ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

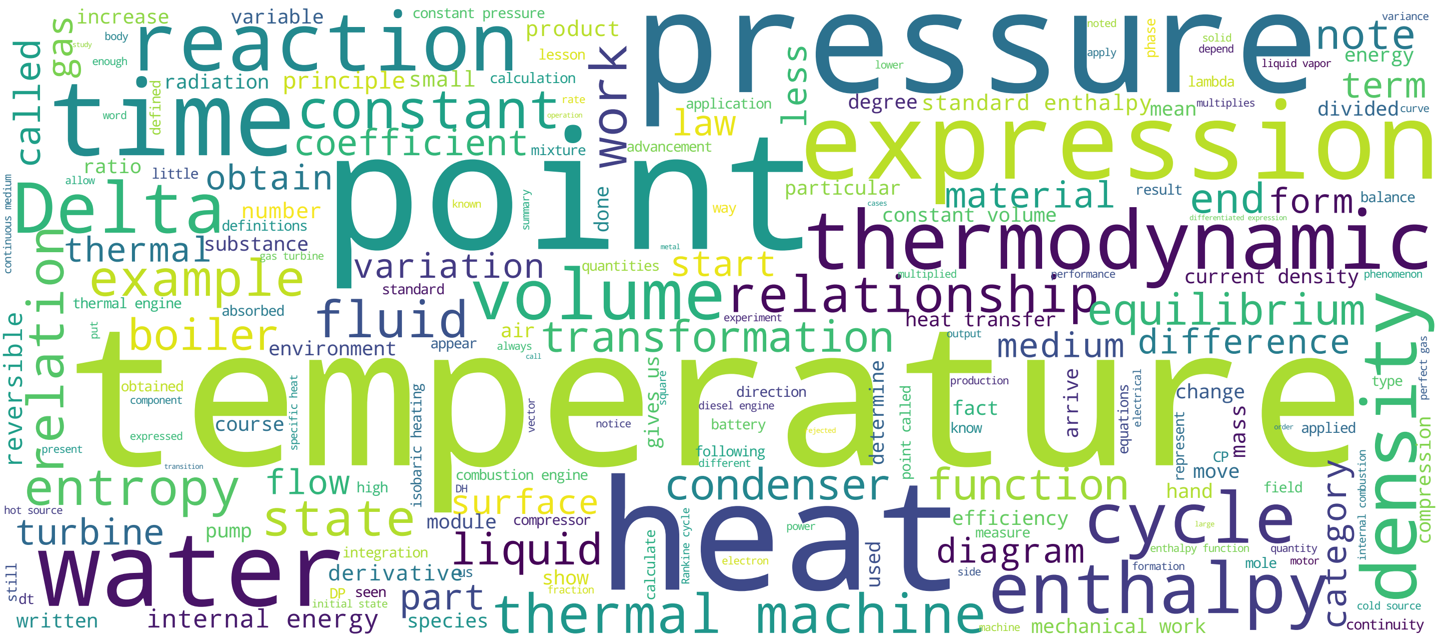
RESCIF
Réseau d'excellence des sciences de l'ingénieur de la Francophonie

Thermodynamique

Introduction aux machines thermiques

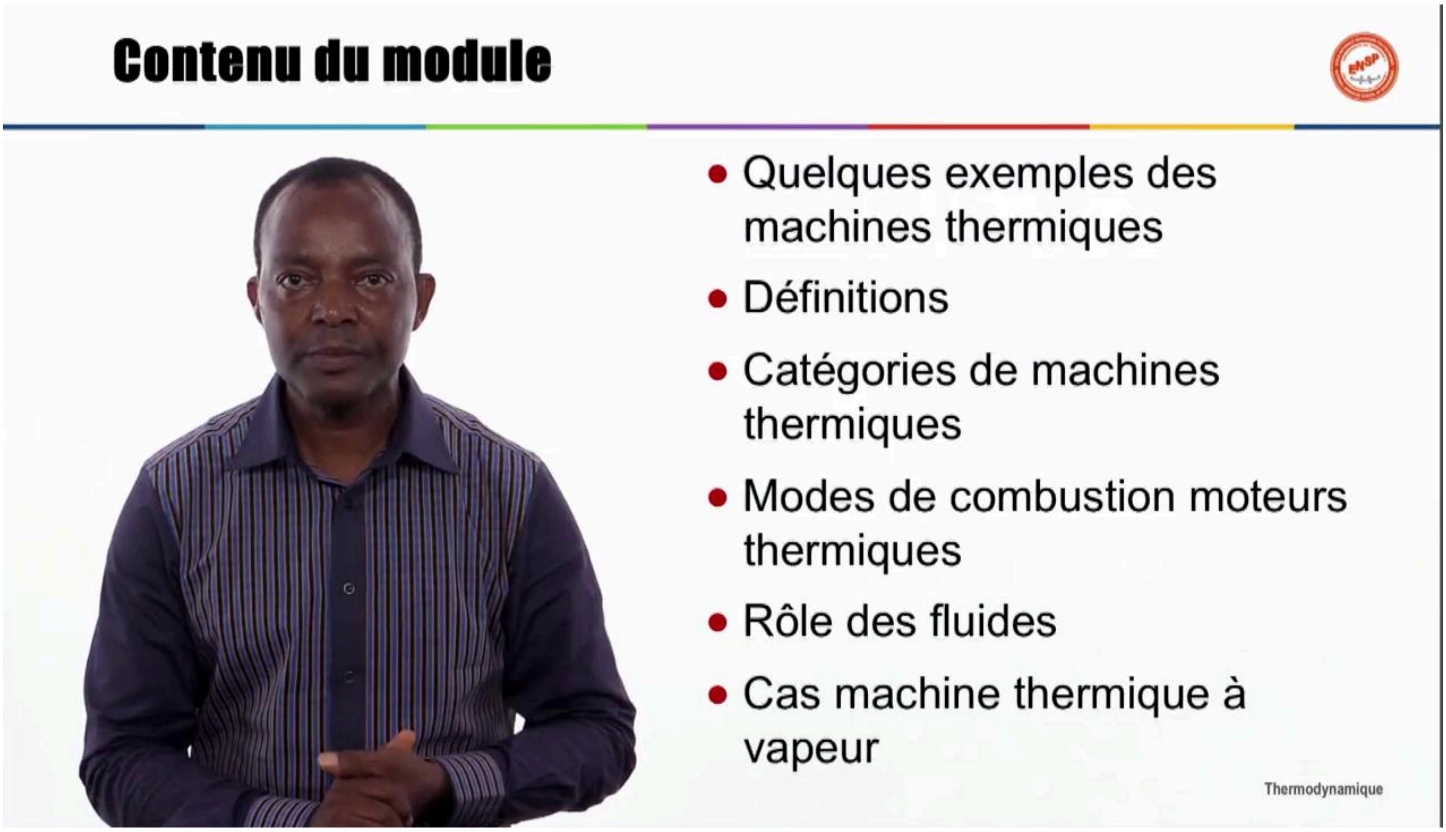
Richard Mollier, 1863 - 1935

Ing. Dr André Talla, ENSP – Yaoundé - Cameroun



Video

EPFL

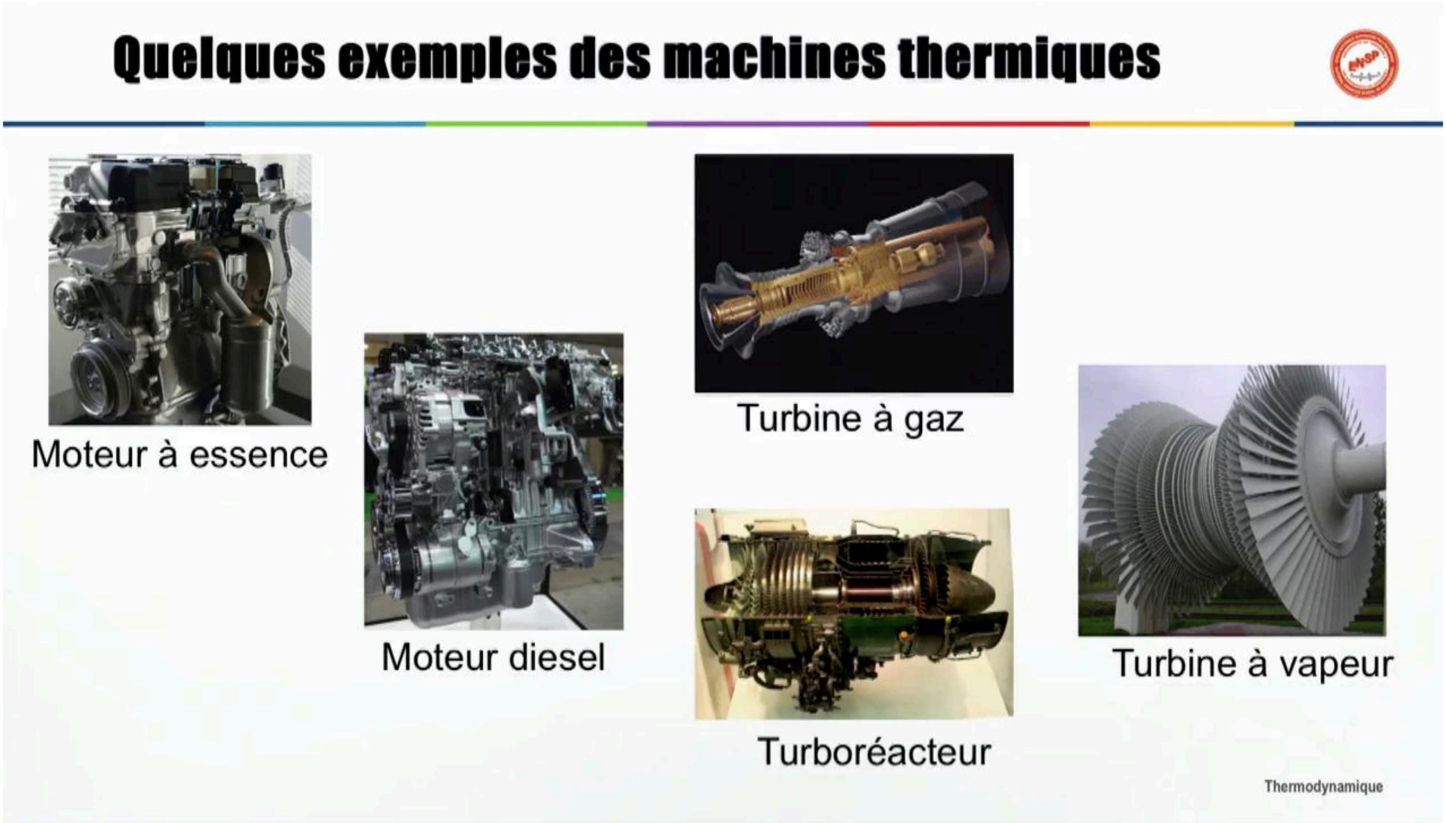


Hello to all, I am happy to find you a new shot. Thermodynamics reef coordinated by the Ecole Polytechnique of Lausanne and related to fluids. Today, we will bring our attention to the means devoted to the introduction to thermal machines. Let's move on to the summary of this module. To fix the ideas. We will start by giving some examples of thermal machines. Then we will give two definitions to situate the thermal machine in the field of thermodynamics. The third point will focus on on the different categories of thermal machines. A word will then be said about the combustion model. For the particular case of thermal engines, the following point will be devoted to the role that fluids play in these machines. We will end this module by examining the case of the operation of a steam engine, moving on to some definitions of thermal machines, we have.

Notes

Summary

0m 05s

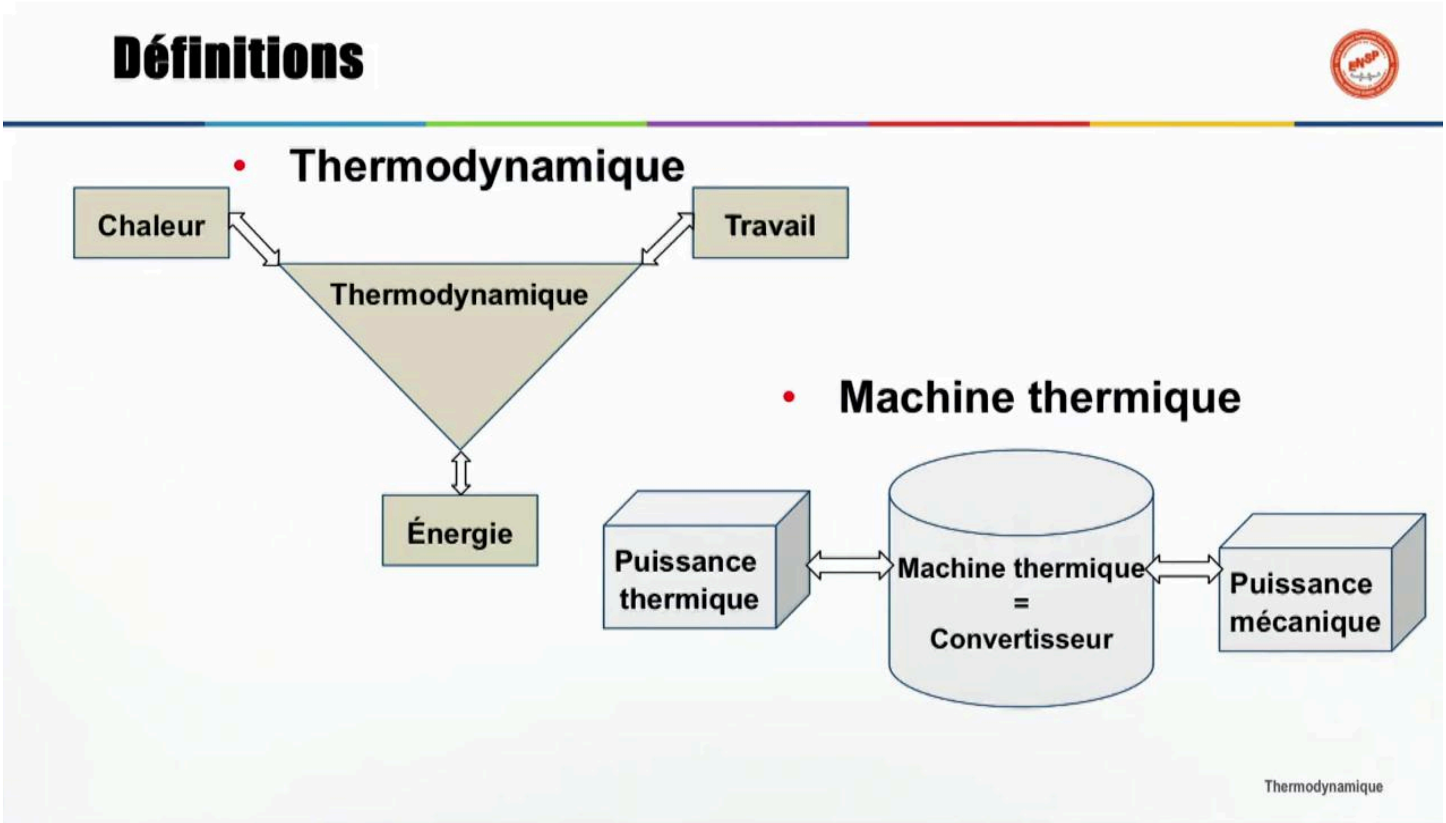


The gasoline engine, also known as the internal combustion engine. In this engine, the fuel mixture is is done in a carburetor and the combustion is initiated by a spark plug. The diesel engine differs from the gasoline engine by the absence of the carburetor, mixtures, of the combustion ingredients and the absence of the spark plug. Then we have the steam turbine driven by steam produced in a wood-fired heat energy boiler. The gas turbine, on the other hand, is set in motion by the energy kinetics of the gases resulting from the combustion of the fuel mixture. The last example concerns the turbojet engine used in aircraft. We have given just a few examples noting that this list is far from exhaustive.

Notes

Summary

1m 16s



Let's move on to definitions. First, thermodynamics. It is about this field of science which establishes the relationship between heat, work and energy. The machine allows for a converter from a thermal power to a mechanical power or vice versa.

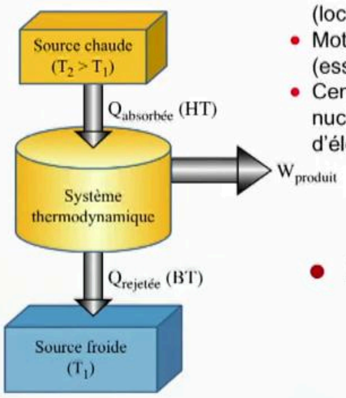
Notes

Summary

2m 13s

Catégories de machines thermiques

- **Moteurs thermiques**



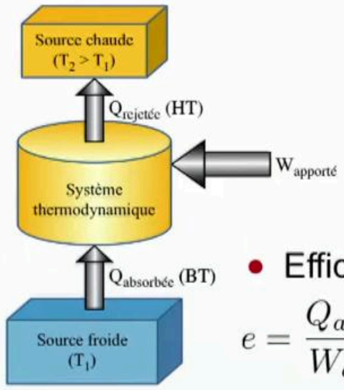
Exemples
- Machines à vapeur (locomotives…)
- Moteurs à combustion (essence ou diesel)
- Centrales thermiques ou nucléaires (production d'électricité)

- Rendement

$$\eta = \frac{-W_{produit}}{Q_{absorbée}} < 1$$

$$\eta = 1 + \frac{Q_{rejetée}}{Q_{absorbée}}$$

- **Machines à transfert de chaleur**



- Efficacité

$$e = \frac{Q_{absorbée}}{W_{apporté}} > 1$$

$$e = \frac{Q_{absorbée}}{-(Q_{absorbée} + Q_{rejetée})}$$

Thermodynamique

This leads us to categorize these machines. First, we have the thermal engines. Here, the thermodynamic system takes heat from high. Temperature at the hot spring. A fraction of this heat energy is converted into mechanical work cd outside and the other fraction is rejected to the cold source at low temperature. The efficiency of this motor, which is less than one, is given by. The expression being equal to less than W product on was absorbed W produced on work cd outside and counted negatively by convention and Cu absorbed. It is the heat received by the system and by convention is counted positively. If the application of the first principle of thermodynamics, this expression is still written, being equal to a plus Q rejected on q absorbed. As an example, in this category of thermal machines, we will mention. The steam engines that can still be found in some locomotives, combustion engines either gasoline or diesel. Thermal or nuclear power plants for the production of electricity. As a second category. We have the heat transfer machine in this category of mechanical work and supplied to the thermodynamic system which consequently takes heat from the cold source at low temperature and rejects the heat to the hot source at high temperature.

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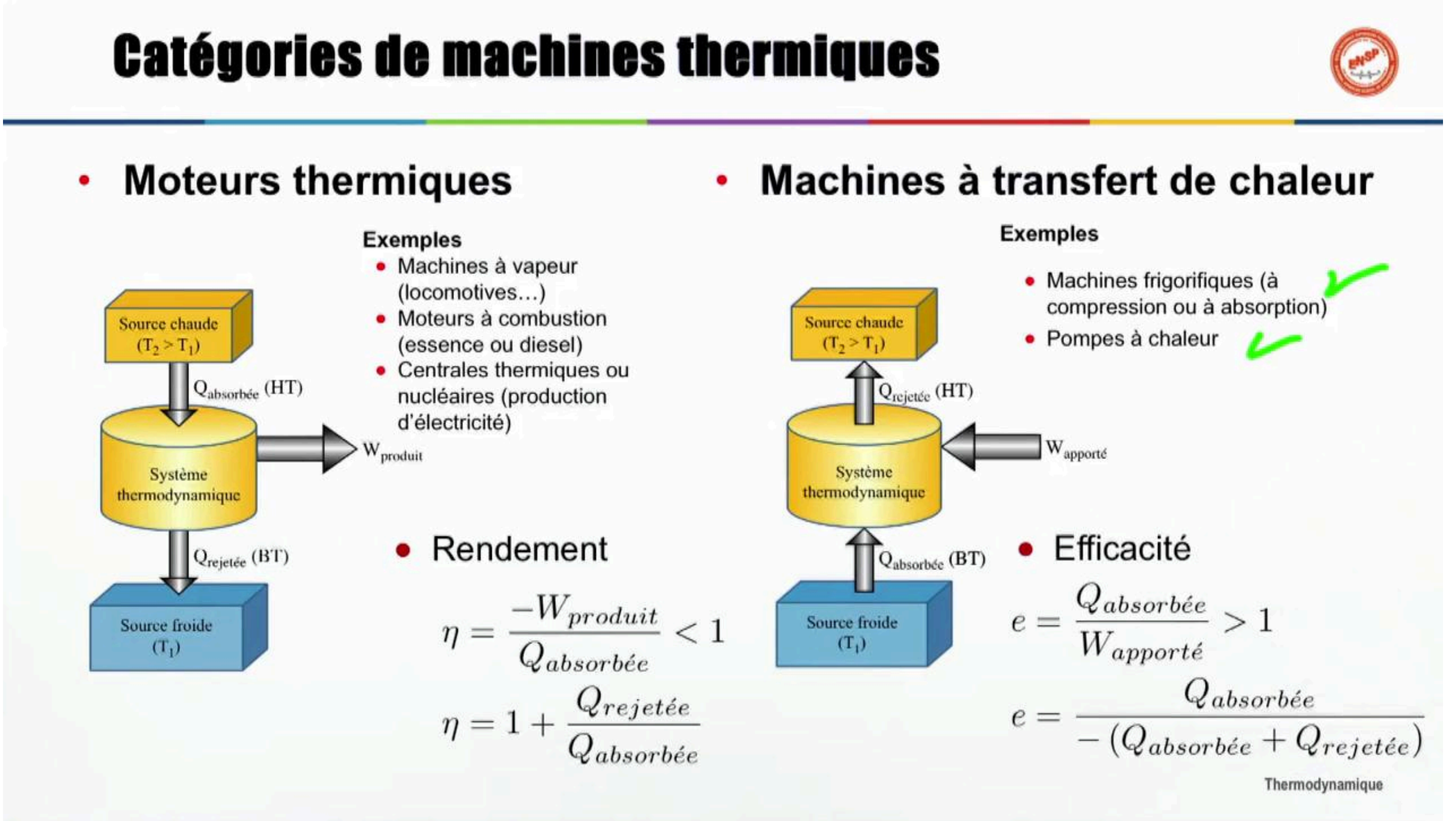
Summary

2m 39s



The efficiency of such a machine is given by. The expression is equal to Q absorbed on W brought once again by applying the first principle of thermodynamics. This expression is written equal to cooked, absorbed over less cooked absorbed plus q rejected. As an example in this category of thermal machines, we quote compression or absorption refrigeration machines and heat pumps.

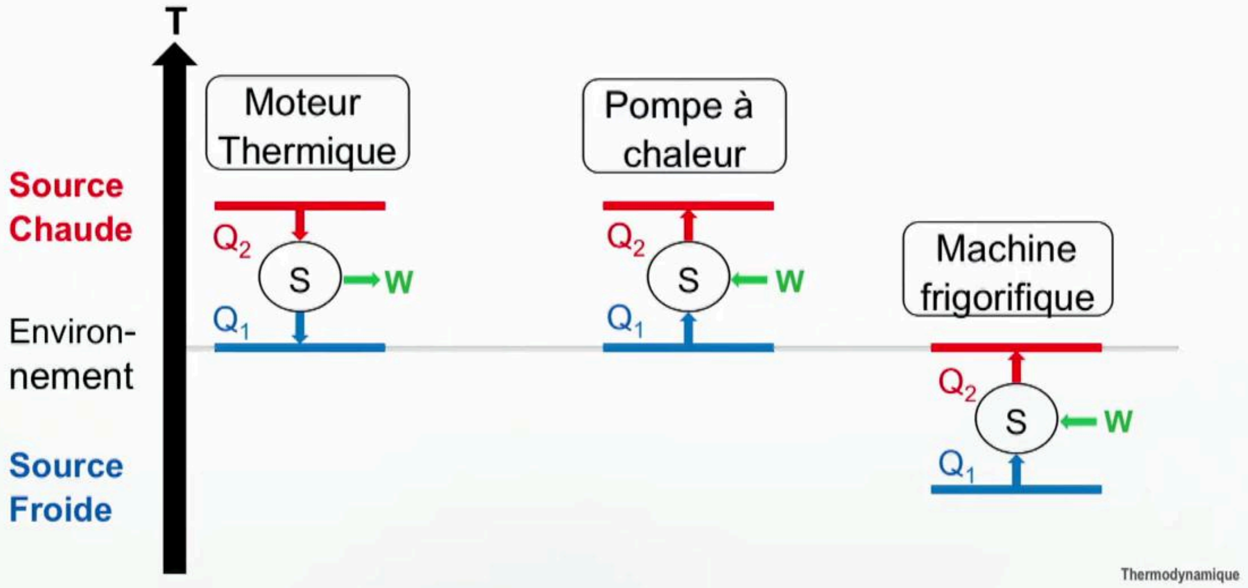
Notes

Summary

4m 25s

Catégories de machines thermiques

Vue d'ensemble machines thermiques dithermes

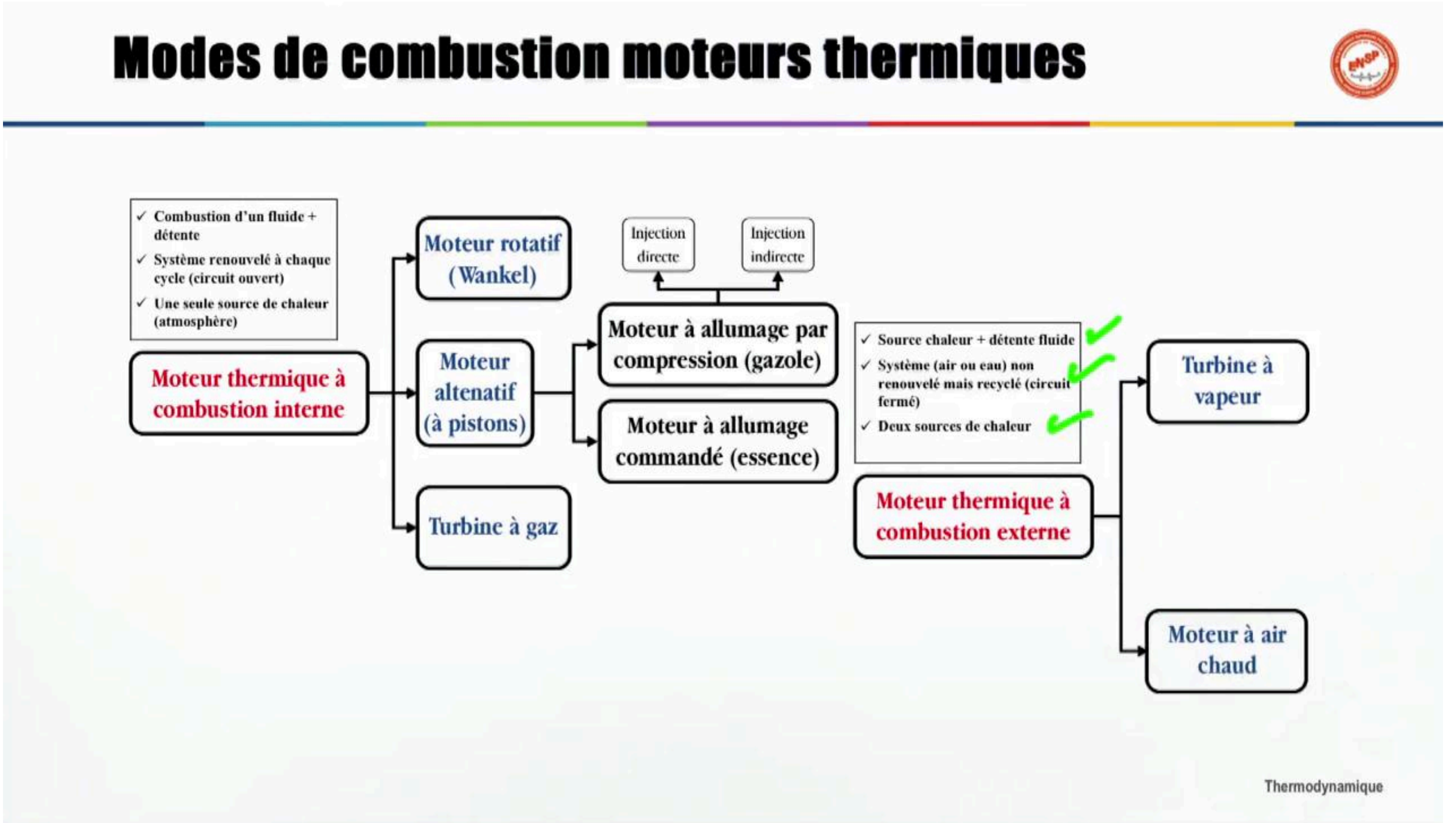


This diagram gives us an overview thermal machines in a thermal engine. The thermodynamic fluid takes heat from the hot source, produces mechanical work W and rejects heat to the outside environment. In a heat pump. The thermodynamic system receives a mechanical prework of the heat to the environment outside and rejects the heat to the hot source. For the refrigeration machine, the thermodynamic system receives a mechanical prework of the heat at the cold source and rejects the heat to the outside environment.

Notes

Summary

4m 58s

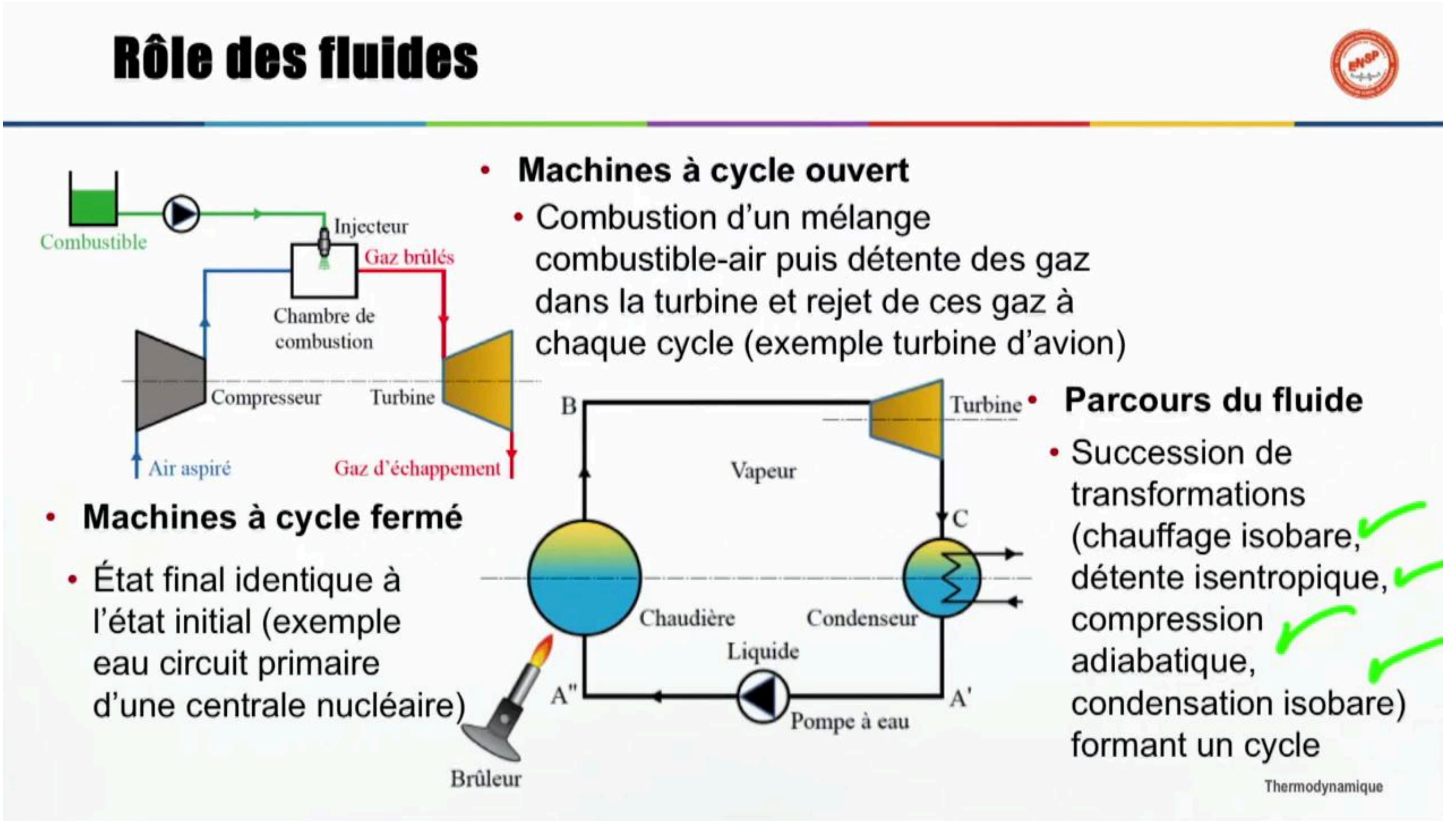


Now it's time for the combustion models for the particular case of thermal engines. Let's start with the internal combustion engine. This category of engines includes the rotary engine still Wankel's qualified engine, the reciprocating piston engine and the gas turbine. If we are interested in engines and includes the spark ignition engine or. The gasoline engine, the compression ignition engine, the diesel engine. In the category of diesel engines, we distinguish the injection engine and the indirect injection engine. Note that in this range of engines and combustion of a fluid followed by the relaxation of the latter to produce mechanical work, the thermodynamic system is renewed at each cycle. We talk about the open cycle. The engine works with only one heat source which is the atmosphere. Then we have the category of external combustion engines. This type of engine includes the steam turbine and the hot air engine. Note that in this range of engines, there is no heat and a coolant effect followed by the expansion of these to produce mechanical work. The thermodynamic system can be air or water. Note that this system is not renewed but recycled. This is called a closed circuit. The engine operates with two heat sources.

Notes

Summary

5m 41s



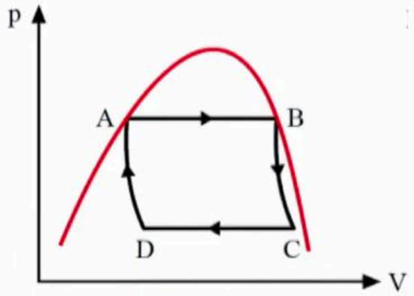
Let us now turn to the role that applied thermodynamics could play. Let's start with the open cycle machines. We have the combustion chamber, fed on the one hand through a fuel tank by means of a pump and a navigator. On the other hand, pulsed aid thanks to a compressor. The turbine. Is then activated by the expansion of the burnt gases. The gases are then released with each cycle. This is the example of an aircraft turbine. As far as closed cycle machines are concerned, we have the boiler which receives heat to bring water from the liquid state to the vapor state. The turbine is then driven by the steam expansion produced to the next step, i.e. to the condenser. The vapors are brought to a liquid state, the liquid obtained and then is returned to the boiler by means of a pump. Circulations here, the final state is identical to the initial state. This is the example of the water in the primary circuit of a nuclear power plant. As a fluid path, in either case, the cycle is formed by a succession of transformations in particular. Isobaric heating, isotopic expansion, adiabatic compression and isobaric condensation.

Notes

Summary

7m 41s

Du cycle de CARNOT au cycle de RANKINE



Cycle de Carnot

Cycle de CARNOT

- Cycle idéal de rendement $\eta_C = 1 - \frac{T_f}{T_C}$
- Cycle difficilement réalisable en pratique

Thermodynamique

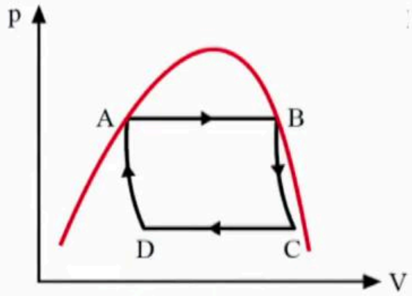
We will now. Such was the case of thermal machines and roughing channels in the Rankine cycle. First, the Carnot cycle. It is characterized by two transformations it to the term or isobaric a, b and c, d and. Adiabatic transformation. B, c and D to. This cycle is ideal with an output is quite equal to a minus of F on PC and F being the temperature of the source cold and it is the temperature of the source is hot. However, it is difficult to achieve in practice because the title of steam may vary in the initial state of the compression stage. That is. The state of the islands is therefore modified in Rankine cycle.

Notes

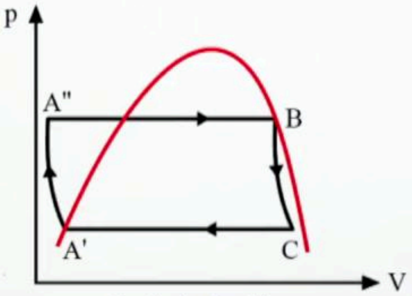
Summary

9m 24s

Du cycle de CARNOT au cycle de RANKINE



Cycle de Carnot



Cycle de Rankine

Cycle de CARNOT

- Cycle idéal de rendement $\eta_C = 1 - \frac{T_f}{T_C}$
- Cycle difficilement réalisable en pratique

Cycle de RANKINE

- Cycle de CARNOT avec compression du mélange liquide-vapeur (D à A), remplacée par une compression de liquide simple (A' à A") puis un chauffage du liquide (A" à A).
- Rendement pratique plus élevé du fait de substitution du compresseur par une simple pompe de circulation du liquide.

Thermodynamique

Take a look at the ranking site to get the rankings. The compression of the liquid-vapor mixture in the Carnot cycle is replaced by by a compression of the team, the single from first to second. Then the compressed liquid undergoes isobaric heating from a second to b. The practical efficiency is higher due to the substitution of the compressor by a simple liquid circulation pump.

Notes

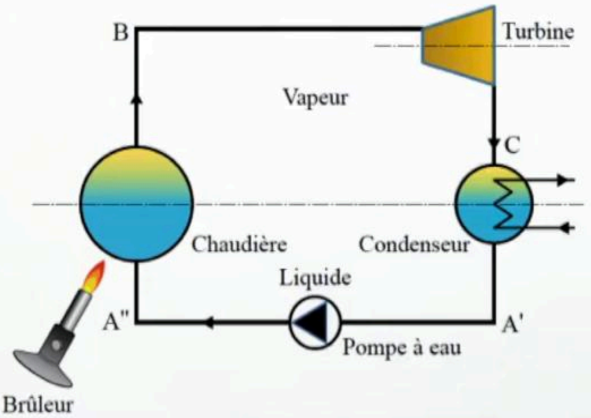
Summary

10m 27s

Cas machine thermique à vapeur

Différentes transformations au cours du cycle de Rankine

- **Chaudière (transformation A''AB)**
  Chauffage isobare (A"A) + évaporation isobare (AB) du liquide jusqu'à l'état de vapeur saturante en B ;



- **Turbine (Transformation BC)**
  Détente isentropique de la vapeur saturante donnant du travail au milieu extérieur ;
- **Condenseur (Transformation CA')**
  Liquéfaction totale du mélange liquide-vapeur au point A' ;
- **Pompe (Transformation A'A'')**
  Rejet des condensats dans la chaudière et fermeture du cycle.

Thermodynamique

We will now deal with the case of steam thermal machines. Let's now look at the different transformations of the cycle at the boiler. We have an isobaric heating from to second to, followed by isobaric evaporation of the liquid to the saturated steam state b at the turbine. We have a topical relaxation of the saturating vapor of B enough to give mechanical work to the external environment. As for the condenser, it ensures the total liquefaction of the liquid-vapor mixture from point C to the point called. Finally, the pump discharges the condensate into the turbine and the cycle is closed.

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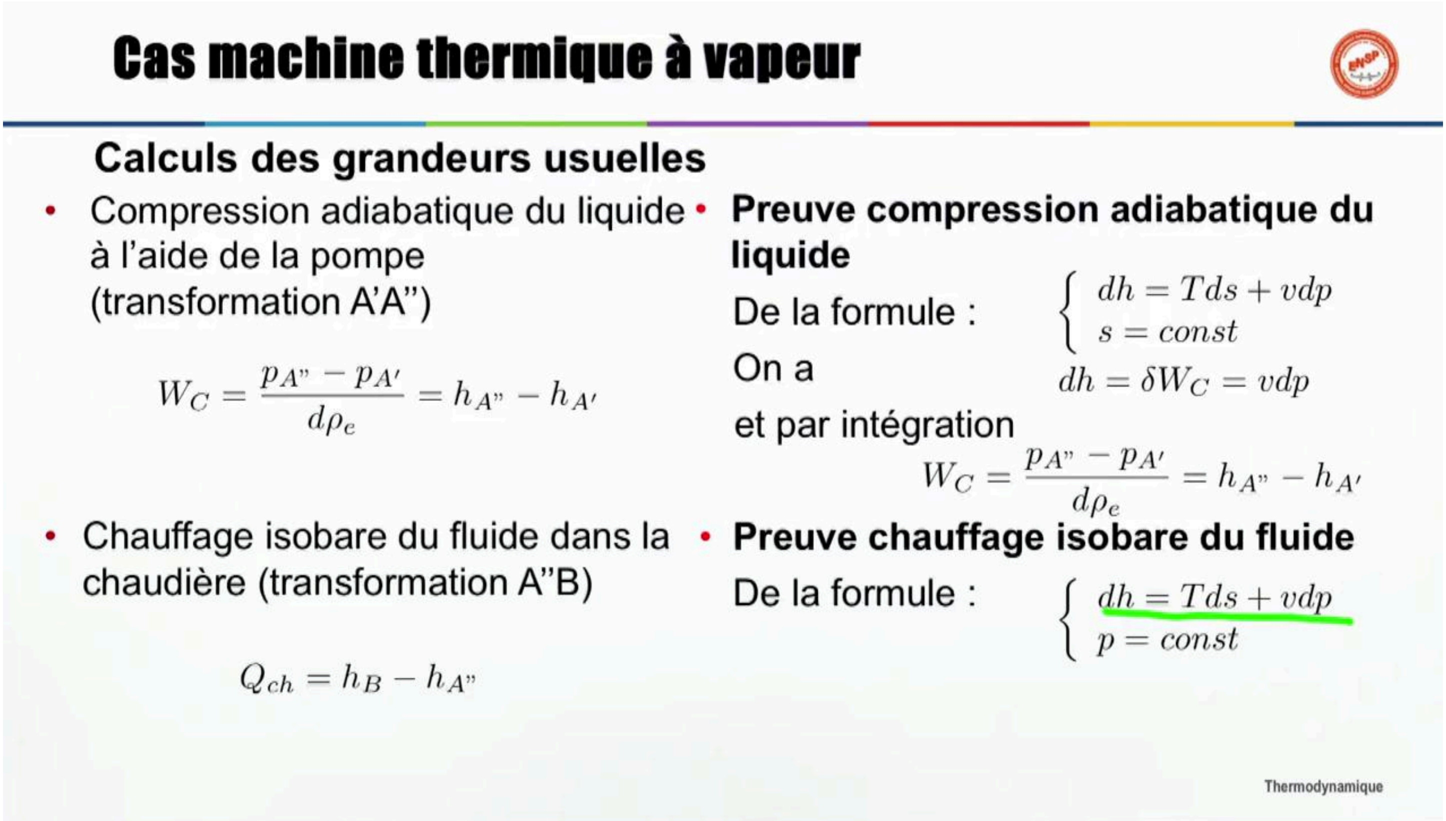
Summary

11m 07s



Let's see the calculations of some quantities. Freezing first, adiabatic compression of the liquid with the pump, this is the transformation per second. The work of the pump is given by the expression WC equal to the pressure at the point, i.e. minus the pressure at the called point, the whole divided by the density of the fluid that multiplies the density of the water. This work can still be obtained by. The enthalpy of the point, i.e., fist pumping, calling. Or can they whistle cries? The differentiated expression of the enthalpy function, namely. DH is equal to TDS plus DP. The compression is adiabatic. We have an S that does not vary. And finally B is equal to Delta WC which is equal to VDB. In this equation we obtain WC equal to the pressure difference between the point to know and the point to P. The whole, divided by the density of the fluid, can multiply the density of the water which is still equal to to the difference in enthalpy between the point at second and the point called. Concerning isobaric heating in the boiler, the heat supplied to the system is given by the expression. Q at the boiler, at the end of a belt between the boiler outlet and the inlet of this to the presses, we write again the expression differentiated from the enthalpy function, i.e.

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Summary

12m 03s

Cas machine thermique à vapeur

Calculs des grandeurs usuelles

- Compression adiabatique du liquide à l'aide de la pompe (transformation A'A")

$$W_C = \frac{p_{A"} - p_{A'}}{d\rho_e} = h_{A"} - h_{A'}$$

- **Preuve compression adiabatique du liquide**

De la formule : $\begin{cases} dh = Tds + vdp \\ s = const \end{cases}$

On a $dh = \delta W_C = vdp$

et par intégration

$$W_C = \frac{p_{A"} - p_{A'}}{d\rho_e} = h_{A"} - h_{A'}$$

- Chauffage isobare du fluide dans la chaudière (transformation A"B)

$$Q_{ch} = h_B - h_{A"}$$

- **Preuve chauffage isobare du fluide**

De la formule : $\begin{cases} dh = Tds + vdp \\ p = const \end{cases}$

On a $dh = Tds = \delta Q_{ch}$

et par intégration $Q_{ch} = h_B - h_{A"}$

Thermodynamique

equal to higher TDS DP. The heating is isobaric. The pressure is equal to a constant. We arrive in a DH equal to TDS which is equal to Delta Q Boiler. The integration of this equation leads us. Accusers in the boiler at different temperatures, the point to know is point B.

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Summary

13m 57s

Cas machine thermique à vapeur

- Détente adiabatique de la vapeur dans la turbine (transformation BC)

$$W_d = h_C - h_B$$

- **Preuve détente adiabatique de la vapeur**

De la formule : $\begin{cases} dh = \delta Q + vdp \\ \delta Q = 0 \end{cases}$

On a $dh = \delta W_d = vdp$

et par intégration $W_d = h_C - h_B$

- Liquéfaction isobare du fluide dans le condenseur (transformation CA')

$$Q_{cond} = h_{A'} - h_C$$

- **Preuve condensation isobare du fluide**

De la formule : $\begin{cases} dh = Tds + vdp \\ p = const \end{cases}$

Thermodynamique

Let's see what happens when the steam relaxes. Adiabatically lies in the turbine, it is the transformation to lower. The work resulting from this relaxation is given by the expression. W. D. Unlike a belt between point C at the turbine outlet and point B at the entrance of the latter. The proof is in the pudding, we resort once again to the differentiated expression of the function enthalpy, i.e. DH equal to Delta Q plus DP. The transformation being isotopic. Delta Q is zero. We get. DF dh equal to Delta W which is equal to v. DP. The integration of this equation gives us the expression of the work provided by the turbine, namely. WD is equal to the difference in enthalpy between the center point of the turbine and point B at the turbine inlet. Finally, let's look at the isobaric liquefaction of the fluid in the condenser. This is the transformation. It is the heat given off by the system at the condenser is given by the expression condenser and at the end of a belt between the condenser outlet, i.e. the point called and the inlet of the condenser, i.e. the point C. We will refer us once again to prove it to the differentiated expression of the enthalpy function, namely. DH.

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Summary

14m 23s

Cas machine thermique à vapeur

- Détente adiabatique de la vapeur dans la turbine (transformation BC)

$$W_d = h_C - h_B$$

- **Preuve détente adiabatique de la vapeur**

De la formule : $\begin{cases} dh = \delta Q + vdp \\ \delta Q = 0 \end{cases}$

On a $dh = \delta W_d = vdp$

et par intégration $W_d = h_C - h_B$

- Liquéfaction isobare du fluide dans le condenseur (transformation CA')

$$Q_{cond} = h_{A'} - h_C$$

- **Preuve condensation isobare du fluide**

De la formule : $\begin{cases} dh = Tds + vdp \\ p = const \end{cases}$

On a $dh = Tds = \delta Q_{Cond}$

et par intégration $Q_{cond} = h_{A'} - h_C$

Thermodynamique

Is equal to VDB. The transformation being done at constant pressure, we arrive at the DDS which was a delta ku at the condenser. The integration of this equation gives us that condensate equal to H. AP ac ap being the output of the condenser and this is the input of the condenser, let's now look at the efficiency of this motor.

Notes

Summary

16m 12s

Cas machine thermique à vapeur

- Rendement du moteur thermique

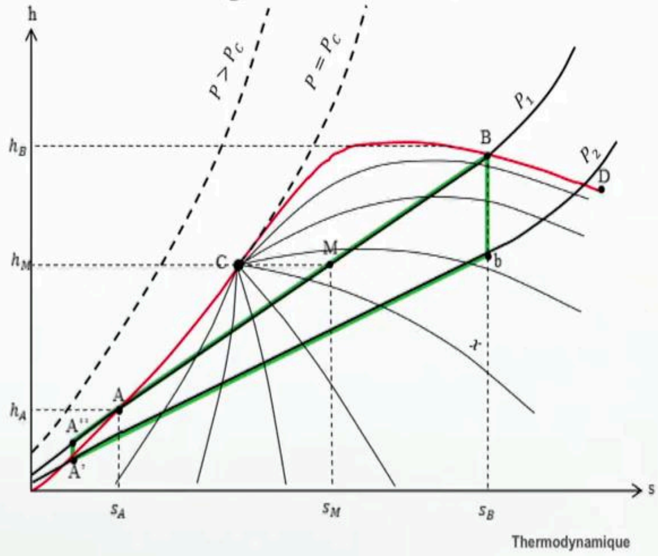
$$\eta = \frac{|W_d + W_C|}{Q_{ch}} = \frac{h_B - h_C - \left(\frac{p_{A''} - p_{A'}}{d\rho_e}\right)}{h_B - h_{A''}}$$

- **Remarque**

Calculs des grandeurs usuelles $\Rightarrow$ connaissance valeurs de l'enthalpie aux points caractéristiques du cycle

Nécessité d'exploitation des diagrammes ou des tables thermodynamiques

Tracé du cycle de Rankine dans le diagramme de Mollier



It is defined as the ratio between the net work taken in absolute value and the heat supplied to the system at the boiler. We write in. State is equal to the absolute value of the expansion work at the turbine. Plus the compression work at the pump. All divided by the heat received by the boiler. By replacing different parameters of this expression by their value, we obtain a final expression of the motor efficiency which is written. State equal to HB, it is the enthalpy at point B minus associated. The enthalpy at the point is minus the pressure at the point in parentheses, namely the pressure at the point called the rate divided by the density of the fluid as multiplied by the density of water, all this divided by the enthalpy end between point B and point A second. We can notice that the calculations of the usual quantities in a thermal model require the knowledge of enthalpy values at the characteristic points of the cycle. There is therefore a need to operate thermodynamic diagrams or tables. This diagram gives the representation of the thermodynamic cycle in the diagram de Mollier that we will review in the last module of this lesson.

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Summary

16m 42s

Cas machine thermique à vapeur

- Rendement du moteur thermique

$$\eta = \frac{|W_d + W_C|}{Q_{ch}} = \frac{h_B - h_C - \left(\dfrac{p_{A''} - p_{A'}}{d\rho_e}\right)}{h_B - h_{A''}}$$

- **Remarque**

Calculs des grandeurs usuelles $\Rightarrow$ connaissance valeurs de l'enthalpie aux points caractéristiques du cycle

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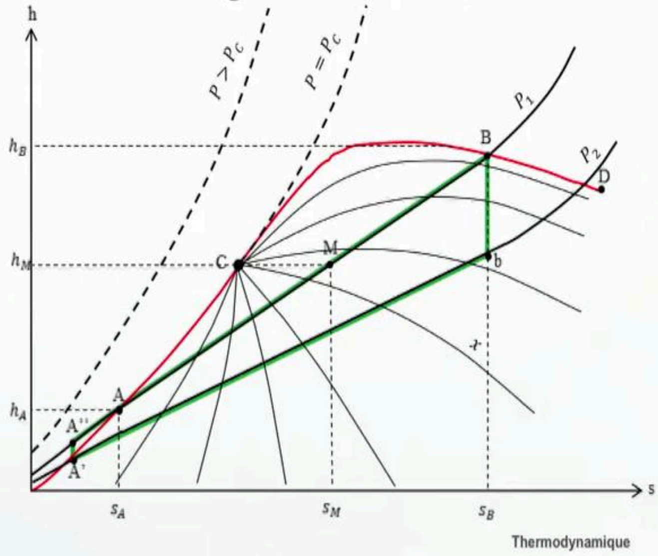
Tracé du cycle de Rankine dans le diagramme de Mollier

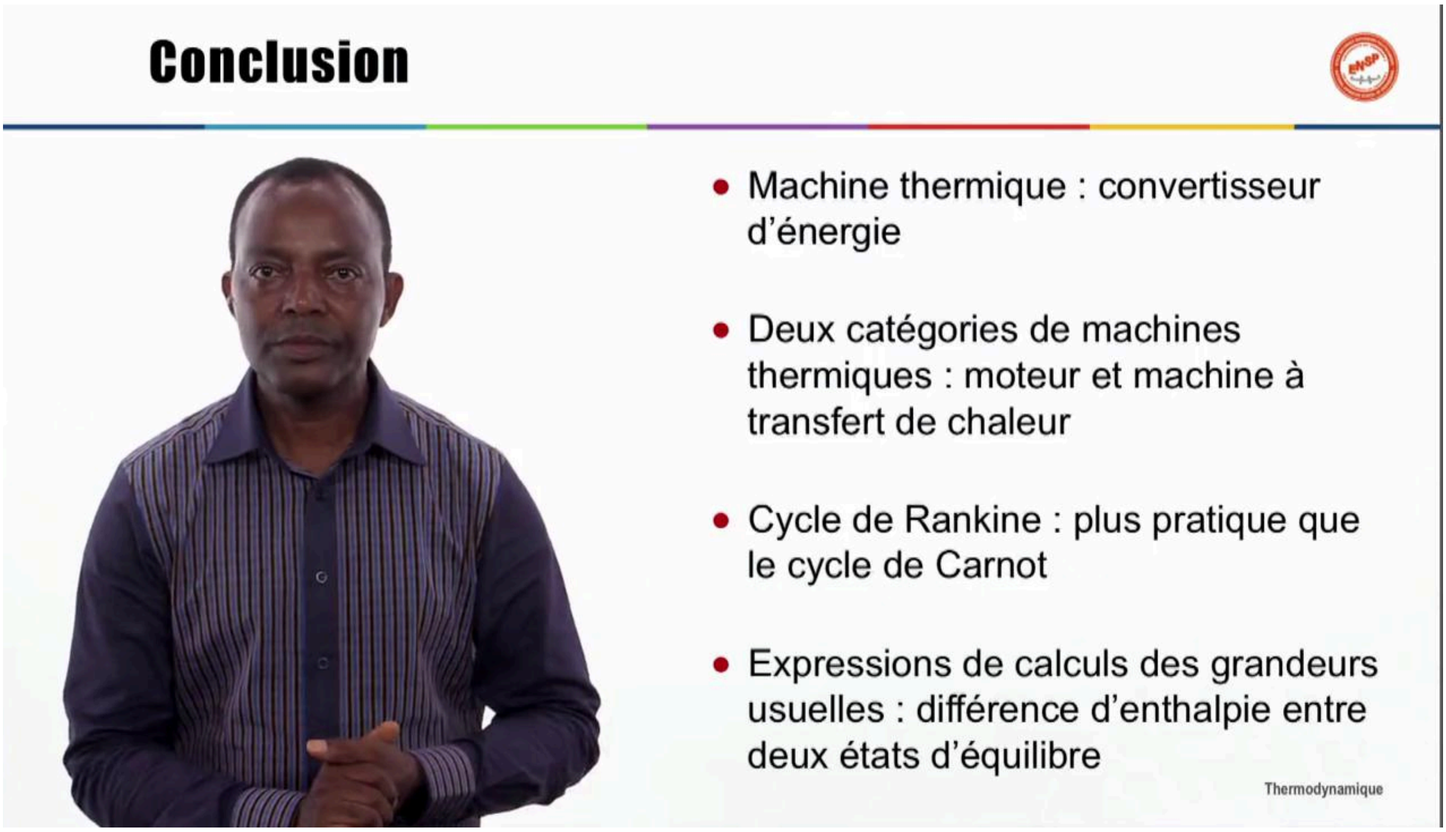


In summary, we have an isotopic composition at the pump, followed by heating and isobaric evaporation in the boiler. At the turbine, there is isotopic expansion followed by of isobaric condensation in the condenser and the cycle is therefore closed.

Notes

Summary

18m 20s



At the end of this module we will note that a thermal machine is an energy converter. We will also note that we have two categories of thermal machine, namely the motor and the heat transfer machine. We will then note that the cycle Rankine cycle is more practical than the canon cycle and finally, we will note the expressions of calculation with a usual gas which we worked out in its module dedicated to the production of thermal machines. See you soon!

Notes

Summary

18m 43s