The stages of the refrigeration cycle engineering essay

The second law of thermodynamics is described as the “ most fundamental law of science” (Khemani, 2008). It is fundamental in the sense that it can be used to explain not only refrigerators and heat engines but highly advanced phenomena such as the big bang. It has been put aptly in the words of Classius as “ it is impossible for a process to occur that has the sole effect of removing a quantity of heat from an object at a lower temperature and transferring this quantity of heat to an object at a higher temperature” (Mortimer, 2008). This essentially means that “ heat cannot flow spontaneously from a cooler to a hotter body if nothing else happens” (Mortimer, 2008) i. e. there needs to be an external agency to effect the change.

In kitchen refrigerators, the closed box inside is able to be kept cool by the removal of heat from the inside of the box and depositing it on the outside. Because the heat will not move freely from the cold inside to the hot outside, as by the second law, it is important for it to be made to do so, this is done by using an intermediate fluid (Littlewood, 2004) which absorbed heat on the inside. This intermediate fluid is known as a refrigerant and carries the heat outside of the box whereby it it released into the air as heat as shown in (Littlewood, 2004).

Figure 1 – the flow of heat within the refrigerator – a schematic (Littlewood, 2004)

The fluid circulates within the pipe which passes in and out and can be found at the back of the refrigerator. It is kept by using a compressor (which uses electricity from the home) and allows it to work effectively without violating the second law of motion. (Littlewood, 2004)

THE FIRST LAW

Refrigerator takes in energy from a region that needs to be cooled (or kept cold) and deposits this heat energy into some other region that is outside of the refrigerator. In order to work, there has to be some mechanism in place, where the work done by a compressor and its electric motor is utilized. Using the First Law of Thermodynamics we can write: (Littlewood, 2004)

Figure 2 – the first law of thermodynamics (Littlewood, 2004)

QC – QH = -W

Where:

Qc – energy or heat of the cold system

QH = energy or heat of the hot system

W = work done

Since work is done on the refrigerator by another device (the compressor), rather than by the refrigerator itself, the work is done is deemed negative because of sign conventions. This is part of the first law (Littlewood, 2004).

Suppose that 2. 4 MJ of work is used to remove 5. 2 MJ of heat from the inside of the refrigerator, then an amount of heat QH = QC + W = 5. 2 MJ + 2. 4 MJ = 7. 6 MJ must be added to the kitchen.

The refrigerator is termed as a closed system and it possesses a constant composition:

U’ = U + (âˆ, U/âˆ, V) T dV

U’ = U + (âˆ, U/âˆ, T) V dT

U’ = U + (âˆ, U/âˆ, V) T dV + (âˆ, U/âˆ, T) T dT

dU (âˆ, U/âˆ, V) T dV + (âˆ, U/âˆ, T) V dT

According to Bain (2010), there are four basic parts to any refrigerator:

Compressor

Heat

Expansion valve

Refrigerant

The exchanging pipes are a coiled set of pipes that is placed strategically outside of the unit. The refrigerant as will be discussed later on is a liquid that has the ability to evaporate efficiently so that inside the refrigerator is kept cooled. (Bain, 2010)

A gas can be cooled by adiabatic expansion if the process is enthalphic. The gas expands through a process barrier from one constant pressure to the next and the temperature difference in observed. Insulation of the system made the process adiabatic. The result is that a lower temperature was absorbed on the on a low pressure side and the change in the temperature is proportional to the change in pressure. (Bain, 2010)

🚺„ T µ 🚺„ P

Figure 3 – schematic of a domestic refrigerator (Bain, 2010)

When an energy | qc| is removed from a cool source at some temperature Tc, and then deposited in a warmer sink at a temperature Th, the change in entropy is: (Atkins & dePaula, 2006)

Atkins & dePaula (2006) also indicated that the process is not spontaneous because the entropy generated in the warm sink is not enough to overcome the loss of entropy from the cold souce. And because of this more energy needs to be added to the stream that enters the warm sink to generated the entropy required by the system. They further indicated that the outcome is expressed as the coefficient of performance, c:

The less the work required to achieve a given transfer, the greater the coefficient of performance and the more efficient the refrigerator (Atkins & dePaula, 2004). Because | qc| is removed from the cold source, the work | w| is added to the energy stream, the energy deposited as the heat in the hot sink | qh| = | qc| + | w|. Therefore,

From:

We can have an expression in terms of the temperature alone, which is possible if the transfer is performed reversibly (Atkins & dePaula, 2006):

Where:

c = thermodynamic optimum coefficient of temperature

Tc = temperature of the cold sink

Th = temperature of the hot sink

For a refrigerator, it important that a very low coefficient of performance. For a refrigerator withdrawing heat from ice cold water (Tc = 273 K) in a typical environment (Th = 293K), c = 14. As an example, to remove 10 kJ (enough to freeze 30 g of water), requires transfer of atleast 0. 71 kJ as work. (Atkins & dePaula, 2005)

The work to maintain a low temperature is very important when designing refrigerators. No thermal insulation is perfect, so there is always some form of energy flowing as heat into a specific sample at a rate that is proportional to the temperature difference. (Atkins and de Paula, 2006).

Figure 4 – (a) " the flow of energy as heat from a cold source to a hot sink is not spontaneous. As can be seen, the entropy increase of the hot sink is smaller than the entropy increase of the cold source, so there is a net decrease in entropy" (Atkins & dePaula, 2006).

(b) " The process becomes feasible if work is provided to add to the energy stream. Then the increase in entropy of the hot sink can be made to cancel the entropy of the hot source" (Atkins & dePaula, 2006)

he rate at which energy leaks happen is written as:

Where:

A = a constant that depends on the size of the sample and details of the simulation

Tc = temperature of the cold sink

Th = temperature of the hot sink

The minimum power, P, required to maintain the original temperature difference by pumping out that energy by heating the surroundings is:

As can be seen the power increases as the square of the temperature difference (Th – Tc).

THE REFRIGERATION CYCLE

The gas is pumped continuously at a steady pressure, the heat exchanger (which brings the required temperature) and then through a porous plug inside container that is thermally insulated. A phase change heat pump uses a liquid that has a low boiling point to transfer heat from a cooler area to a warmer one, in refrigerators. This heat pump is the most commonly used in domestic refrigerators. It employs a liquid, known as a refrigerant which has a low boiling point. The liquid requires energy (called latent heat) to evaporate, and it drains that energy from its surroundings in the form of heat. When the vapor condenses again, it releases the energy (in the form of heat). A refrigerant is a compound used in a heat cycle that undergoes a phase change from a gas to a liquid and back. … Latent heat describes the amount of energy in the form of heat that is required for a material to undergo a change of phase (also known as change of state). Two latent heats are typically described. … (Bambooweb, 2009)For other uses, see CFC (disambiguation). …

The pump operates a cycle in which the refrigerant changes state from its liquid form to the vapour form and vice versa. This process occurs repeatedly and I known as the refrigeration cycle. In this cycle, the refrigerant condenses and heat is released in one point of the cycle. It is the boiled (or evaporated) so that it absorbs heat in another point of the cycle. The widely used refrigerant is hydro fluorocarbon (HFC) known as R-134a (1, 1, 1, 2 – tetrafluoroethane) and CCl_2F_2 (dichlorodifluoromethane). Other substances such as liquid ammonia, propane or butane, are be used but because of their highly flammable nature, they are disregarded as a good refrigerant. 1930 (MCMXXX) was a common year starting on Wednesday (link is to a full 1930 calendar). … (Bambooweb, 2009)For other uses, see CFC (disambiguation). …

In the refrigerator the fluid used (e. g. CCl_2F_2) fluid is liquefied by compression then vaporized by sudden expansion which gives a cooling effect. The compressor, in itself does not create a “ cooling effect” directly, as might be expected. The “ cooling effect” is created when the refrigerant absorbs the heat from the cooled space. This is accomplished with a heat exchanger. (Bambooweb, 2009)For other uses, see CFC (disambiguation). … A heat exchanger is a device built for efficient heat transfer from one fluid to another, whether the fluids are separated by a solid wall so that they never mix, or the fluids are directly contacted. …

The refrigeration cycle can be divided in two parts:

The liquefaction stage

The evaporation stage

LIQUEFACTION STAGE

The refrigerant vapour undergoes recycling by itself into the liquid form by the extraction of heat from a vapour at a higher temperature. The refrigerant is compressed by the compressor where a low pressure and low temperature condition is created. This is accomplished by an evaporating coil. During the compression process, the vapour of the refrigerant undergoes a temperature change (as an effect of the compression process). Additionally, the work of compression to create the high temperature and pressure vapour also contributes to the temperature change experienced by the vapour. The condenser that is located where the temperature is higher (i. e. the higher temperature heat sink) collects the vapour. Heat is then removed from the refrigerant and in lieu of this it condenses to it's liquid state, hence the name for the condenser.

Using the Joule-Thompson coefficient: For a perfect gas μ = 0

Cp + Cv = (âˆ‚ H/âˆ‚ T)p – (âˆ‚ U/âˆ‚ T)p

Introducing: H = U + pV = nRT into the first term:

Cp – Cv = (âˆ‚ U/âˆ‚ T)p + nR – (âˆ‚ U/âˆ‚ T)p = nR

EVAPORATION STAGE

As the refrigerant leaves the condenser, the next part of the cycle begins. This is accomplishe when a high temperature and high pressure liquid passes through a metering device that is found within the refrigeration. The valve allows a specific quantity of liquid coolant to pass into the evaporation chamber. Evaporation chambers are relatively low pressure and this encourages coolant evaporation. Newly evaporated coolant is drawn though the cooling coils (typically a fan is used to blow air over the coils). Thus, the evaporative process produces the cooling effect. The refrigerant then is pulled to the compressor in the suction line where it will be compressed into a high temperature, high pressure gas and sent to the external heat sinking coils. Capillary action or capillarity is the ability of a narrow tube to draw a liquid upwards against the force of gravity. …

A refrigerator pumps heat up a temperature gradient. The cooling efficiency of this operation depends on the amount of heat extracted from the cold temperature reservoir (the freezer compartment), , and the work needed to do so. Since a practical refrigerator operates in a cycle to provide a continuous removal of heat, for the cycle. Then, by the conservation of energy (or first law), , where is the heat ejected to the high temperature reservoir or the outside.

The measure of a refrigerator performance is defined as the efficiency expressed in terms of the coefficient of performance (). Since the purpose is to extract the most heat () per unit work input (), the coefficient of performance for a refrigerator, , is expressed as their ratio:

Where, the conservation relationship given above is used to express the work in terms of heat.

For normal refrigerator operation, the work input is less than the heat removed, so the is greater than 1. Refrigerators are commonly referred to as heat pumps of more specifically a it is a reversible heat pump because they basically " pump" heat.

Figure 5 – A simple stylized diagram of a heat pump's vapor-compression refrigeration cycle: 1) condenser, 2) expansion valve, 3) evaporator, 4) compressor.

Opening a food refrigerator or freezer heats up the kitchen rather than cooling it because its refrigeration cycle rejects heat to the indoor air. This heat includes the compressor's dissipated work as well as the heat removed from the inside of the appliance.

The COP for a heat pump in a heating or cooling application, with steady-state operation, is:

Where:

Î" Qcool is the amount of heat extracted from a cold reservoir at temperature Tcool,

Î" Qhot is the amount of heat delivered to a hot reservoir at temperature Thot,

Î" A is the compressor's dissipated work.

EFFICIENCY

The efficiency of a refrigerator (known as the coefficient of performance, COP) is defined as

For example, if 20 MJ are removed from the inside of the refrigerator by doing 7. 5 MJ of work, then the coefficient of performance is equal to 20/7. 5 = 2. 67.

SUMMARY OF THERMODYNAMIC OF A REFRIGERATOR AFTER ONE CYCLE

Change in internal energy = 0

Change in heat is > 0

Total work > 0

Total volume change = 0

Change in Gibb’s free energy = 0

Entropy change of the system = 0

Entropy change of the universe > 0