

Présentation du module



- Diagramme de Mollier $h(s)$
- Diagramme LOG $p(h)$

Thermodynamique

Hello to all. I will sign up for this other meeting with you at the whistle one month of the year coordinated by the Polytechnic of Lausanne and related to fluids. Today, we will focus on the module dedicated to Mollier diagrams and refrigeration diagrams. Right away, the summary of this module of a module that includes two parts. We will develop in a first step time the physical approaches governing the Mollier diagram, then we will repeat the same process for the logarithmic diagram P of H , commonly known as the refrigeration diagram.

Notes

Summary



0m 04s

Diagramme de Mollier $h(s)$ - principe



- Diagramme utilisé pour le calcul des grandeurs thermodynamiques intervenant dans les projets (Q , W , etc.)
- Comporte l'enthalpie spécifique en ordonnée et l'entropie spécifique en abscisse
- Fonction enthalpie : $h = u + pv$
Soit $dh = \delta Q + v dp$
- Fonction entropie : $ds = \frac{\delta Q}{T}$
d'où $dh = T ds + v dp$
- Si $p = \text{const}$ et $h_0 = 0$ par convention, alors par intégration :

$$h_M = \int_{S_0}^{S_M} T ds$$

Thermodynamique

Not common in the first part of this chapter on the Mollier diagram, noting first that this is the diagram used for the calculation thermodynamic quantities involved in the focus on the cycles of steam, including the heat and work involved. This coordinate system includes the specific enthalpy on the ordinate and the specific entropy on the abscissa. Seeing the principle on which is based the Mollier diagram, the enthalpy function h is defined by the relation $h = u + pv$ where u here being the internal energy, p the pressure of the system and V the volume. Either by differentiation of h is equal to $\delta q + p \delta v$ higher than $p \delta v$ of attack. Here the heat is charged by the system. Moreover, the function p is defined by. The relationship of S is equal to $\delta Q / T$. Here, the system temperature is replaced by T , which changes to in the differentiated expression of the one-mat function. We get $dh = T ds + v dp$. If p is a constant and zero, i.e. the enthalpy at the initial point is equal to zero. By convention, we have by integration $h_M = \int_{S_0}^{S_M} T ds$. This means that the Mollier diagram h is and deduced from the entropy diagram of successive integrations.

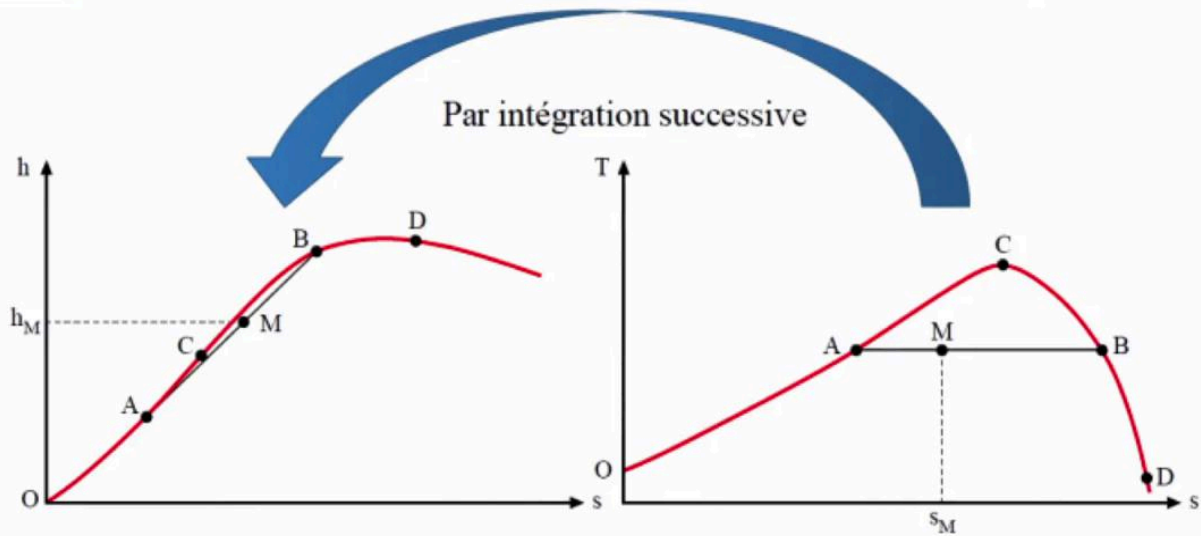
Notes

Summary



Om 50s

Diagramme de Mollier $h(s)$ - principe



Courbe de saturation diagramme $h(s)$: image par la même application de la courbe de saturation du diagramme $T(s)$ (voir positions des points A, B, C et D)

Thermodynamique

From this point of view, the saturation curve of the H diagram of S is the image and of the same application of the saturation curve of the D diagram of S . We can note the translation of the positions from point A in the TS diagram to point A in the HTS diagram. Similarly, the other points, namely CBS become CB and in the HDS diagram going to the elaboration of the family curves that form the Mollier diagram starting with the des.

Notes

Summary



2m 41s

Diagramme de Mollier h(s) – Isobares



Preuve

- Pente d'une isobare :

$$\left. \frac{\partial h}{\partial s} \right|_P = T$$

Pente d'une isobare = T en diagramme h(s)

- Expression différentiée de l'enthalpie :

$$dh = T ds + v dp$$

- Transformation isobare :

$$p = \text{const}$$

- D'où $dh = \delta Q = T ds$

- Finalement

$$\underline{\left. \frac{\partial h}{\partial s} \right|_P = T}$$

Thermodynamique

At the bottom, first the slope of an isobar. Then we can note that the slope of a isobaric corresponds to the temperature a HS diagram. This slope represents the derivative partial of H with respect to s at constant pressure, which is equal to D. For proof, we start with the formula DH equal to d cvd p a. For an isobaric transformation, p is equal to a constant. We obtain dh equal to delta Q which is equal to TDS. As a result, the partial lifting with respect to s at constant pressure is equal to p.

Notes

Summary



3m 16s

Diagramme de Mollier $h(s)$ – Isobares



- Zone liquide : compression isentropique du liquide

d'où $\Delta h \cong v_0(p - p_0)$

h varie peu quand on passe d'une isobare à l'autre par compression isentropique d'un liquide

Donc isobares ~ confondues avec la branche OC de la courbe de saturation (voir graphe précédent)



How does the pressure in the liquid zone evolve? For an isotopic composition of the liquid, we obtain Δh equal to $v_0 \cdot (p - p_0)$ at h varies little when going from a isobaric to the other by completion at the peak of a liquid. In other words, the low water is practically merged with the beach. Oh, that's saturation curve. Make the previous graph.

Notes

Summary



4m 00s

Diagramme de Mollier $h(s)$ – Isobares



- Zone liquide : compression isentropique du liquide

$$\text{d'où } \Delta h \cong v_0(p - p_0)$$

h varie peu quand on passe d'une isobare à l'autre par compression isentropique d'un liquide

Donc isobares ~ confondues avec la branche OC de la courbe de saturation (voir graphe précédent)

Justification

Pour l'eau : $v_0 \cong 0,001 \text{ m}^3 \text{kg}^{-1}$

Si $p - p_0 = 100 \text{ bars}$

on a $\Delta h = 10 \text{ kJkg}^{-1}$ très faible devant les variations d'enthalpie mise en jeu dans les autres transformations

Thermodynamique

The justification is quite simple for water, we have v_0 approximately equal to 0.001 cubic meters per kilogram. Surprisingly p minus p_0 is equal to 100 bars. We obtain Δh equal to ten kilojoules per kilogram very low compared to other variations. The enthalpy involved in the other transformations.

Notes

Summary



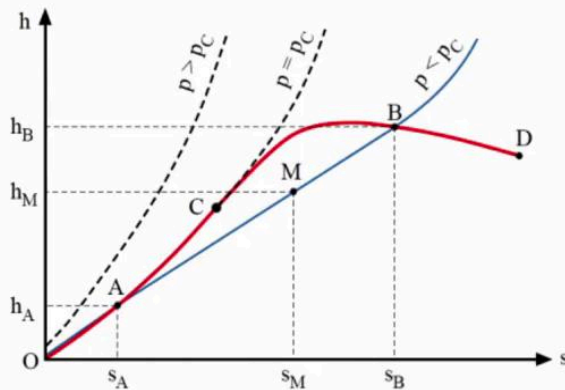
4m 29s

Diagramme de Mollier $h(s)$ – Isobares



- **Zone vapeur sèche :**
Isobare approximée à celle d'un gaz parfait de forme exponentielle

$$h = K' e^{\left(\frac{s}{c_p}\right)}$$



Démonstration

- Expression différentiée de l'entropie :

$$ds = \frac{\delta Q_p}{T} = \frac{C_p dT}{T}$$

- Hypothèse : C_p indépendant de T
- On a donc :

$$\left. \frac{\partial h}{\partial s} \right|_P = T \quad \text{et} \quad T = K e^{\left(\frac{s}{c_p}\right)}$$

Thermodynamique

Let's look at how the pressure inside the saturation curve has evolved. In this area, the fluid is in liquid-vapor form. Lise Aubin corresponds to the line segment A.B of pin TT. As proof, we have just shown that the slope of the stockings is identical to the temperature. That is, partial derivatives with respect to S at constant pressure and Galatea at temperature does not vary during a transformation with phase change. Finally, we have equal access to TS , in other words the equation of a line segment. Let's see how the following evolves the pressure in the passage area in this zone. The isba is similar to that of a perfect gas of exponential format. H is equal to an exponential prime of S over c_p . Here, it is the heat capacity at constant pressure. To prove it. Considering the infinitesimal form of the entropy function in an isobaric transformation, we then write s is equal to Delta Kuiper Suter which is equal to $c_p dt$ Suter. Data Kuiper is. Heat is charged to pressure and CP and the heat capacity at constant pressure. Assuming that the capacity The calorific value called constant quotient does not depend on the temperature, we obtain partial derivatives of S at constant pressure equal to a t .

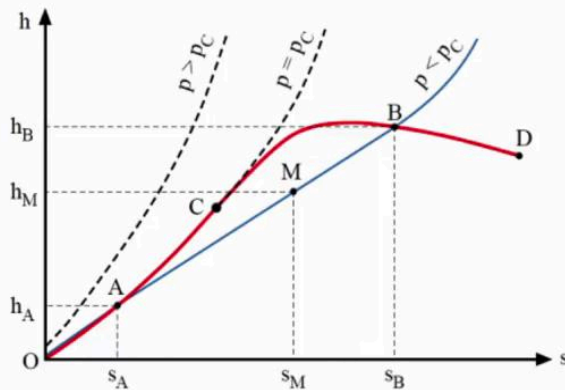
Notes

Summary



4m 54s

- $$h = K' e^{\left(\frac{s}{C_p}\right)}$$



- Expression différenciée de l'entropie :

$$ds = \frac{\delta Q_p}{T} = \frac{C_p dT}{T}$$

- $$\left. \frac{\partial h}{\partial s} \right|_P = T \quad \text{et} \quad T = Ke^{\left(\frac{s}{C_p}\right)}$$

- Finalement : $h = K' e^{\left(\frac{s}{C_p}\right)}$

- Notes



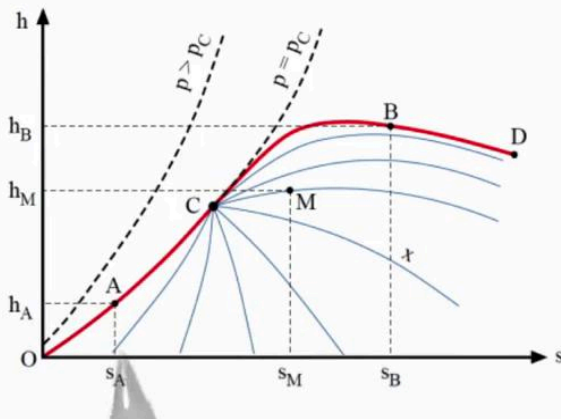
Diagramme de Mollier $h(s)$ – Titre de vapeur



Démonstration

- On a le système d'équations :

$$\begin{cases} ms = m_v s_B + m_l s_A \\ mh = m_v h_B + m_l h_A \\ m = m_v + m_l \end{cases}$$



- La résolution du système donne :

$$\begin{cases} m_v = m \frac{s_M - s_A}{s_B - s_A} \\ m_l = m \frac{s_B - s_M}{s_B - s_A} \end{cases} \quad \text{ou} \quad \begin{cases} m_v = m \frac{h_M - h_A}{h_B - h_A} \\ m_l = m \frac{h_B - h_M}{h_B - h_A} \end{cases}$$

- Finalement :

$$x = \frac{s_M - s_A}{s_B - s_A} \quad \text{et} \quad x = \frac{h_M - h_A}{h_B - h_A}$$

Thermodynamique

Now it's time for the title of the vapor liquids. The title of steam in a state called Favi is by definition x equal to m_v over m m_v and the mass of the steam and m . The mass of the mixture shows that x is equal to to the entropy at the point M located in the zone of the liquid-vapor mixture minus. The entropy of point A is located on the saturation curve separating the liquid part of the Bel Air liquid vapor part, the whole divided by the entropy of point B located on the saturation curve separating the superheated steam part and the liquid steam part. It is still equal to the enthalpy of point M, minus the enthalpy of point A on the enthalpy of point B, minus the enthalpy of point A. Then we can note that the gas curve which represents the bundle of curves all converge at the critical point if or title is undefined. For proof, it is enough to write the following system of equations. First equation $m s$ is equal to $m_v s_B$ plus $m_l s_A$ to. The second equation is written $m h$ is equal to $m_v h_B$ plus $m_l h_A$ to. The third equation is written m is equal to m_v plus m_l . Note that M is the mass of the mixture in the liquid vapor phase m_v . This is the mass of the vapor in this phase and M the mass of the liquid.

Notes

Summary



6m 55s

Diagramme de Mollier $h(s)$ – Titre de vapeur



Démonstration

- On a le système d'équations :

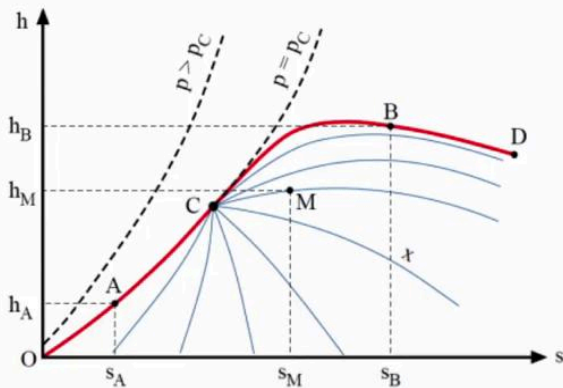
$$\begin{cases} ms = m_v s_B + m_l s_A \\ mh = m_v h_B + m_l h_A \\ m = m_v + m_l \end{cases}$$

- La résolution du système donne :

$$\begin{cases} m_v = m \frac{s_M - s_A}{s_B - s_A} \\ m_l = m \frac{s_B - s_M}{s_B - s_A} \end{cases} \quad \text{ou} \quad \begin{cases} m_v = m \frac{h_M - h_A}{h_B - h_A} \\ m_l = m \frac{h_B - h_M}{h_B - h_A} \end{cases}$$

- Finalement :

$$x = \frac{s_M - s_A}{s_B - s_A} \quad \text{et} \quad x = \frac{h_M - h_A}{h_B - h_A}$$



Thermodynamique

Point A is located on the saturation curve in a saturated liquid state. Point B is also located on the saturation curve in saturated vapor state. If we solve this system of equations, Let's consider first the first and the last equation. The resolution gives us m_v equal to m . The rate multiplied by s_B to be divided by $s_B - s_A$ is then m . It is equal to m multiplied by $s_M - s_A$ divided by $s_B - s_A$. Considering the second and third equation, we obtain after solving m_v equals to m , all multiplied by $h_B - h_A$ to be divided by $h_B - h_A$. Purchase afterwards. m_l . Rates multiplied by $h_B - h_A$. m_l divided by $h_B - h_A$. Finally, by dividing m_v by m , we obtain the expression of the vapor title. Namely x is equal to the entropy at the point, m at point A divided by the entropy at point B. Ethiopia at point a or x is equal to the enthalpy at point M, minus the enthalpy at point a the rate divided by the enthalpy at point B, the enthalpy at point A.

Notes

Summary



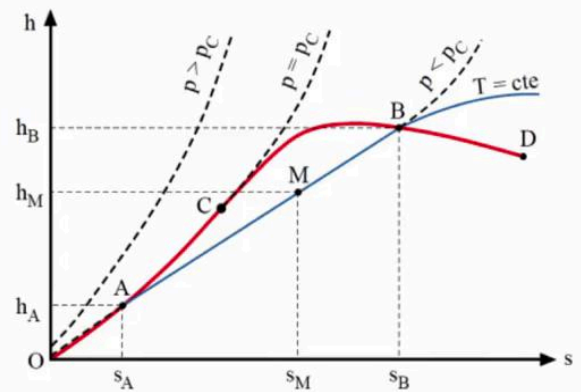
8m 46s

Diagramme de Mollier $h(s)$ - Isothermes



- **Zone mixte** : Isobares et isothermes rigoureusement confondues

Le changement d'état liquide-vapeur se fait à pression et température constantes



Thermodynamique

Let us now examine the shape of the X's at the end. In the mixed zone. We have already as the thermal waters merge with the isobars due to the coexistence of two liquid-vapor phases in the dry vapor zone.

Notes

Summary



10m 18s

Diagramme de Mollier $h(s)$ - Isothermes

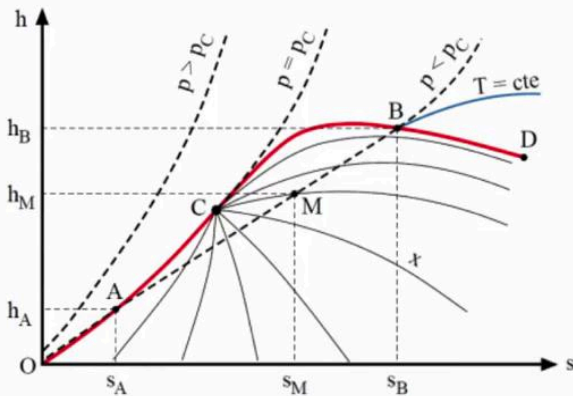


- **Zone vapeur sèche** : isothermes tendent vers l'horizontale loin de la courbe de saturation (propriétés des gaz parfaits)

Preuve

- Expression fonction enthalpie :

$$h = u + pv \text{ et } dh = du + d(pv)$$



Thermodynamique

The other terms tend towards the horizontal, far from the saturation curve. We have the property of perfect gases to demonstrate this statement by taking the expression of the enthalpy function, namely. H is equal to U plus CPV . The differentiation of sites works or gives equal ages to U plus.

Notes

Summary

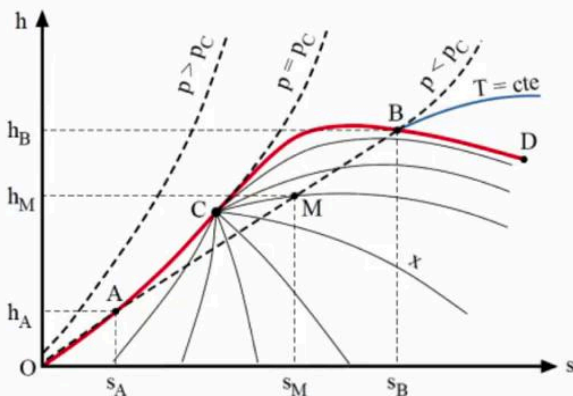


10m 37s

Diagramme de Mollier $h(s)$ - Isothermes



- **Zone vapeur sèche** : isothermes tendent vers l'horizontale loin de la courbe de saturation (propriétés des gaz parfaits)



Preuve

- Expression fonction enthalpie :

$$h = u + pv \text{ et } dh = du + d(pv)$$

- Transformation gaz parfait d'un état à l'autre : $du = du_{\text{isochore}} + du_{\text{isotherme}}$

$$\text{avec } du_{\text{isochore}} = c_v dT \text{ et } du_{\text{isotherme}} = 0$$

$$\text{d'où } dh = c_v dT + \frac{R}{M} dT = \left(c_v + \frac{R}{M} \right) dT$$

$$\text{puis } dT = 0$$

$$\text{donc } h = \text{const}$$

Thermodynamique

PVs for a transformation of a perfect gas from one state to another. We write that du it is equal to $c_v dt$ and u iso term equal to zero. The authors had had occasions equal to $c_v dt$ and u iso term equal to zero. Note that these vehicles represent the heat capacity at constant volume by replacing spaces with values in the previous expression. We obtain DH equal to C_v , DP Plus and Air Su MDT . Note that represents here the constant of perfect gases and M the molar mass. By putting a factor DT , we write DH is equal to c_v plus R if $m dt$ to the transformation is it to the term dt is equal to zero. Finally, dh is equal to zero and the integration gives us H equal to a constant.

Notes

Summary

11m 06s



Diagramme de Mollier h(s)

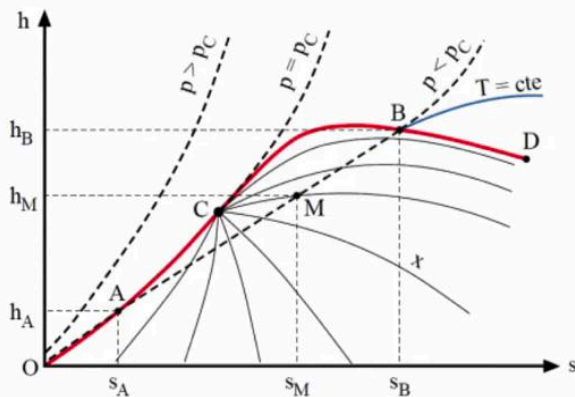
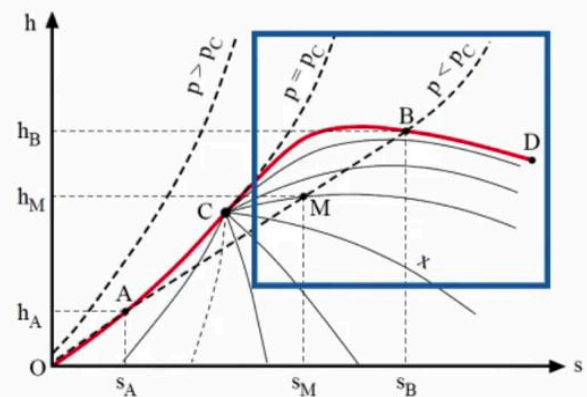


Diagramme de MOLLIER de la vapeur d'eau avec toutes les courbes décrites ci-dessus



Utilisation diagramme que pour la vapeur sèche ou saturante à titre élevé

Thermodynamique

This figure represents the Mollier diagram of the water vapor with all the curve described above. It is important to note that the industrial diagram does not have the dry steam or saturated steam area. At high title.

Notes

Summary



12m 11s

Diagramme de Mollier h(s)

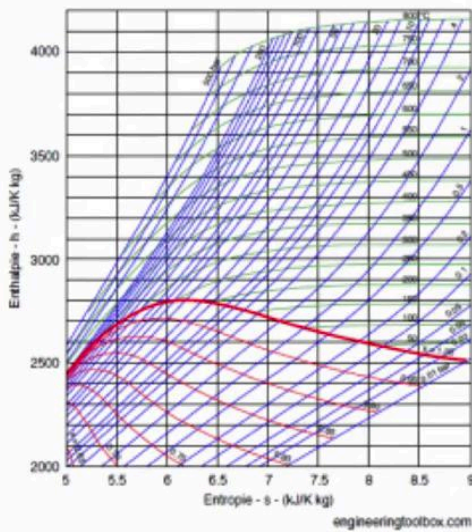


Diagramme industriel de Mollier pour la vapeur d'eau

Remarques

- Courbes de volumes spécifiques représentées sur certains diagrammes : utiles dans le dimensionnement des appareils et tuyauteries (détermination du débit volume)
- Diagramme de MOLLIER inexploitable dans la zone liquide ou même liquide - vapeur à titre faible : détermination des fonctions \underline{h} , \underline{s} ; \underline{T}_e , \underline{P}_s à l'aide des tables thermodynamiques.

Thermodynamique

This high figure shows an example of a diagram Mollier's industrial value for water vapor. We have two important points to make. The first remark concerns the curve of specific volume which is represented on some diagrams. These curves are useful for. The sizing of the devices is further determined by determining the volume flow. Concerning the second remark, the Mollier diagram is not usable in the liquid or even liquid to vapor area. Does it have small consequences? The determination of enthalpy functions. Entropy of egg boiling temperature and saturation pressure. PS it is done with the help of thermodynamic tables.

Notes

Summary

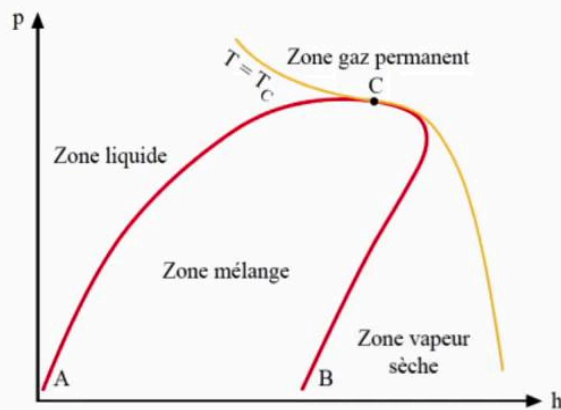
12m 36s



Diagramme LOG p (h)



- Diagramme des frigoristes
- Comporte la pression sur une échelle semi-logarithmique en ordonnée et l'enthalpie spécifique en abscisse



Thermodynamique

- **Courbe de saturation ACB et isotherme T_c**

Partagent le plan en quatre zones correspondant aux états :

- liquide,
- liquide-vapeur,
- vapeur sèche (ou gaz) et
- gaz permanent.

Let's now move on to the second part of this module dedicated to the Lopez diagram of H. This is the diagram commonly used by refrigeration engineers. The coordinate systems of these diagrams include the pressure to be given on a scale logarithmic and the specific enthalpy in abscissa. The saturation curve at C and B and the critical and C autems divide the plane into four zones corresponding to in liquid, vaporous liquid, dry vapor and permanent gas states.

Notes

Summary

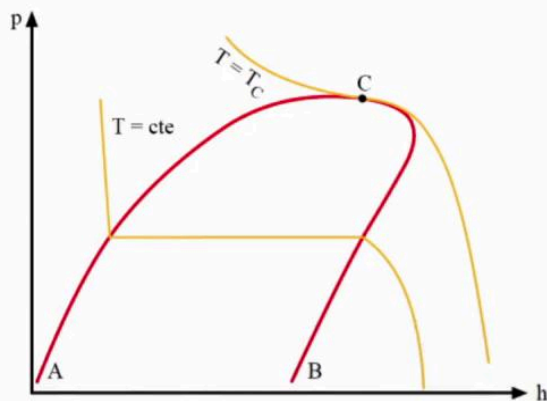


13m 30s

Diagramme LOG p (h) - Isothermes



- **Zone vapeur sèche** : isothermes tendent vers la verticale loin de la courbe de saturation (propriétés des gaz parfaits)



Justification

- Quand p tend vers 0, on a un gaz parfait
- Comme précédemment démontré dans le cas du diagramme de Mollier, nous avons alors :

$$dh = \left(c_v + \frac{R}{M} \right) dT = 0 \text{ car } T = \text{const}$$

Donc $h = \text{const}$ loin de la courbe de saturation

Thermodynamique

Examining the shape of the heights in the liquid zone, we have the Hautes-Alpes and the Autem which are practically merged. This is justified by the fact that for the written, the enthalpy h varies very little had the pressure, and this quantity does not depend only on the temperature in the mixed zone. We have the isobars. And the other terms which are rigorously confused. The justification results from the fact that the change of state liquid vapor is carried out at constant pressure and temperature in the dry zone. The other terms tend towards the vertical, far from saturation. We have the properties of perfect gases to prove this. Note that when p in. Around zero, we have a perfect gas. As previously demonstrated in the case of the Mollier diagram, we then have. of Age equal to c_v plus and received $m dt$ which is equal to zero cases. The temperature does not vary in. By integrating this equation, we have h . Equal to a constant away from water saturation this time in the diagram.

Notes

Summary

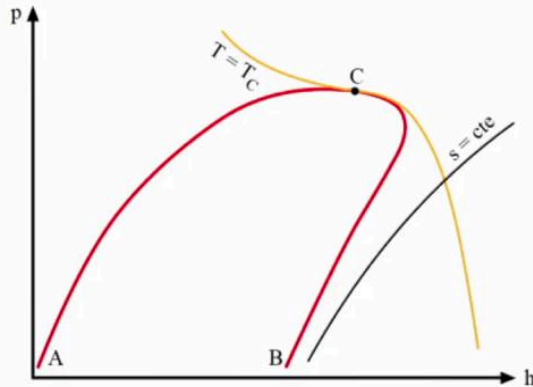


14m 15s

Diagramme LOG p (h)-Isentropes



- **Zone liquide** : Isentropes presque verticales



- **Preuve**

La relation $dh = Tds + vdp$ donne :

$$\left. \frac{\partial h}{\partial p} \right|_s = v \quad \text{et} \quad \left. \frac{\partial p}{\partial h} \right|_s = \frac{1}{v}$$

v est faible pour le liquide et donc $1/v$ élevé, d'où la forme verticale de l'isotrope

Pour un liquide, h varie très peu avec la pression

Thermodynamique

Let's move on to the form of the envelopes in the liquid zone, the one three are almost vertical. To prove this, we start with the expression enthalpy differential, namely higher TDS of the p, which gives partial derivatives of the pump a little constant p equal to V. Let partial derivatives of p by not equal a tracking to V and low for liquids and in a tracking V and the V of the vertical form of. The one three for team H varies very little with the pressure in the dry zone.

Notes

Summary

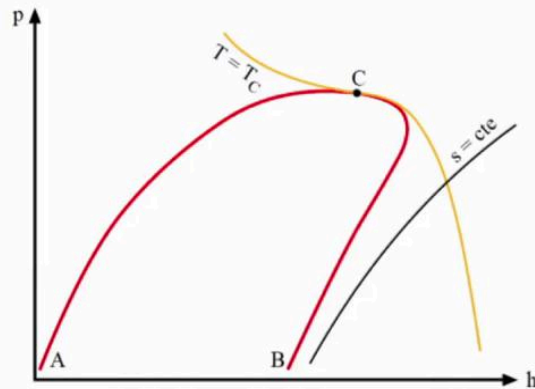


15m 48s

Diagramme LOG p (h)-Isentropes



- **Zone vapeur sèche** : Isentropes sous forme curviligne
- **Preuve**



v est élevé pour la vapeur et donc $1/v$ faible, d'où la forme curviligne de l'isotrope

Thermodynamique

We have the zizanie in curvilinear form. The justification results from the fact that V is high for steam and in a cv is low for water. The curvilinear shape of three.

Notes

Summary

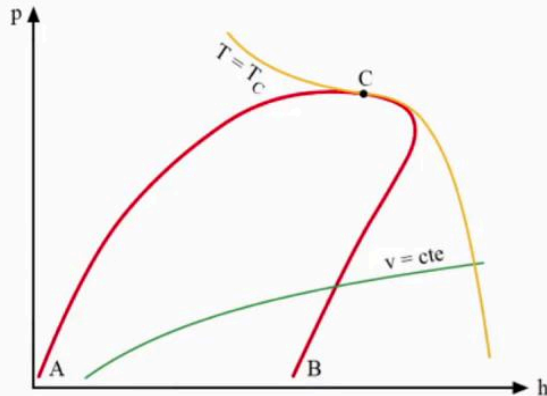


16m 34s

Diagramme LOG p (h)- Isovolumes



- **Zone vapeur sèche** : allure semblable aux isotopes, mais de pentes relativement plus faibles



Preuve

Quand on s'éloigne de la courbe de saturation, on a un gaz parfait.

Nous avons :

$$pv = nRT \quad \text{et} \quad p dv + v dp = nR dT$$

$$\text{si } v = \text{const}, \text{ alors } v dp = nR dT, \quad dh = C_p dT$$

$$\text{et } dp = \frac{nR}{c_p} \frac{1}{v} dh = \left(1 - \frac{1}{\gamma}\right) \frac{1}{v} dh$$

$$\text{donc } \left. \frac{\partial p}{\partial h} \right|_v = \left(1 - \frac{1}{\gamma}\right) \frac{1}{v}$$

Thermodynamique

I have time now. The look on the shape of the iso volumes. In the liquid zone, the curve of equal volume seems almost vertical as justification, noting that for a liquid as the enthalpy, the volume. H varies little. Had the pressure then to prove it. When we move away from the saturation curve, we have a perfect gas. You write then PV is equal to n is the law of perfect gases. By differentiating this equation, we get a higher POS. DP is equal to n rdt. For an ISO volume transformation, the volume does not vary. Finally one had dp equal to n rdt in DH is equal to CPD t it comes. DP is equal to N and received CP as the IP so followed DH by replacing n r on CP by its value, we write whose DP is equal to one on Gama as follows v. DH. Note that GAMA represents here the adiabatic exponent defined by the ratio cp to cv, cp being the capacity calorific capacity at constant pressure and cv the calorific capacity at constant volume. Finally, the partial in relation to a constant volume gives a gamma, a tracking, hence the shape of the iso volume in the dry area which has a relatively smaller breakdown than the slope of the others, ending with the title of liquid to vapor mixture.

Notes

Summary



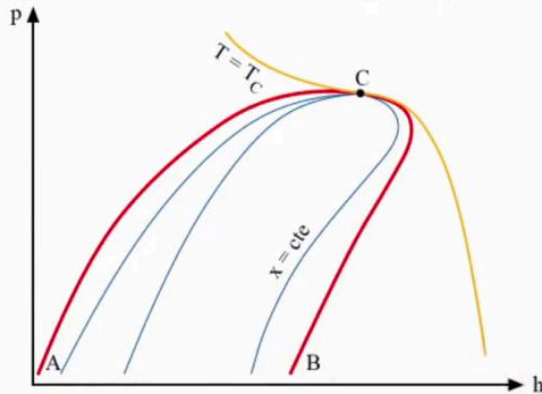
Diagramme LOG p (h)-titre de vapeur



- Définition : $x = \frac{m_v}{m}$

où m_v masse de vapeur et m masse du mélange

On montre que : $x = \frac{h_M - h_A}{h_B - h_A}$



Preuve

Il suffit d'écrire :

$$\begin{cases} m = m_v + m_l \\ mh_M = m_v h_B + m_l h_A \end{cases}$$

Il résulte de ce système d'équation que :

$$\begin{cases} m_v = m \frac{h_M - h_A}{h_B - h_A} \\ m_l = m \frac{h_B - h_M}{h_B - h_A} \end{cases}$$

Thermodynamique

We have seen previously that the steam title in the mixed zone is by definition X is equal to m_v on m . m_v is the mass of steam and m the mass of the mixture. We show that X is equal to M . H to H_B . As h_M and the enthalpy of a point M located in the mixing zone HK is the enthalpy of point A located on the saturation curve on the liquid side and H_B . The enthalpy of the saturation point on the steam side. The altitude curve converges at the critical point C or. The title is undefined. For proof, it is enough to describe the system of equations. M and M_v , plus m_l and M . H_m is equal to $m_v H_B$, plus m_l to this. Note that the unknowns of these systems of equations are M . That is, the mass of the steam in the mixture and m_l . The mass of the liquid in the mixture. The resolution of these systems of equations gives him m_v equal to M as multiplies a on h_b . A . Then it equals m facta of h_b h_m divided by h_b minus a . We then deduce the expression of the title seen previously.

Notes

Summary



18m 48s

Diagramme LOG p (h)

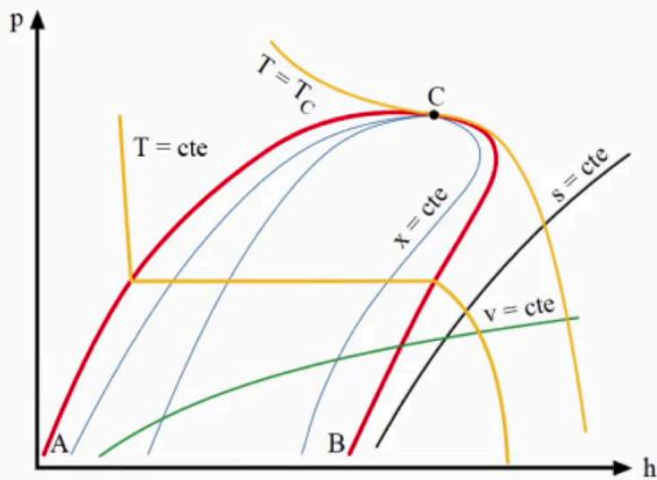
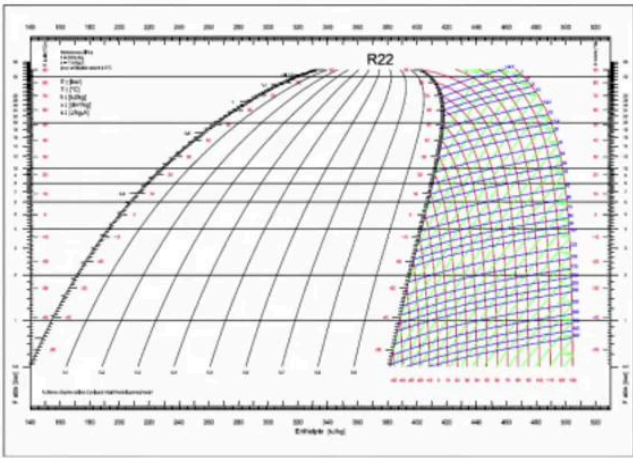


Diagramme LOG p (h) avec toutes les courbes décrites ci-dessus



Exemple diagramme LOG p (h) pour le R22

Thermodynamique

This figure shows the diagram Lopez of H with all the curve described above. We before the other terms. The altitude curve, the jobs. The volumes, and the figure below represents finally an example of a diagram their pedaling for the F-22 took place before the antelopes. The thermal waters are in red, the volume waters in blue. The highs and lows, undoubtedly horizontal and the Alps are vertical lines.

Notes

Summary



Conclusion



- Diagramme de Mollier utilisé dans les projets
- Diagramme de MOLLIER inexploitable dans la zone liquide ou liquide - vapeur à titre faible
- Diagramme LOG p (h) utilisé pour le dimensionnement des réfrigérateurs/pompes à chaleur

Thermodynamique

At the end of this fourth and last section, we will note module, from this lesson on fluids, that the Mollier diagram is used to calculate the thermodynamic quantities involved in industrial projects, especially steam circuits. We will then note that this diagram is inoperable in the area described or the steam team did. Finally, we note that the Locks P diagram of H, also called refrigeration diagram, is used particularly for the sizing of refrigerators and heat pumps. Thank you for this meeting.

Notes

Summary



21m 15s