ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

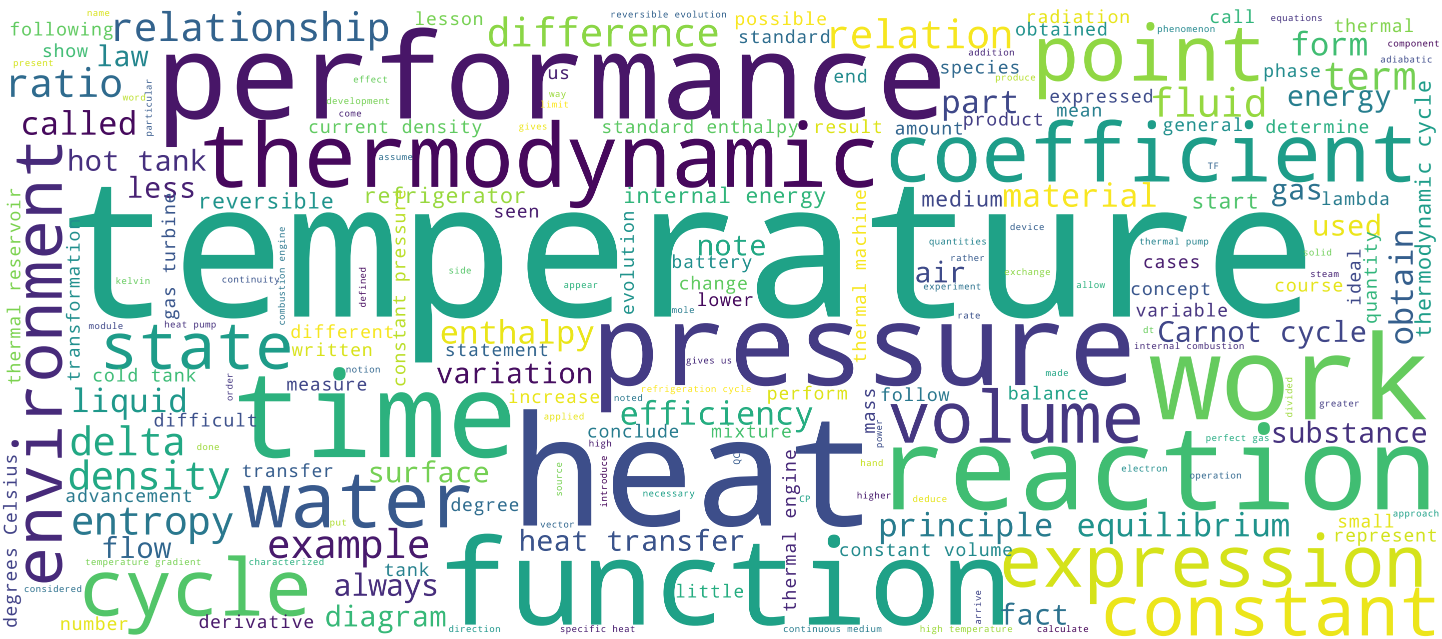
RESCIF
Réseau d'excellence des sciences de l'ingénieur de la Francophonie

Thermodynamique

Cycles Thermodynamiques

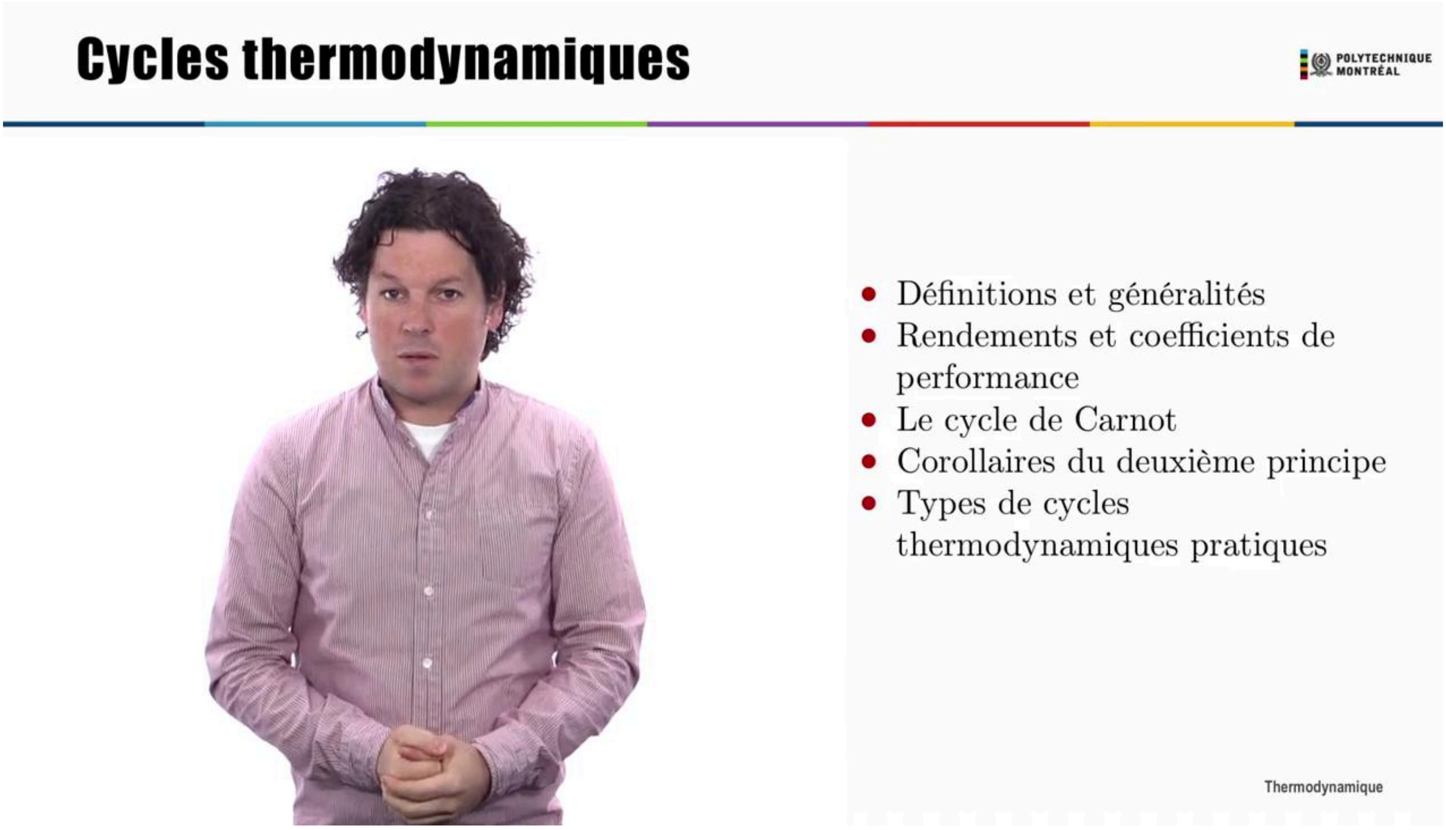
POLYTECHNIQUE MONTRÉAL Prof. Etienne Robert

Nicolas Léonard Sadi Carnot, 1796-1832



Video

EPFL

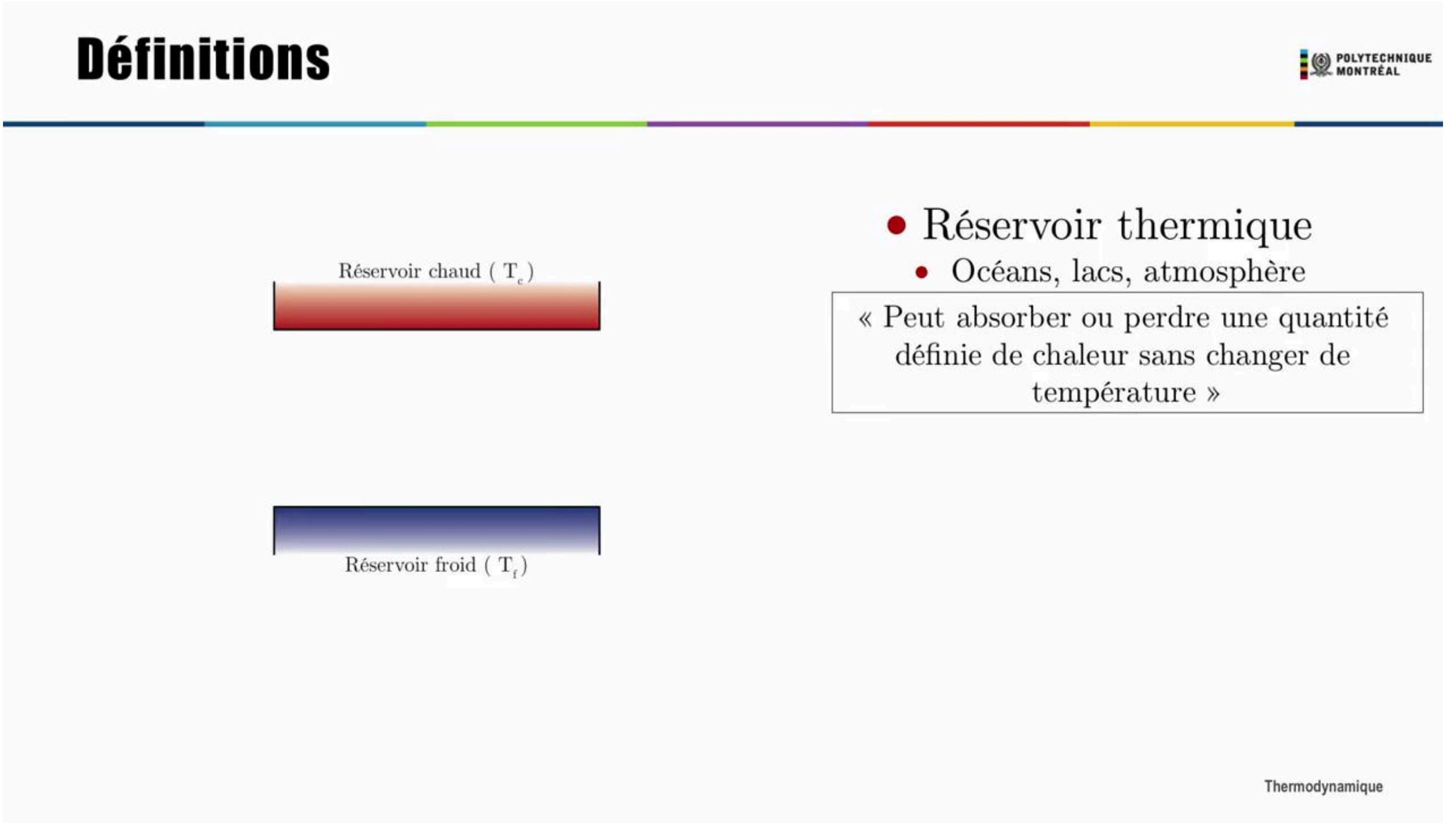


Hello. Welcome to the thermodynamics lesson. My name is Etienne Robert and I am based at École Polytechnique de Montréal. In this first lesson, I will begin by introducing some of the basic concepts on thermodynamics before presenting in a more detailed way the formulates the concepts of efficiency and coefficient of performance. Then follows the Carnot cycle as well as the two corollaries that he involves the second principle of thermodynamics, and I will conclude with a brief description of the different types of thermodynamics that we meet in practice.

Notes

Summary

0m 04s



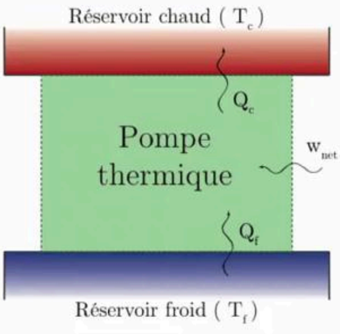
So let's start with the notion of a thermal reservoir. A cycle exchanges heat with the thermal reservoirs. For thermodynamic analysis, it is an idealized concept, that we suppose capable of absorbing or to give up a defined amount of heat without changing the temperature. They are therefore characterized only by their temperature. For the following, TCD will note the temperature of a hot tank and TF of a cold tank. In practice, thermal reservoirs can be oceans or lakes, the atmosphere or a substance that changes phase at constant pressure.

Notes

Summary

0m 30s

Définitions



- Réservoir thermique
  - Océans, lacs, atmosphère

« Peut absorber ou perdre une quantité définie de chaleur sans changer de température »

- Machine thermique
  - Moteur: produit du travail à partir de la chaleur.
  - Pompe thermique : utilise du travail pour transférer de la chaleur contre un gradient de température.
  - Cycle thermodynamiques

Thermodynamique

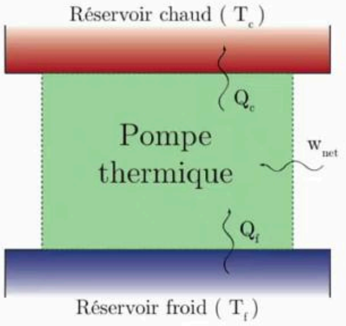
We will call a thermal machine a system which accepts heat from a hot tank, produces a clean work and transmits the rest of the heat to a cold tank. The exchanges between the system and its environment will be denoted QC and Kiev. For thermal transport and W9 for work, the thermal pump performs the opposite operation. It receives heat from a cold tank and a work of its environment and discharges it into a hot tank. The machines and thermal pumps are based on the use of thermodynamic cycle, i.e. on a succession of transformations imposed on a volume of matter, usually a fluid that ultimately returns it to its state initial and changing heat and work with the environment of the system.

Notes

Summary

1m 01s

Rendements



$$COP_{PT} = \frac{Q_C}{W_{entrée}} = \frac{Q_C}{Q_C - Q_F} = \frac{1}{1 - \frac{Q_F}{Q_C}}$$

$$COP_R = \frac{Q_F}{W_{entrée}} = \frac{Q_F}{Q_C - Q_F} = \frac{1}{\frac{Q_C}{Q_F} - 1}$$

- Mesure de performance :

$$\eta_{th} = \frac{\text{Sortie désirée}}{\text{Entrée fournie}}$$

- Moteur thermique : rendement

$$0 \leq \eta_{th} \leq 1$$

- Pompe thermique et réfrigérateur

$$0 \leq COP \nleq 1$$

Thermodynamique

To quantify the value of cycles thermodynamics, we need to define a notion of performance. In general, we will talk about the performance that we will always be defined as the ratio between a quantity that we want compared to what was provided to obtain it. For a thermal engine, we want to obtain work by providing heat from a hot tank. The performance will therefore be expressed as by the ratio between the outgoing work and the incoming heat, which is equivalent to a minus the ratio of heat transferred to the cold tank compared to that obtained from the hot tank. According to the first principle, this yield will always be between zero and one. For thermal pumps, two cases must be considered if you want to heat a house, for example, you want to maximize the heat transferred to the hot tank QC in relation to the work done. If, on the other hand, you want to keep something cold with a refrigerator, we will rather try to maximize QF. Therefore, two definitions must be considered to measure the performance of heat pumps and refrigerators. Moreover, unlike the efficiency of a thermal engine, the first principle does not require these quantities to be less than or equal to one.

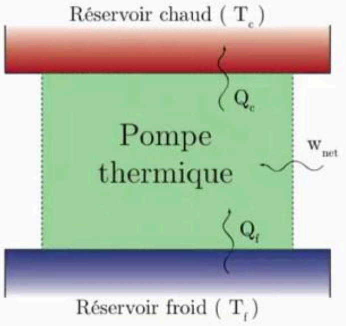
Notes

Summary

1m 42s

Rendements

POLYTECHNIQUE MONTRÉAL



$$COP_{PT} = \frac{Q_C}{W_{entrée}} = \frac{Q_C}{Q_C - Q_F} = \frac{1}{1 - \frac{Q_F}{Q_C}}$$

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- Moteur thermique : rendement

$$0 \leq \eta_{th} \leq 1$$

- Pompe thermique et réfrigérateur

$$0 \leq COP \nleq 1$$

Thermodynamique

We therefore generally speak of a coefficient performance or CSP rather than output with the CSP of the heat pumps defined as the ratio between the heat transmitted to the hot spring and the work done. For refrigerators, we consider the transfer to the cold source and in both cases, we can again express the coefficients of performance as a function only of the temperature ratio QF to QC for the thermal pump and QC on that F for the refrigerator.

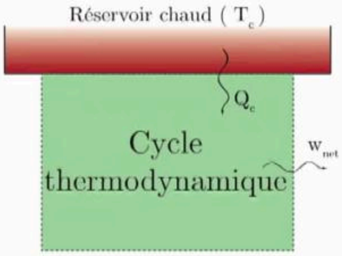
Notes

Summary

2m 51s

Énoncés du deuxième principe

POLYTECHNIQUE MONTRÉAL



- Énoncé de Clausius

« Aucun système ne peut uniquement (c'est-à-dire sans apport de l'environnement) transmettre de la chaleur d'un corps froid à un corps chaud. »

- Énoncé de Kelvin-Plank

« Aucun système ne peut accomplir un cycle et effectuer un travail net sur l'environnement en recevant de la chaleur d'un seul réservoir. »

Thermodynamique

From these basic concepts, we can introduce the two statements of the second principle of thermodynamics, the most common or the most known. In these statements, in fact, it is not a rigorous mathematical demonstration. It is rather a set of observations that were formalized in the mid-19e century in this form. Although they are based solely on on observations, these statements have never been proven. False. The first statement is the one of Rudolf Clausius and states that no system can only i.e. without any contribution from the environment, transmit heat from a cold body to a warm body. This statement expresses the evidence that heat is not transmitted spontaneously from a cold body to a warm body and results in that a refrigerator cannot function without external work and that its coefficient of performance cannot be infinitely high. The second statement is that of Kelvin Planck and expresses that no system can complete a cycle and do a neutral job on the environment by receiving heat from a single tank. In other words, a thermal engine will always have a heat rejection to a cold tank and its efficiency will therefore always be less than one.

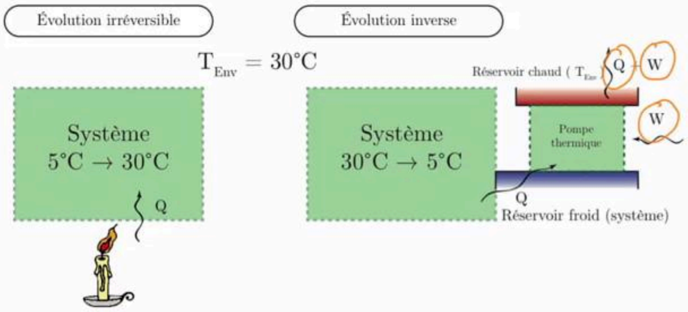
Notes

Summary

3m 19s

Évolutions réversibles et irréversibles

POLYTECHNIQUE MONTRÉAL



- Évolution irréversible
  - Laisse des traces sur l'environnement
  - Friction, mélange, etc.
  - Transfert de chaleur avec différence de température

Thermodynamique

Therefore, the statements of the second principle indicate to us that there are limits to what is physically possible to perform, with a thermodynamic cycle, limits in terms of performance and limits in terms of direction. Exchanges and evolution between the different states that make up a thermodynamic cycle can be classified as follows as either reversible or irreversible. The difference is that only a reversible evolution can be made in both directions without leaving a trace on the environment. For example, a heat transfer due to to a temperature gradient is an irreversible evolution, because to perform the reverse operation, a heat transfer is required against high temperature, which requires a work input. So, if you heat a system from 5 to 30 degrees Celsius and we want to bring it back to the initial state, we need a refrigerator that uses a work W. And therefore the load to restore the environment is equal to the heat initially received by the system, plus the work. It is necessary to perform to reverse the transfer in addition to the heat transfer with temperature gradient. Other common phenomena that are intrinsically irreversible are dry or viscous friction and the mixing between substances by diffusion.

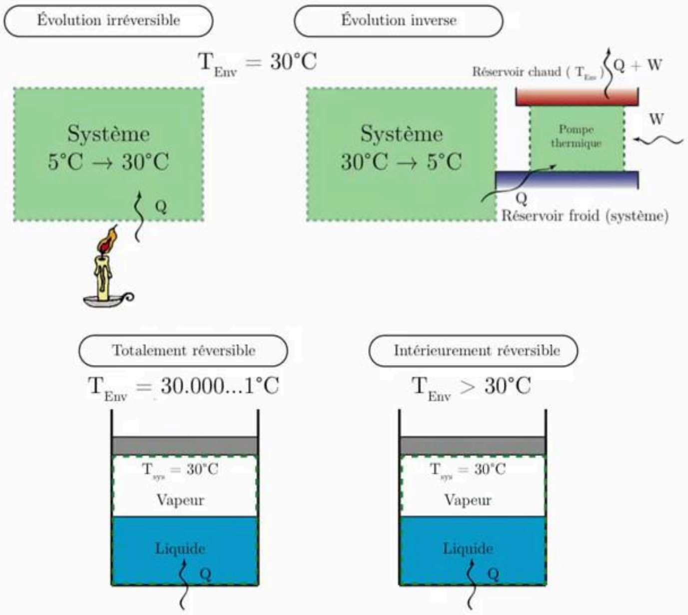
Notes

Summary

4m 21s

Évolutions réversibles et irréversibles

POLYTECHNIQUE MONTRÉAL



- Évolution irréversible
  - Laisse des traces sur l'environnement
  - Friction, mélange, etc.
  - Transfert de chaleur avec différence de température
- Évolution réversible
  - Concept idéalisé
  - Fournit plus de travail, consomme moins d'énergie
  - Limite théorique de performance

Thermodynamique

As you can imagine, the opposite concept of evolution is reversible evolution, which is an idealization that is difficult to approach. It is however a very useful concept for thermodynamic analyses, because reversible evolutions represent a theoretical performance limit. Reversible expansion provides the most work and reversible compressions require the least. For the purposes of thermodynamic analysis, we can conceive of evolutions reversible that would be very difficult to achieve in practice. For example, a heat transfer through an infinitely small temperature gradient. In reality, it would take a surface infinitely large exchange contact area to perform such an operation. But the idealized concept does not remain very useful, as we shall see shortly.

Notes

Summary

5m 31s

Le cycle de Carnot

Cycle de production d'énergie

- 4 évolutions réversibles
- Moteur thermique optimal

Nicolas Léonard Sadi Carnot, 1796-1832

Thermodynamique

This brings us to Mr. Nicolas Léonard Sadi Carnot who was the first to realize a cycle composed entirely of evolution reversible, would be an ideal in terms of performance that would be impossible to beat. So, you may have noticed a difference between Sadi Carnot and the other fathers of thermodynamics that you have to which you have been exposed so far. The difference is his age. Mr. Carnot made his major contribution at the age of 28. So he was the first to conceive a theoretical cycle which was composed of four reversible revolutions. This theoretical cycle is still used today as a benchmark in terms of performance and the CF bears its name.

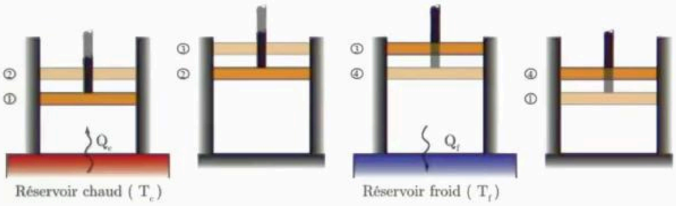
Notes

Summary

6m 13s

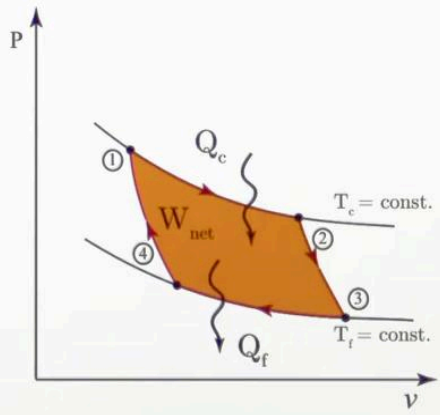
Le cycle de Carnot

POLYTECHNIQUE MONTRÉAL



Evolution	Caractéristiques
1-2	Expansion isotherme
2-3	Expansion adiabatique
3-4	Compression isotherme
4-1	Compression adiabatique

Diagramme P-v



Thermodynamique

This is the Carnot cycle, from a fluid that we will ask here is a perfect gas which is initially at high temperature and high pressure in the one state. The Carnot cycle operates as follows. The first evolution is an iso term expansion, so the volume increases, the piston moves upwards and the temperature is kept constant. The temperature has risen constantly as the volume expands. Heat is added to keep the temperature constant. The expansion then continues in a adiabatic, i.e. without heat input between points two and three. The reverse operations are carried out in the same order as the first phase compression between three and four in an ISO term and then between four and adiabatically. The Carnot cycle is very difficult to approach in practice. Mainly because of the one two and three four developments. As you can see in the PV diagram or work sessions during the one two and two three evolutions and we gives work to the system between points three and four and four and one. Developments that are of particular concern problem are the developments one two and three four during which work and heat must be supplied simultaneously or extract work and heat from the system. If we take now the cycle of Carnot, we make the four operations. In the opposite direction, we obtain an optimal refrigeration cycle by analyzing the Carnot cycle.

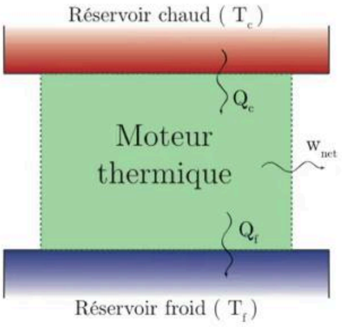
Notes

Summary

6m 50s

Corollaires du deuxième principe

POLYTECHNIQUE MONTRÉAL



$$\eta_{th} = \frac{W_{net}}{Q_c} = 1 - \frac{Q_f}{Q_c}$$

Thermodynamique

There are two corollaries to the second principle of thermodynamics. Firstly, we find that the performance of an irreversible cycle will always be lower than that of a reversible cycle. We can verify this corollary by observing two systems operating between the same thermal reservoirs.

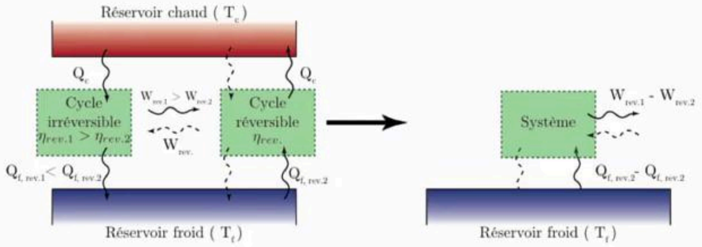
Notes

Summary

8m 11s

Corollaires du deuxième principe

POLYTECHNIQUE MONTRÉAL



- Corollaire 1 :

« Le rendement d'un cycle irréversible est inférieur à celui du cycle réversible entre les mêmes réservoirs. »

- Corollaire 2 :

« Tous les cycles réversibles opérant entre les mêmes réservoirs ont le même rendement. »

Thermodynamique

The first one is an irreversible thermal engine and the second one a cycle of Carnot reversed, thus an optimal refrigeration cycle. If the thermal efficiency of the former is higher than the latter, this one will produce more work from the heat received from the hot source than what is necessary for the Carnot cycle returns this same heat to the same tank. The balance of these two machines will therefore be equivalent to the production of mechanical power from a single heat source, which is forbidden by virtue of Kelvin Planck's statement of the second principle. We conclude that the efficiency of an irreversible cycle must always be lower than the efficiency of a reversible cycle operating between the same two tanks. The second corollary states that the performance of all cycles reversible operating between the same tanks must be identical. Once again, we can verify the truth of this corollary by considering two cycles which interact with the same reservoirs. It is the former, a higher yield than the latter. The net result of these two centuries is again the production of work from a single tank.

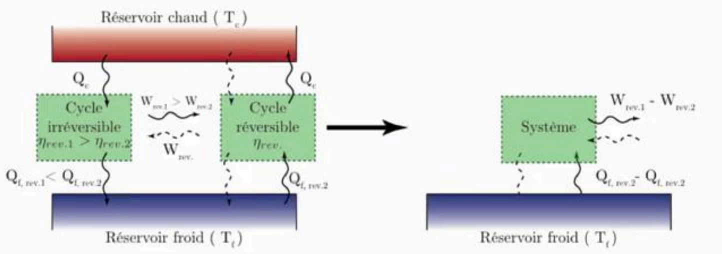
Notes

Summary

8m 26s

Corollaires du deuxième principe

POLYTECHNIQUE MONTRÉAL



$$\eta_{th,max} = 1 - \left(\frac{Q_f}{Q_c}\right)$$

- Corollaire 1 :

« Le rendement d'un cycle irréversible est inférieur à celui du cycle réversible entre les mêmes réservoirs. »

- Corollaire 2 :

« Tous les cycles réversibles opérant entre les mêmes réservoirs ont le même rendement. »

- Le cycle de Carnot :

« Rendement maximum qu'il est possible d'obtenir entre deux réservoirs. »

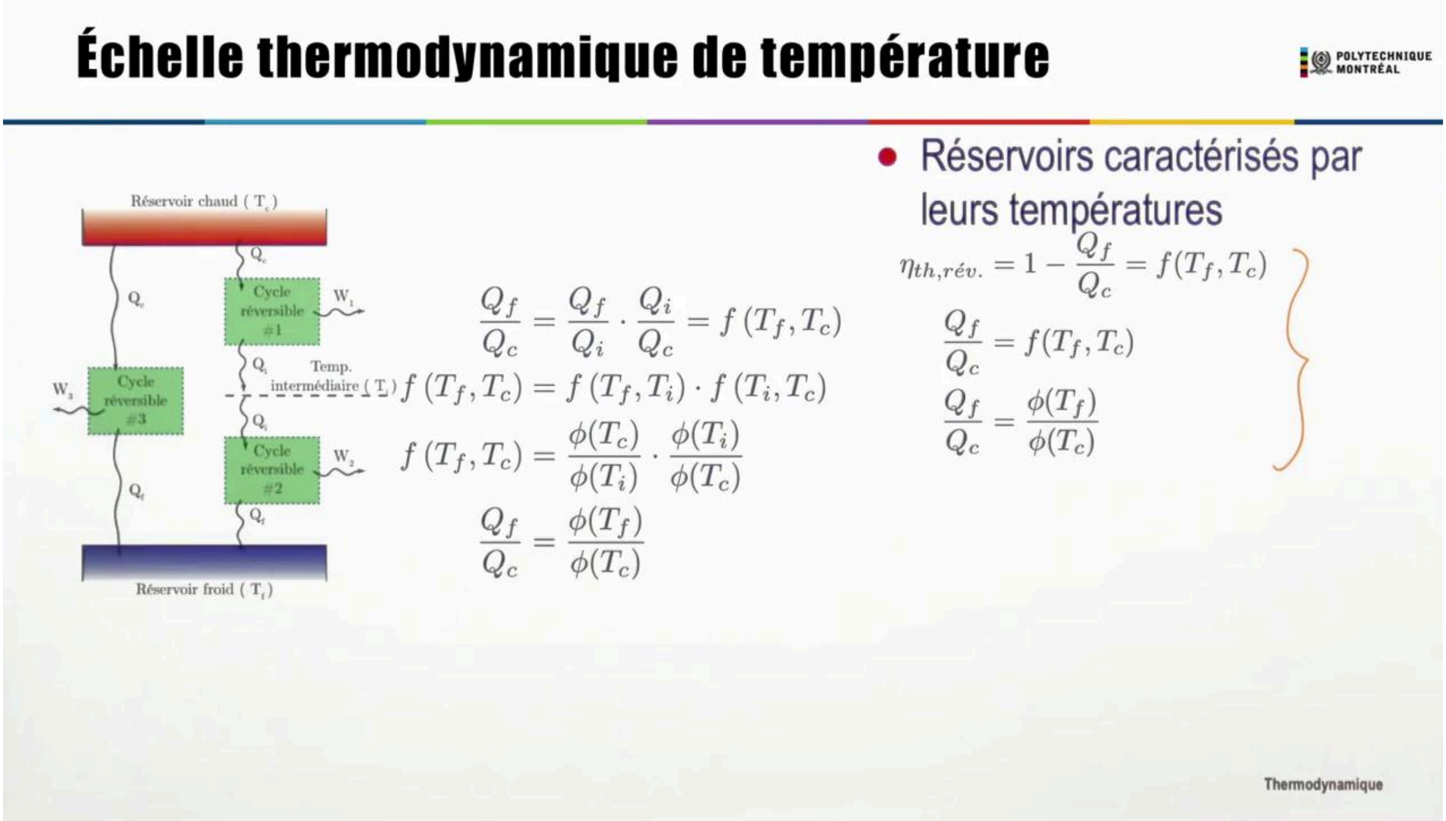
Thermodynamique

We can therefore conclude that the cycle of Carnot will provide the maximum yields that can be obtained between two and that this one will be expressed, as for all the thermal engines, as a minus the ratio between the amount of heat given off to the cold source, divided by that received from the hot source.

Notes

Summary

9m 28s

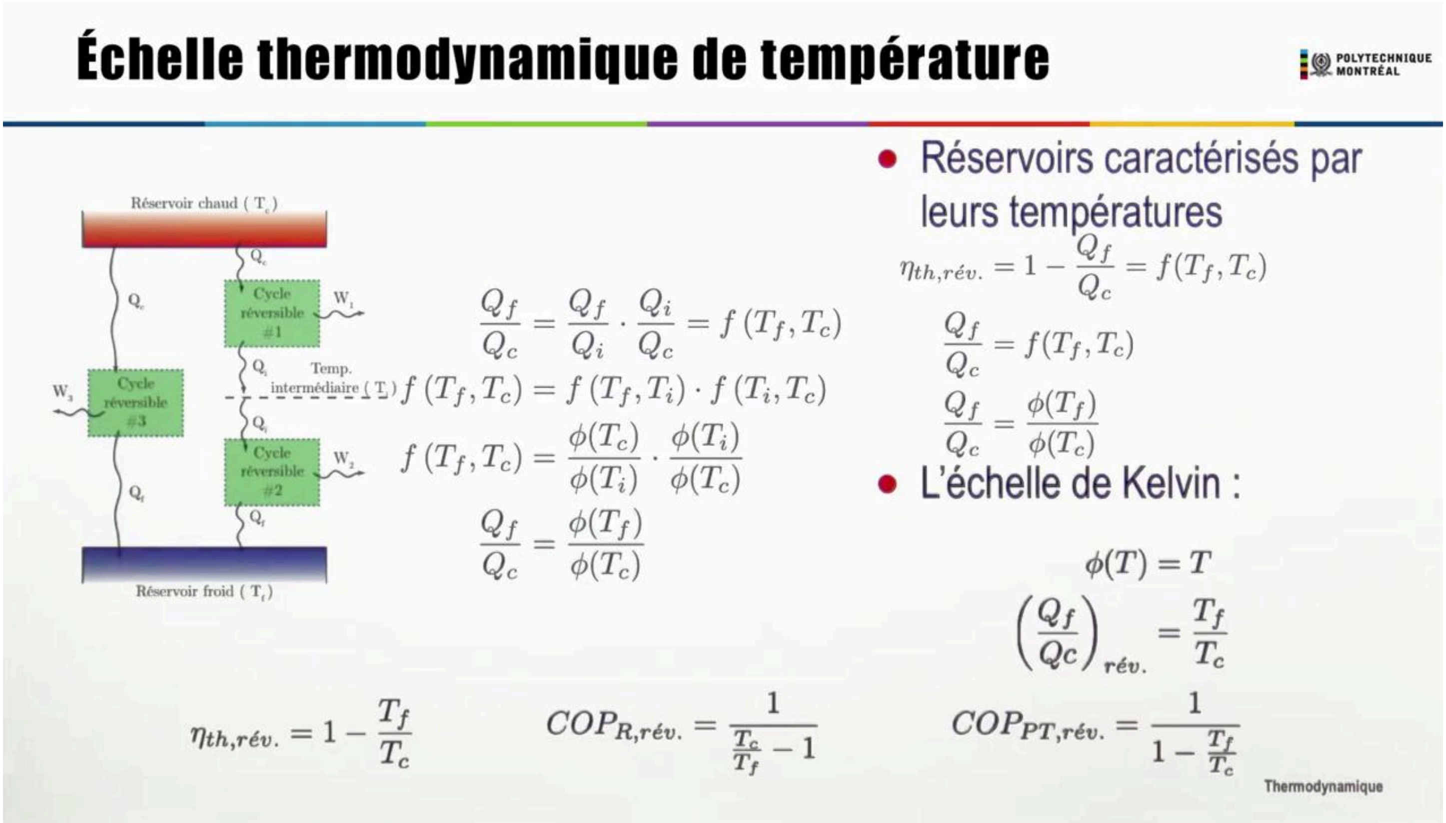


However, since thermal reservoirs are characterized only by their temperature, it is in fact their only property. We can therefore deduce that the thermal efficiency must also be a function of only the temperature of the two tanks. It would therefore be interesting to find a tool to replace the ratio of heat exchanged quantities QC and Kiev by functions of the temperature of these same reservoirs calling these functions fi, DTC and Fides TF. It is possible to imagine a large number of functions of temperature that will verify these relationships here. We will do a small exercise to highlight some constraints imposed on these functions, i.e. two thermal tanks between which are placed reversible thermal machines. One operates directly between the temperatures and EDF, while two others are connected in series between the same two tanks. These two machines connected in series interact with each other at an intermediate temperature that we will call flow. Like all reversible cycles operating between the same tanks must have the same performance. It follows that the performance of the first cycle must be equal to that of the second cycle. of a cycle equivalent to the combination of the other two.

Notes

Summary

9m 44s



So it is sure that F must be equal to QF. Multiplied by who on QC? Like the members on the left and exclusively according to TC and TF. It must be the same story. The same should be true for the right-hand member. So we must be able to make the dependency on. Says this member here. To make it disappear. The form of the filter function, which defines each of the tanks must be such that we can write that F on QC is equal to the field function of TF on the function Fi of TC. That it comes to propose a solution simple and elegant for the form of the temperature function. He did not suggest that I simply use the temperature one degree kelvin as a function of temperature. It is thus possible to replace the ratio of the heat quantities QC and QF exchanged by the tanks, simply by the ratio of the temperatures in kelvin of these two tanks. We thus obtain an expression for performance and coefficients of performance of thermal machines, which is only a function of the temperatures. But beware, these relationships down here are only valid for reversible systems.

Notes

Summary

10m 50s

Exercices – rendement cycle de Carnot et COP

POLYTECHNIQUE MONTRÉAL

	Moteur à combustion interne	Turbine à gaz	Turbine à vapeur (combustion)	Réfrigérateur
T_f	25°C	25°C	25°C	-20°C
T_c	1500°C	1300°C	620°C	25°C
$(\eta_{th}$ ou $COP)_{rév.}$	0.83	0.81	0.67	5.62
$(\eta_{th}$ ou $COP)_{réel}$	0.3-0.4	0.4-0.5	0.45	2

Thermodynamique

To illustrate the power of the concept of optimal reversible sex introduced by Carnot, considering the following examples. Either an internal combustion engine evolving in a 25 degree Celsius environment. If we assume that the combustion provides energy to the system at a temperature of 1500 degrees Celsius, a Carnot cycle can convert 83% of this energy into mechanical work. In reality, the efficiency of the engines internal combustion engines hardly reaches 30 to 40%. The difference between these two values represents the associated cost to the irreversibility present in the real engine. For a gas turbine in which the combustion gases are supplied at a speed permanent at 1300 degrees Celsius, the Carnot efficiency is 80 whereas real machines achieve yields of 40 to 50%. We can therefore conclude that, all things considered, the irreversibility is more significant in the engines internal combustion engines than in gas turbines. The situation is very different for steam turbines, for which the maximum temperature is limited by the capacity of the materials to resist steam at very high temperatures.

Notes

Summary

12m 01s

Exercices – rendement cycle de Carnot et COP

POLYTECHNIQUE MONTRÉAL

	Moteur à combustion interne	Turbine à gaz	Turbine à vapeur (combustion)	Réfrigérateur
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Thermodynamique

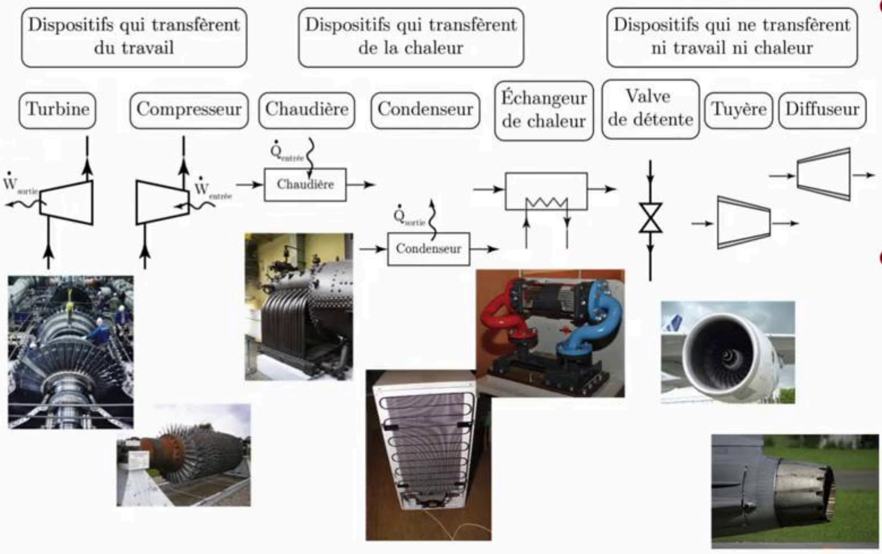
Assuming a maximum temperature of 620 degrees Celsius, a typical value for a large installation, we arrive at an efficiency of 67%, while the best real machines reach about 45% for refrigeration cycles. The expression of the coefficient of performance tells us that the greater the difference the more work it will take to transfer the temperature to the a given amount of heat between the two tanks. In the case of a system operating between room temperature and -20 degrees Celsius, the reversible coefficient of performance is five for a 62. In other words, in the reversible case, a work area provides what is needed to extract 5.62 joules from the source and push it into the hot spring. For a real domestic refrigerator. The coefficient of performance is usually closer to two. This is largely due to the difficulty of heat transfer with air.

Notes

Summary

13m 04s

Les cycles réels et leurs composantes



- Cycle de Carnot
  - Suppose expansion et détente simultanément avec transfert de chaleur
  - Difficile à approcher en pratique
- Cycles réels : composantes réelles
  - Piston/cylindres
  - Turbines
  - Pompes et compresseurs

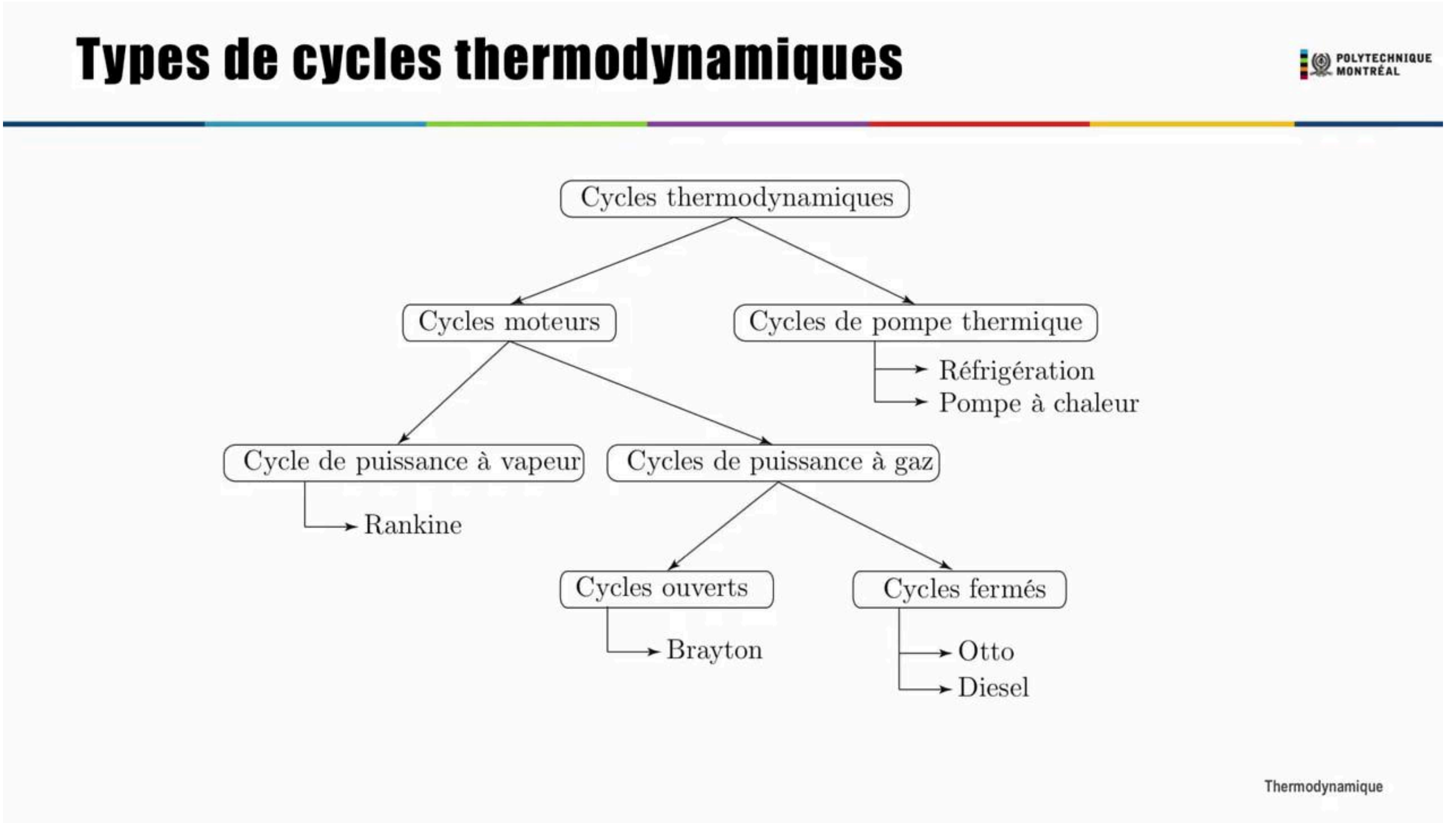
Thermodynamique

The differences between the reversible and real sexes will be largely caused by the limitations of the devices used to carry out the evolutions which constitute the cycle. For example, two developments in the cycle of Carnot suppose that work and heat are transferred simultaneously to a fluid, a task that is very difficult, if not impossible to perform with real devices, but has been created. It is composed of elements generally operating in steady state, which exchange either work or heat or neither with the environment. For the first category, This is referred to as a piston, turbine cylinder or compressor system. Do you see some examples here? As well as the representations diagrams that are used in the following. In the most general case, we will call the devices that transfer heat between a system and its environment, heat exchangers. When a heat exchanger involves a phase change. This is called a boiler or condensate. Some devices do not involve work or heat. They simply transform in which form the energy is in the fluid. These are, for example, trigger valves used to lower the pressure, or diffusers and nozzles placed in the at the front and rear of aircraft engines. The function of the diffusers is to convert the kinetic energy into in pressure increase and vice versa for the nozzle.

Notes

Summary

13m 57s



From its basic components. A wide variety of cycles can be designed for different tasks production of mechanical power, cold or heat. First, we distinguish between the five engines that produce of work and the resistant circles that consume it. Resistant circles are essentially circles thermal pumping systems that are classified as refrigerators or heat pumps, depending on whether you want to produce cold or heat. And these comments can be subdivided into gas or steam power cycles, depending on whether or not the working fluid undergoes a phase change during the cycle. The vast majority of circles The modern power generation system uses the Rankine cycle or a variation of it. Gas power rings can be further subdivided into dependencies. They operate on volumes of fluids open or closed, common open circles. The most common is the Brighton SEC, which is used for example in gas turbines or in aeronautical propulsion. Finally, the closed gas power cells are used for to produce work in power and free configurations. This is called the auto or diesel cycle. They are, of course, widely used for automotive propulsion. The following modules will present the cycles in more detail closed gas and rain glass power and refrigeration cycles.

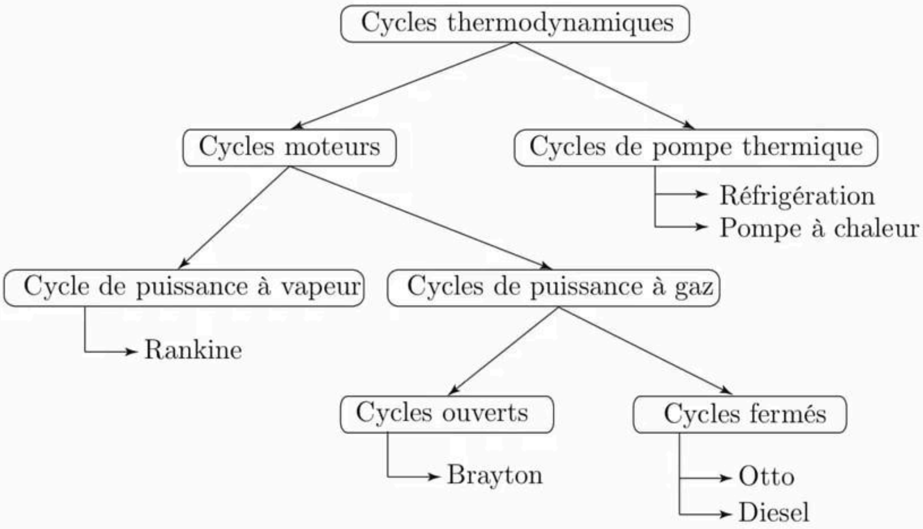
Notes

Summary

15m 23s

Types de cycles thermodynamiques

POLYTECHNIQUE MONTRÉAL



Thermodynamique

This concludes this introductory module on thermodynamic cycles. We had the opportunity to learn that reversible evolutions are an ideal that we must seek to approach and that a thermodynamic cycle which contains only evolutions reversible is therefore an ideal to achieve in terms of efficiency. An ideal that we will never be able to surpass. This represents a limit that physics imposes on what it is possible to is possible with a thermodynamic cycle. By analyzing the Carnot cycles, we were also able to determine or to define the concept of performance and coefficient of performance, and that these are only a function of the temperature of the hot tanks and cold tanks used for the cycle. Thank you.

Notes

Summary

16m 44s