

INDUSTRIAL PROCESS

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SESSION 3 HEAT PROCESS

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Heat process

Flash smelting

Flash smelting ([Finnish](#): *Liekkisulatus*) is a [smelting](#) process for [sulfur](#)-containing ores^[1] including [chalcopyrite](#). The process was developed by [Outokumpu](#) in [Finland](#) and first applied at the [Harjavalta](#) plant in 1949 for smelting copper ore.^{[2][3]} It has also been adapted for [nickel](#) and [lead](#) production.^[2]

A second flash smelting system was developed by the International Nickel Company ('[INCO](#)') and has a different concentrate feed design compared to the Outokumpu flash furnace.^[4] The **Inco flash furnace** has end-wall concentrate injection burners and a central waste gas off-take,^[4] while the **Outokumpu flash furnace** has a water-cooled reaction shaft at one end of the vessel and a waste gas off-take at the other end.^[5] While the INCO flash furnace at Sudbury was the first commercial use of oxygen flash smelting,^[6] fewer smelters use the INCO flash furnace than the Outokumpu flash furnace.^[4]

Flash smelting with oxygen-enriched air (the 'reaction gas') makes use of the energy contained in the concentrate to supply most of the energy required by the furnaces.^{[4][5]} The concentrate must be dried before it is injected into the furnaces and, in the case of the Outokumpu process, some of the furnaces use an optional heater to warm the reaction gas typically to 100–450 °C.^[5]

The reactions in the flash smelting furnaces produce copper [matte](#), iron oxides and [sulfur dioxide](#). The reacted particles fall into a bath at the bottom of the furnace, where the iron oxides react with [fluxes](#), such as [silica](#) and [limestone](#), to form a [slag](#).^[7]

In most cases, the slag can be discarded, perhaps after some cleaning, and the matte is further treated in converters to produce blister copper. In some cases where the flash furnaces are fed with concentrate containing a sufficiently high copper content, the concentrate is converted directly to blister in a single Outokumpu furnace^[8] and further converting is unnecessary.

The sulfur dioxide produced by flash smelting is typically captured in a [sulfuric acid plant](#), removing the major environmental effect of smelting.^[9]

[Outotec](#), formerly the technology division of Outokumpu, now holds Outokumpu's patents to the technology and licenses it worldwide.

Objectives of Heat Treatments

Heat Treatment is the *controlled heating and cooling of metals to alter their physical and mechanical properties without changing the product shape*. Heat treatment is sometimes done inadvertently due to manufacturing processes that either heat or cool the metal such as welding or forming.

Heat Treatment is often associated with *increasing the strength of material*, but it can also be used to *alter certain manufacturability objectives* such as improve machining, improve formability, restore ductility after a cold working operation. Thus it is a very enabling manufacturing process that can not only help other manufacturing process, but can also improve product performance by increasing strength or other desirable characteristics.

Steels are particularly suitable for heat treatment, since they respond well to heat treatment and the commercial use of steels exceeds that of any other material. Steels are heat treated for one of the following reasons:

1. [Softening](#)
2. [Hardening](#)
3. [Material Modification](#)

Common Heat Treatments

Softening: Softening is done *to reduce strength or hardness, remove residual stresses, improve toughness, restore ductility, refine grain size or change the electromagnetic properties of the steel*.

Restoring ductility or removing residual stresses is a necessary operation when a large amount of cold working is to be performed, such as in a cold-rolling operation or wire drawing. [Annealing](#) — full Process, spheroidizing, normalizing and [tempering](#) — austempering, martempering are the principal ways by which steel is softened.

Hardening: Hardening of steels is done *to increase the strength and wear properties*. One of the pre-requisites for hardening is *sufficient carbon and alloy content*. If there is sufficient Carbon content then the steel can be [directly hardened](#). Otherwise the surface of the part has to be Carbon enriched using some [diffusion treatment hardening](#) techniques.

Material Modification: Heat treatment is used to modify properties of materials in addition to hardening and softening. These processes modify the behavior of the steels in a beneficial manner to maximize service life, e.g., [stress relieving](#), or strength properties, e.g., [cryogenic treatment](#), or some other desirable properties, e.g., [spring aging](#).

THERMODYNAMICS: HEAT

←

Processes with Heat and Work

→

The Carnot Cycle

Though we have shown the net flow of energy and entropy, we haven't proposed a more specific mechanism for the heat engine. The most basic cycle is known as the Carnot cycle, and is simple if not completely accurate for a real engine. Still, it is beneficial to see a simplified picture to understand the basic concepts.

The Carnot cycle consists of four phases. Refer to as we trace the steps of the cycle. At point A, the gas (it needn't be a gas necessarily) is at temperature τ_h with entropy σ_L where the latter represents the lowest entropy attained by the system during the cycle and is distinct from σ_I . The gas is then expanded at constant temperature and the entropy is increased to σ_H at point B. The expansion is isothermal, that is, performed at a constant temperature.

Now, the gas is expanded further, but at constant entropy. The temperature falls to τ_l during this isentropic process and arrives at point C. The gas is then compressed isothermally to point D, and is compressed isentropically back to point A, thus completing one cycle.

The total work accomplished by the system can be written from our previous results as $W = \Delta\tau \times \sigma_h$. Looking at the figure again, we see that this is merely the area enclosed by the rectangle. This yields a nice graphical method of understanding a simple version of a heat engine.

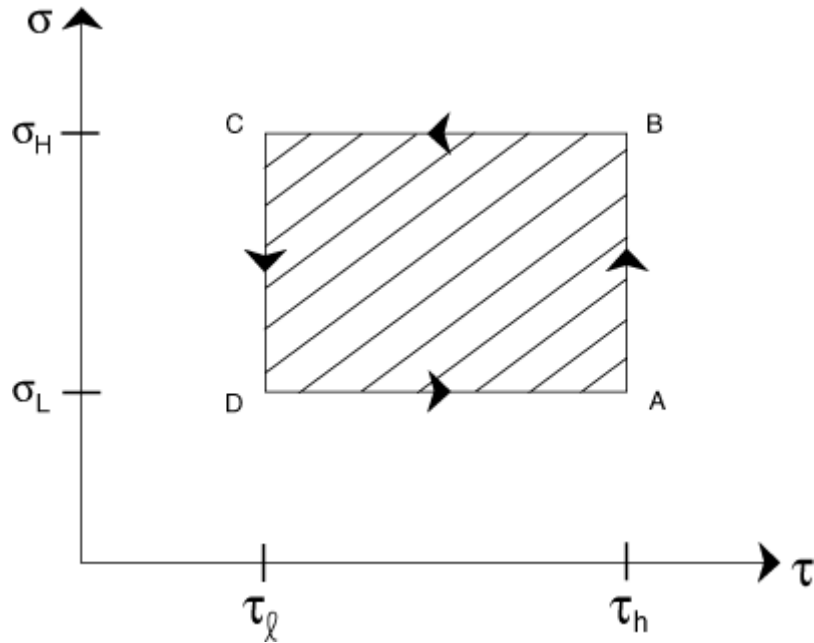


Figure %: A Carnot Cycle

Energies Revisited

We have stressed throughout that knowing well the energy identities makes problem solving much easier, and we have seen this in many of the problems we have tackled. It appears again here, as we discuss processes performed on a gas.

For an isothermal expansion or compression, we wish to deal with an energy where τ appears as a differential. Conventionally, the Helmholtz free energy is used. Barring any diffusive exchange, we can see that dF gives us $dU - dQ$, which is exactly the work done on the system.

For an isobaric process, we wish to use the Enthalpy, for the pressure appears in the differential there. This choice allows us to carefully account for the work done on the system and that done on the environment in a process.

For a process that is both isobaric and isothermal, it makes sense to look at the Gibbs Free Energy.

Therefore, while solving problems, look for what is being held constant so that you can make an appropriate choice of energy.

THERMODYNAMIC PROCESSES FOR AN IDEAL GAS

$$PV^n = \text{Constant}$$

Process	<u>Isobaric</u>	<u>Isochoric</u>	<u>Isothermal</u>	<u>Adiabatic</u>
Variable =>	Pressure	Volume	Temperature.	No Heat Flow
Quantity Constant =>	$\square P = 0$	$\square V = 0$	$\square T = 0$	$Q = 0$
<u>n</u>	0	∞	1	<u>$\gamma = C_p/C_v$</u>
<u>First Law</u>	$\square U = Q - W$	$\square U = Q$ $W = 0$	$\square U = 0$ $Q = W$	$\square U = -W$ $Q = 0$
<u>Work</u> $W = \int P dV$	$P(V_2 - V_1)$	0	$P_1 V_1 \ln\left(\frac{V_2}{V_1}\right)$	$\frac{P_1 V_1 - P_2 V_2}{\gamma - 1}$
<u>Heat Flow</u> Q	$m C_p (T_2 - T_1)$	$m C_v (T_2 - T_1)$	$P_1 V_1 \ln\left(\frac{V_2}{V_1}\right)$	0
<u>Heat Capacity</u>	C_p	C_v	∞	0
<u>Internal Energy</u> $\Delta U = U_2 - U_1$	$m C_v (T_2 - T_1)$	$m C_v (T_2 - T_1)$	0	$m C_v (T_2 - T_1)$
<u>Enthalpy</u> $\Delta H = H_2 - H_1$ $H = U + PV$	$m C_p (T_2 - T_1)$	$m C_p (T_2 - T_1)$	0	$m C_p (T_2 - T_1)$
<u>Entropy</u>	$m C_p \ln \frac{T_2}{T_1}$	$m C_v \ln \frac{T_2}{T_1}$	$nR \ln \frac{V_2}{V_1}$	0*

$\Delta S = S_2 - S_1$ $= \int dQ/T$				
<u>Ideal Gas Relations</u> $\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$ $PV = NkT$	$P_1 = P_2$ $\frac{V_1}{T_1} = \frac{V_2}{T_2}$ $\frac{T_1}{T_2} = \frac{V_1}{V_2}$	$V_1 = V_2$ $\frac{P_1}{T_1} = \frac{P_2}{T_2}$ $\frac{T_1}{T_2} = \frac{P_1}{P_2}$	$T_1 = T_2$ $P_1 V_1 = P_2 V_2$ $\frac{P_1}{P_2} = \frac{V_2}{V_1}$	$Q = 0$ $(S_1 = S_2)^*$ $P_1 V_1^\gamma = P_2 V_2^\gamma$ $\frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{\gamma-1}$

* For Adiabatic Reversible Processes

$$n c_p = m C_p \quad n c_v = m C_v \quad c_p - c_v = R \quad n R = N k$$

$\gamma = C_p/C_v = c_p/c_v =$ Ratio of Specific Heats

C_p = Constant Pressure Specific Heat Capacity (J/kg/ °C)

C_v = Constant Volume Specific Heat Capacity (J/kg/ °C)

c_p = Molar Constant Pressure Heat Capacity (J/mole/oC)

c_v = Molar Constant Volume Heat Capacity (J/mole/oC)

Important Thermal Processes

<u>Isobaric</u>	<u>Isothermal</u>	<u>Isovolumetric</u>
<u>Adiabatic</u>	<u>Isoentropic</u>	<u>Polytropic</u>

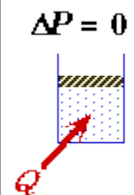
ISOBARIC Pressure is Constant ($\Delta P = 0$)

Example:

Gas Heated in a Cylinder fitted with a movable frictionless piston. The pressure the atmosphere and the pressure due to the weight of the piston remains constant as the gas heats up and expands.

First Law Implications: $\Delta U = Q - W$

Unlike some of the other processes below neither the heat Q , the work W , or the change in internal energy ΔU are necessarily zero in a



constant pressure process.

For an ideal gas, constant pressure [work](#) is easily determined, $W = \int P dV$
 $= P \Delta V$

Part of the heat that flows into the system causes the temperature to rise, $Q = n c_p \Delta T = m C_p \Delta T$, the rest goes into work.

ISOTHERMAL Temperature is Constant ($\Delta T = 0$)

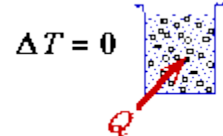
Example 1:

Boiling of water in the open air.

In general most isobaric phase changes are isothermal.

In this example the system does work as the steam-produced pushes against the atmosphere as it expands. Neither the heat Q , the work

W , or the change in internal energy ΔU are zero. In this case $Q = mL_v$ since the water [changes phase](#).



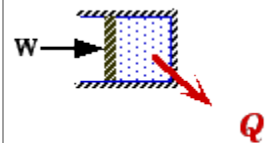
Example 2:

In general for an Ideal gas U is only a function of the temperature so that ΔU is always equal to zero for an isothermal process. Since $\Delta U = 0$ then $W = Q$ from the First Law.

What has to happen for this process to be isothermal is that the gas in a cylinder is compressed slowly enough that heat flows out of the gas at the same rate at which is being done on the gas.

The ideal gas law can be used to determine the [work](#) done $W = PV \ln(V_f/V_o)$ which is also the equation for Q .

Note that $P_1 V_1 = P_2 V_2 = nRT$, the ideal gas law for an isothermal process.



See [Summery Table](#) for more change for an Ideal gas.

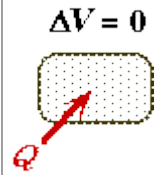
ISOCHORIC (Isovolumetric) Volume is constant ($\Delta V = 0$)

Example:

Heating of a Gas in a Rigid, Closed container.

In this case no work is done on the gas because $W = \int PdV = \int P \cdot 0 = 0$. As a result the First Law implies that the change in internal energy must equal any heat flowing into or out of the system, $\Delta U = Q = n c_v \Delta T = m C_v \Delta T$.

Note that $V_1 = V_2 = nRT_1/P_1 = nRT_2/P_2$, the ideal gas law for constant volume process.



ADIABATIC No heat flows into or out of the system ($Q = 0$)

Example

Compression of a Gas in an Insulated Cylinder.

In this case any change in the internal energy of the gas is due to work done on it or by it, $\Delta U = W$.

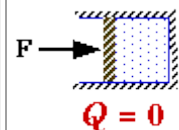
Normally if ΔU changes the temperature of a system will change. Any temperature rise or fall is due to the work done or by the gas alone and not due to heat flowing into or out of the system since $Q = 0$.

If a process is carried out fast enough the heat flow will be small and the process can be approximate as being adiabatic. This happens because heat flow is in general a slow process.

Observe that we did not say that Q is constant because it is not a state variable. Q represents an energy transfer not the heat energy of the system.

In addition to the ideal gas law $PV = NkT$, the quantity PV^γ is constant for an ideal gas where $\gamma = c_p/c_v$, the ratio of molar specific heats.

For an ideal gas the work $W = (P_1V_1 - P_2V_2)/(\gamma - 1)$



See [Summery Table](#) for more change for an Ideal gas.

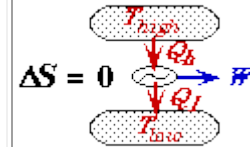
ISOENTROPIC Entropy is constant ($\Delta S = 0$)

Example:

A Heat Engine in which the working fluid undergoes an Adiabatic Reversible cyclic process.

Any isentropic process is also adiabatic since $\Delta U = \int dQ/T$ and $Q = 0$. However, not all adiabatic process are isentropic. Adiabatic free expansion is not isentropic.

For a heat engine to be reversible, not only must the change in entropy of the working fluid be zero but also the net change of the entropy of the environment (heat reservoirs) must also be zero.



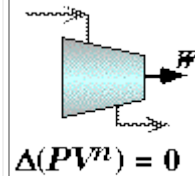
POLYTROPIC PV^n is constant

Here n can be any real number. All the process above can thought of as a special case of a polytropic process for an ideal gas.

- $n = 0$ for Isobaric process since $PV^0 = P = \text{constant}$.
- $n = 1$ for Isothermal process since $PV^1 = PV = NKT = \text{constant}$.
- $n = \infty$ for Isovolumetric process (this one is not so obvious)
- $n = \gamma$ for Adiabatic process (again not so obvious)

Example:

Compression or Expansion of a Gas in a Real System such as a Turbine.



Solids

Strong forces of attraction hold particles close together in fixed regular arrangement. The particles don't have much energy so only vibrate about their fixed positions.

□□□

Liquids

Weaker forces of attraction between particles than solids. particles are close together but can move past each other, and form irregular arrangements. They have more energy than the particles in a solid and move in random directions at low speeds

□□□

Gases

There are almost no forces of attraction between the particles. The particles have more energy than those in liquids and solids and are free to move and travel in random directions at high speeds

□□□

Boiling

Particles are give enough energy to overcome their attraction to each other and form big bubbles of gas (liquids)

□□□

Melting

Heat energy makes the particles vibrate faster until eventually the forces between them are overcome and the particles start to move around

□□□

Condensing/freezing

Bonds are forming between particles which releases energy

□□□

Specific Heat Capacity

The amount of energy needed to raise the temperature of 1kg of a substance by 1 degree

□□□

Specific Latent Heat

The amount of energy needed to change 1kg of a substance from one state to another without changing its temperature

□□□

Specific Latent Heat of Vaporisation

The amount of energy needed to change 1kg of material from liquid vapour to gas without changing its temperature (boiling)

□□□

Specific Latent Heat of Fusion

The amount of energy needed to change 1kg of material from a solid to a liquid without changing its temperature

□□□

Conduction

In solids

□□□

Convection

In liquids and gases

□□□

Dark, matt surfaces

good absorbers and good emitters

□□□

Light, shiny surfaces

Poor absorbers as they reflect lots.
Poor emitters

