a lower heat flux that can be removed by natural or forced convection. It is possible to produce flat heat pipes as thin as 1. In these heat pipes, the temperature drops linearly as the power or condenser temperature is reduced. For some applications, such as satellite or research balloon thermal control, the electronics will be overcooled at low powers, or at the low sink temperatures. Variable Conductance Heat Pipes VCHPs are used to passively maintain the temperature of the electronics being cooled as power and sink conditions change. A reservoir, and 2. When the heat pipe is not operating, the NCG and working fluid vapor are mixed throughout the heat pipe vapor space. Most of the NCG is located in the reservoir, while the remainder blocks a portion of the heat pipe condenser. The VCHP works by varying the active length of the condenser. When the power or heat sink temperature is increased, the heat pipe vapor temperature and pressure increase. The increased vapor pressure forces more of the NCG into the reservoir, increasing the active condenser length and the heat pipe conductance. Conversely, when the power or heat sink temperature is decreased, the heat pipe vapor temperature and pressure decrease, and the NCG expands, reducing the active condenser length and heat pipe conductance. PCHPs have shown milli-Kelvin temperature control. Several different heat pipes act as a thermal diode , transferring heat in one direction, while acting as an insulator in the other: When the thermosyphon is heated at the top, there is no liquid available to evaporate.

Rotating Heat Pipes, where the heat pipe is shaped so that liquid can only travel by centrifugal forces from the nominal evaporator to the nominal condenser. Again, no liquid is available when the nominal condenser is heated. Vapor Trap Diode Heat Pipes. Liquid Trap Diode Heat Pipes. When the nominal condenser is heated, the vapor flow is from the nominal condenser to the nominal evaporator. The NCG is dragged along with the flowing vapor, completely blocking the nominal evaporator, and greatly increasing the thermal resistivity of the heat pipe. In general, there is some heat transfer to the nominal adiabatic section. Heat is then conducted through the heat pipe walls to the evaporator. In one example, a vapor trap diode carried 95 W in the forward direction, and only 4. The vapor flows to the condenser, and liquid returns to the evaporator by capillary forces in the wick. The reservoir eventually dries out, since there is no method for returning liquid. When the nominal condenser is heated, liquid condenses in the evaporator and the reservoir. While the liquid can return to the nominal condenser from the nominal evaporator, the liquid in the reservoir is trapped, since the reservoir wick is not connected. Eventually, all of the liquid is trapped in the reservoir, and the heat pipe ceases operation. Thermosyphons[edit] Most heat pipes use a wick to return the liquid from the condenser to the evaporator, allowing the heat pipe to operate in any orientation. The liquid is sucked up back to the evaporator by capillary action , similar to the way that a sponge sucks up water when an edge is placed in contact with a pool of water. If however the evaporator is located below the condenser, the liquid can drain back by gravity instead of requiring a wick, and the distance between the two can be much longer. Such a gravity aided heat pipe is known as a thermosyphon. Perkins tube, after Jacob Perkins. In a thermosyphon, liquid working fluid is vaporized by a heat supplied to the evaporator at the bottom of the heat pipe. The vapor travels to the condenser at the top of the heat pipe, where it condenses. The liquid then drains back to the bottom of the heat pipe by gravity, and the cycle repeats. Thermosyphons are diode heat pipes; when heat is applied to the condenser end, there is no condensate available, and hence no way to form vapor and transfer heat to the evaporator. As discussed below, the thermosyphons used to cool the Alaska pipe line were roughly 11 to 12 m long. Even longer thermosyphons have been proposed for the extraction of geothermal energy. For example, Storch et al. It can carry higher power over longer distances by having co-current liquid and vapor flow, in contrast to the counter-current flow in a heat pipe. Micro loop heat pipes have been developed and successfully employed in a wide sphere of applications both on the ground and in space. Heat transfer[edit] A heat sink aluminum with heat pipes copper Heat pipes employ evaporative cooling to transfer thermal energy from one point to another by the evaporation and condensation of a working fluid or coolant. Heat pipes rely on a temperature difference between the ends of the pipe, and cannot lower temperatures at either end below the ambient temperature hence they tend to equalise the temperature within the pipe. When one end of the heat pipe is heated, the working fluid inside the pipe at that end evaporates and increases the vapour pressure inside the cavity of the heat pipe. The latent heat of evaporation absorbed by the vaporisation of the working fluid reduces the temperature at the hot end of the pipe. The vapour pressure over the hot liquid working fluid at the hot end of the pipe is higher than the equilibrium vapour pressure over the condensing working fluid at the cooler end of the pipe, and this pressure difference drives a rapid mass transfer to the condensing end where the excess vapour condenses, releases its latent heat, and warms the cool end of the pipe. Non-condensing gases caused by contamination for instance in the vapour impede the gas flow and reduce the effectiveness of the heat pipe, particularly at low temperatures, where vapour pressures are low. The speed of molecules in a gas is approximately the speed of sound, and in the absence of noncondensing gases i. In practice, the speed of the vapour through the heat pipe is limited by the rate of condensation at the cold end and far lower than the molecular speed. The condensation rate is very close to the sticking coefficient times the molecular speed times the gas density, if the condensing surface is very cold. However, if the surface is close to the temperature of the gas, the evaporation caused by the finite temperature of the surface largely cancels this heat flux. If the temperature difference is more than some tens of degrees, the evaporation from the surface is typically negligible, as can be assessed from the vapour pressure curves. In most cases, with very efficient heat transport through the gas, it is very challenging to maintain such significant temperature differences between the gas and the condensing surface. Moreover, this temperature differences of course corresponds to a large effective thermal resistance by itself. The bottleneck is often less severe at the heat source, as the gas densities are higher there, corresponding to higher maximum heat fluxes. The condensed working fluid then flows back to the hot end of the pipe. In the case of vertically oriented heat pipes the fluid may be moved by the force of gravity. In the case of heat pipes containing wicks, the fluid is returned by capillary action. When making heat pipes, there is no need to create a vacuum in the pipe. One simply boils the working fluid in the heat pipe until the resulting vapour has purged the non-condensing gases from the pipe, and then seals the end. An interesting property of heat pipes is the temperature range over which they are effective. However, the boiling point of water depends on the absolute pressure inside the pipe. In an evacuated pipe, water vaporizes from its triple point 0. The heat of vaporization greatly exceeds the specific heat capacity. Almost all of that energy is rapidly transferred to the "cold" end when the fluid condenses there, making a very effective heat transfer system with no moving parts. Gaugler of General Motors in , who patented the idea, [28] [29] but did not develop it further. George Grover independently developed capillary-based heat pipes at Los Alamos National Laboratory in , with his patent of that year [30] being the first to use the term "heat pipe", and he is often referred to as "the inventor of the heat pipe". In the absence of gravity, the forces must only be such as to overcome the capillary and the drag of the returning vapor through its channels. This was understandable given the low weight, high heat flux, and zero power draw of heat pipes â€" and that they would not be adversely affected by operating in a zero gravity environment. The first application of heat pipes in the space program was the thermal equilibration of satellite transponders. This causes severe discrepancies in the temperature and thus reliability and accuracy of the transponders. The heat pipe cooling system designed for this purpose managed the high heat fluxes and demonstrated flawless operation with and without the influence of gravity.

4: Heat transfer - Wikipedia

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This volume contains papers presented in the Numerical Modeling of Basic Heat Transfer Phenomena in Nuclear Systems session at the National Heat Transfer Conference, by authors form different.

6: Heat pipe - Wikipedia

Heat transfer formulation of phase change with a line heat source In this section, an analytical model is presented for melting processes of a phase change material, with a line heat source in the centerline of cylindrical coordinates, based on past models discussed in Refs.

7: Our People - Purdue Engineering

Recent work on miscroscale phase-change heat transfer, including flow boiling and flow condensation in microchannnels (with applications to microchannel heat sinks and microheat exchangers) as well as bubble growth and collapse on microheaters under pulse heating (with applications to micropumps and thermal inkjet printerheads), is reviewed.

8: International Heat Transfer Conference 11

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