People's Democratic Republic of Algeria

Ministry of Higher Education and Scientific Research

MUSTAPHA STAMBOULI UNIVERSITY OF MASCARA

FACULTY OF SCIENCE AND TECHNOLOGY

Course handout

THERMODYNAMICS II

Presented by:

Dr. SAHNOUN Rachid

This course is intended for 2nd Year/Mechanics undergraduate students

Algeria

2024

Foreword :

Thermodynamics deals with the concepts of heat and temperature and the inter-conversion of heat and other forms of energy. The four laws of thermodynamics govern the behaviour of these quantities and provide a quantitative description.

The thermodynamics module is a fundamental module intended for students of the second year of the mechanics degree. The objectives of this course are to teach students the techniques of heat and work production and the main technical elements used in this vast field.

Prior knowledge is recommended, mainly phase changes and thermodynamics. In the first chapter we will discuss the basic concepts of thermodynamics.

The second chapter deals with Propriety thermodynamics of substances pure. Mastering this key to understanding the change of phase.

The elements of a refrigeration machine are discussed in the third chapter such as Thermodynamics of vapors and humid air; dry air; dry temperature and relative humidity.

In the fourth and fifth chapters, we will talk about Gas Compression and gas relaxation.

The lasts chapter's deals with cycles to produced heat and cycles to produced work the reverse of the refrigeration cycle and therefore are intended for heating by a simple conversion of a reversing valve.

A large number of solved exercises finalizes this handout.

Contents

INTRODUCTION:

Thermodynamics deals with the concepts of heat and temperature and the inter-conversion of heat and other forms of energy. The four laws of thermodynamics govern the behaviour of these quantities and provide a quantitative description.

Thermodynamics in physics is a branch that deals with heat, work and temperature, and their relation to energy, radiation and physical properties of matter.

To be specific, it explains how thermal energy is converted to or from other forms of energy and how this process affects matter. Thermal energy is the energy that comes from heat. The movement of tiny particles within an object generates this heat, and the faster these particles move, the more heat is generated.

Thermodynamics is not concerned about how and at what rate these energy transformations are carried out. It is based on the initial and final states undergoing the change. It should also be noted that Thermodynamics is a macroscopic science. This means that it deals with the bulk system and does not deal with the molecular constitution of matter.

CHAPTER I

Chapter1: The basic concepts of thermodynamics

1.1 The basic concepts of thermodynamics :

1.1.1 Closed systems :

A closed system always contains the same matter. There can be no transfer of mass across its boundary. A special type of closed system that does not interact in any way with its suroundings is called an isolated system.

1.1.2 Property, state, and process :

A property is a macroscopic characteristic of a system such as mass, volume, energy, pressure, and temperature to which a numerical value can be assigned at a given time without knowledge of the previous behavior (history) of the system.

The state refers to the condition of a system as described by its properties. Since there are normally relations among the properties of a system. When any of the properties of a system changes, the state changes and the system is said to undergo a process. A process is a transformation from one state to another.

1.1.3 Extensive and Intensive properties :

A property is called extensive if its value for an overall system is the sum of its values for the parts into which the system is divided. Mass, volume, and energy are extensive. Intensive properties are not additive in the sence previously considered. Pressure, temperature, and specific volume are important intensive properties.

1.2 The three principles of thermodynamics :

1.2.1 First law of thermodynamics :

$\Delta U = Q + W$ is mathematical statement of the law of thermodynamics, which states that « The energy of an isolated system is constant ». It is commonly stated as the law of conservation of energy i.e., energy can neither be created nor destroyed

The second law of thermodynamics asserts that energy has quality as well as quantity, and actual processes occur in the direction of decreasing quality of energy.

The zeroth law of thermodynamics states that two bodies are in thermal equilibruim if both have the same temperature reading even if they are not in contact.

A system of fixed mass is called a closed system, or control mass, and a system that involves mass transfer across its boundaries is called an open system, or control volume.

The second law of thermodynamics deals with the availability of energy to perform useful work. The only possible natural processes are those that either decrease or, in the ideal case, maintain, the availability of the energy of the universe. The science of thermodynamics defines a material property called entropy, which quantifies the second law. The entropy of universe must increaseor, in the ideal case; remain constant in all natural processes.

The first principle postulates that, for any closed system describing a cycle (final state thermodynamically identical to the initial state), the heat exchanged with the environment is strictly equal (and of opposite sign) to the work exchanged with the environment during of this cycle; this is true for a cycle described in an irreversible manner as for a reversible cycle. We can write :

$$\oint \delta Q + \oint \delta W = 0$$

1.2.2 second law of thermodynamics :

The first law of thermodynamics tells us about the relationship between the heat absorbed and the work performed on or by a system. It puts no restrictions on the direction of heat flow. However, the flow of heat is unidirectional from higher temperature to lower temperature. In fact, all naturally occurring processes wheither chemical or physical will tend to proceed spontaneously in one direction only.

Mathematically, this assessment leads to:

$$dS = dS_e + dS_i \quad ; dS_i \geq 0$$

Where dS_e the net isentropic flow due to exchanges with the external environment and dS_i is the production of entropy due to internal changes in the system. This formulation contains within itself the entire second principle.

CHAPTER II

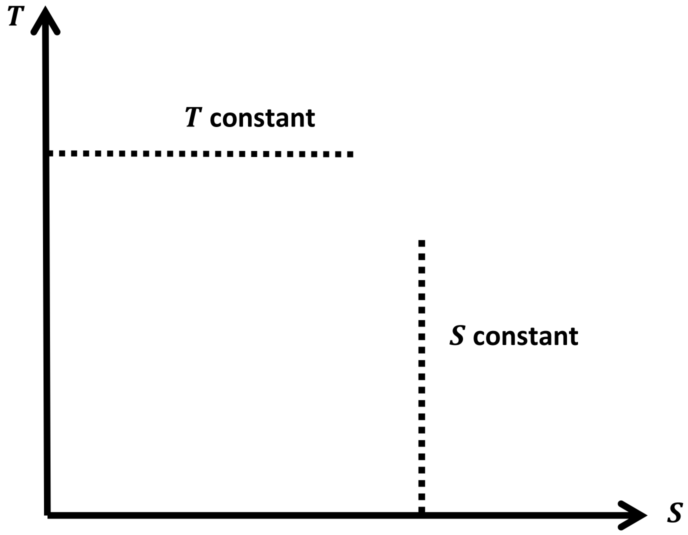
Chapter 2 : Thermodynamic properties of pure substances

2.1 State diagrams :

The general tables of thermodynamic properties give six properties for the pure substances T, P, v, h, u and s. For most pure substances, the relationships between thermodynamic properties are too complex to be expressed by simple equations.

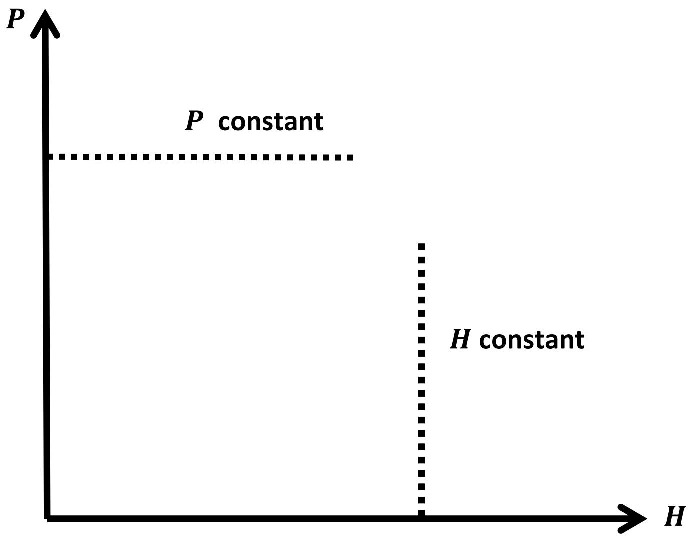
2.1.1 Diagram T-S :

The entropy diagram (T, s) which directly visualizes reversible heat transfers and the various possible irreversibilities



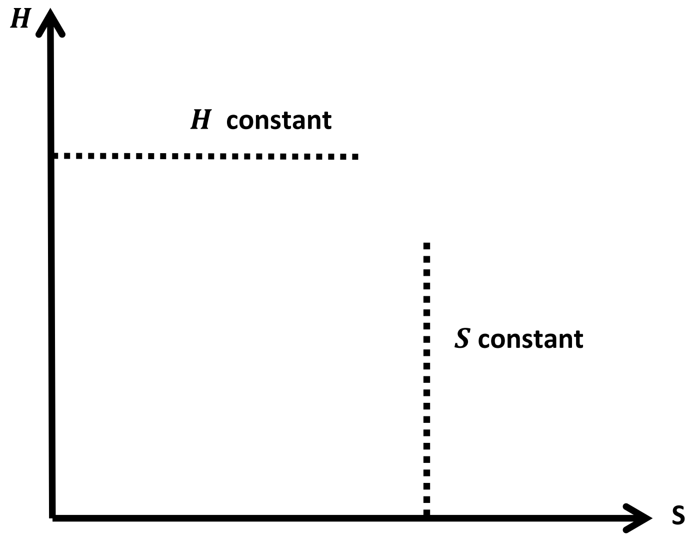
2.1.2 Diagram P-H :

In the so-called refrigeration diagram, we plot the enthalpy on the abscissa, and the pressure on the ordinate, most often on a logarithmic scale.



2.1.3 Diagram H-S :

The Mollier diagram (h, s) which is only a transform of the previous one, intended to directly show the energy transfers in an open system, and which has the advantage that the enthalpy intervenes directly in the coordinates and can therefore be read without difficulty.



2.2 Thermodynamic tables :

Thermodynamic property data can be received in various ways, including tables, graphs and equations. We use tables of thermodynamics properties, which are commonly available for pur, simple compressible substances of engineering interest. The use of these tables is an important skill. The ability to locate states on property diagrams is an important related skill.

Saturation property tables:

The properties of water vapor and liquid water are listed in tables.

These are often referred to as the superheated vapor tables and compressed liquid tables, respectively. That is, for a given pressure the property values are given as the temperature increases to the saturation temperature.

Tables of superheated steam properties:

The superheated steam region depicts steam at a temperature higher than its saturation temperature. Should saturated steam be heated at constant pressure, its temperature will rise, producing superheated steam.

2.2.1 Equation of state :

$$\boldsymbol{PV = \frac{m}{M} RT}$$

m: mass of gas

M: molecular weight

R: universal constant $(8.314 \frac{\mathrm{J}}{\mathrm{Mole}} \mathrm{K})$

Since $\mathrm{n} = \frac{\mathrm{m}}{\mathrm{M}}$ is the number of moles of the gas

The equation of state of an ideal gas is:

$$\boldsymbol{PV = nRT}$$

2.2.2 Equation of state of an ideal gas

The representation of real gases is generally of the form

$$\boldsymbol{(p + \pi)(V - Nb) = NRT}$$

π is called internal pressure, it accounts for the forces of attraction between molecules, which are added within the fluid to the pressure forces exerted on a surface.

2.2.3 Developments of Viriel :

When the temperature is too low or the pressure too high, it is no longer possible to approximate the behavior of a real gas using the ideal gas model, which becomes much too imprecise. One solution may be to develop the PV product in powers of 1/V or p. We thus obtain relations of the form:

$$pV = NRT + \left(1 + \frac{B(T)}{V} + \frac{C(T)}{V^2} + \cdots.\right) \; Or$$
$$pV = NRT + (1 + B'(T)p + C'(T)p^2 + \cdots..)$$

If we truncate these developments to order zero, we find the ideal gas law.

2.2.4 Van Der Waals equation :

The most famous relationship of this type is that of VAN DER WAAL

$$\left(p + \frac{N^2 a}{V^2}\right)(V - Nb) = NRT$$

The constants and b are characteristic of a given fluid. The VAN DER WAALS equation makes it possible to account for the behavior of most real gases over wide ranges of temperature and pressure.

CHAPTER III

Chapter 3: Thermodynamics of vapors and humid air:

3.1 : Vapor thermodynamics :

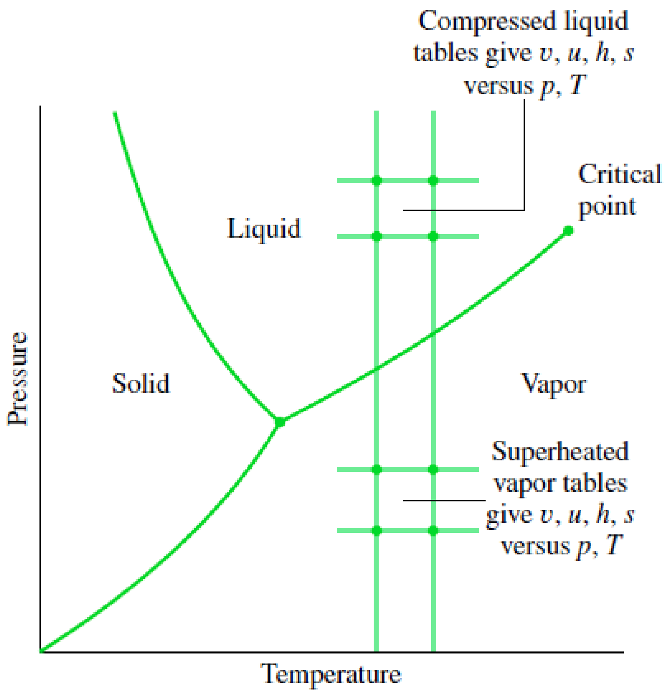


Figure 3.1: Sketch of the phase diagram for vapor used to discuss the structure of the superheated vapor and compressed liquid tables.

3.1.1 Phase change of a pure body:

3.1.2 Calculation of state variables:

<u>Steam quality:</u>

The quality x is the mass proportion of saturated vapor contained in a liquid-vapor mixture.

Example A mass of 1 Kg of water with a titer of 0.2 contains 0.8 Kg of saturated liquid and 0.2 Kg of saturated vapor. These 0.2 kg, however, occupy the majority of the available volume.

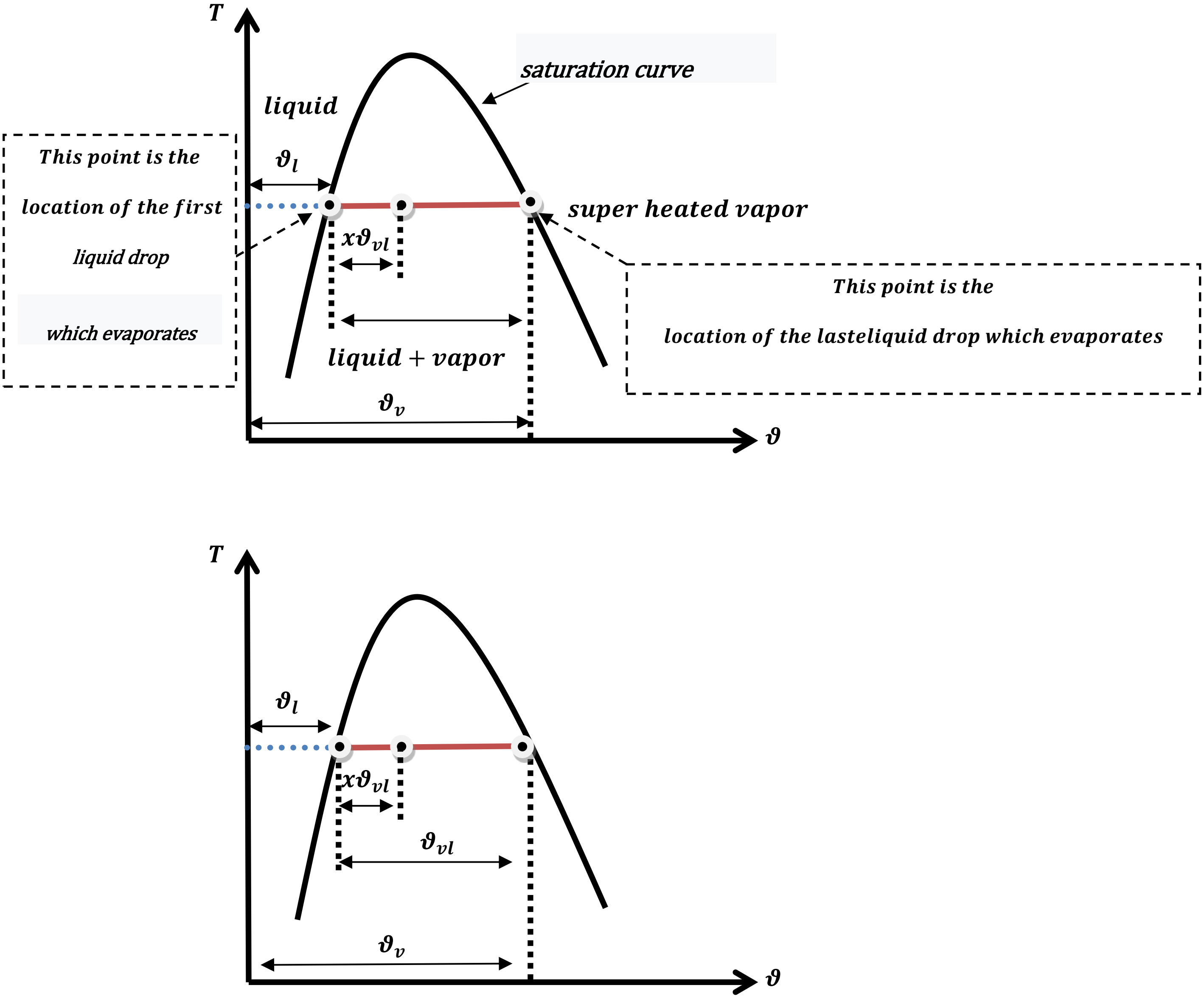


Fig. 3.2. Saturation curve.

Specific volume:

$$\vartheta = \frac{V}{m} \tag{I.1}$$

$$\vartheta_v = \vartheta_l + \vartheta_{vl} \tag{I.2}$$

$$\vartheta_x = (1-x)\vartheta_l + x\vartheta_{vl} \tag{I.3}$$

In the same way we have;

$$h_x = (1-x)h_l + xh_{vl} \tag{I.4}$$

$$U_x = (1-x)U_l + xU_{vl} \tag{I.5}$$

$$S_x = (1-x)S_l + xS_{vl} \tag{I.6}$$

$$x = \frac{m_{vapeur}}{m_{totale}} \quad (I.7)$$

$$V = m\vartheta \quad (I.8)$$

$$m_f = m_t - m_g \quad (I.9)$$

$$m_t\vartheta_x = (m_t - m_g)\vartheta_f + m_g\vartheta_g \quad (I.10)$$

Devided bym_t ,

$$\vartheta_x = (1 - x)\vartheta_f + x\vartheta_g \quad (I.11)$$

$$\vartheta_x = \left(\vartheta_f - x\vartheta_f\right) + x\vartheta_g \quad (I.12)$$

$$\vartheta_x = \vartheta_f + x\vartheta_g - x\vartheta_f \quad (I.13)$$

$$\vartheta_x = \vartheta_f + x(\vartheta_g - \vartheta_f) \quad (I.14)$$

$$\vartheta_x = \vartheta_f + x(\vartheta_{fg}) \quad (I.15)$$

$$x = \frac{\vartheta_x - \vartheta_f}{\vartheta_{fg}} = \frac{\vartheta_x - \vartheta_f}{\vartheta_g - \vartheta_f} \quad (I.16)$$

Humid Air:

Air in the atmosphere normally contains some water vapor (or moisture) and is refered to as atmospheric air. By contrast, air that contains no water vapor is called dry air. It often convenient to treat as a misture of water vapor and dry air since the composition of dry air remains relatively constant, but the amount of water vapor changes as a result of condensation and evaporation from oceans, lakes, rivers, showers, and even the humain body. Although the amount of water vapor in the air is small, it plays a major role in humain confort. Therefore, it is an important consideration in air-conditioning applications.

Characteristics of humid air:

Relative humidity, a measure of moisture content:

The amount of water vapor in the air at any given time is usually less than that required to saturate the air. The relative humidity is the percent of saturation humidity, generally calculated in relation to saturated vapor density.

$$Relative\ Humidity = \frac{actual\ vapor\ density}{saturation\ vapor\ density} \times 100\%$$

The most common units for vapor density are gm/m3. For example, if the actual vapor density is 10 g/m3 at 20°C compared to the saturation vapor density at that temperature of 17.3 g/m3 , then the relative humidity is

$$R.H. = \frac{10g/m^3}{17.3g/m^3} \times 100\% = 57.8\ \%$$

The relative humidity can be equivalently defined in terms of the water vapor pressure in the air compared to its saturation vapor pressure.

Humidity ration or specific humidity:

Another means of measuring the moisture content in moist air is calculating the humidity ratio, defined as the mass of the water vapor to the mass of dry air:

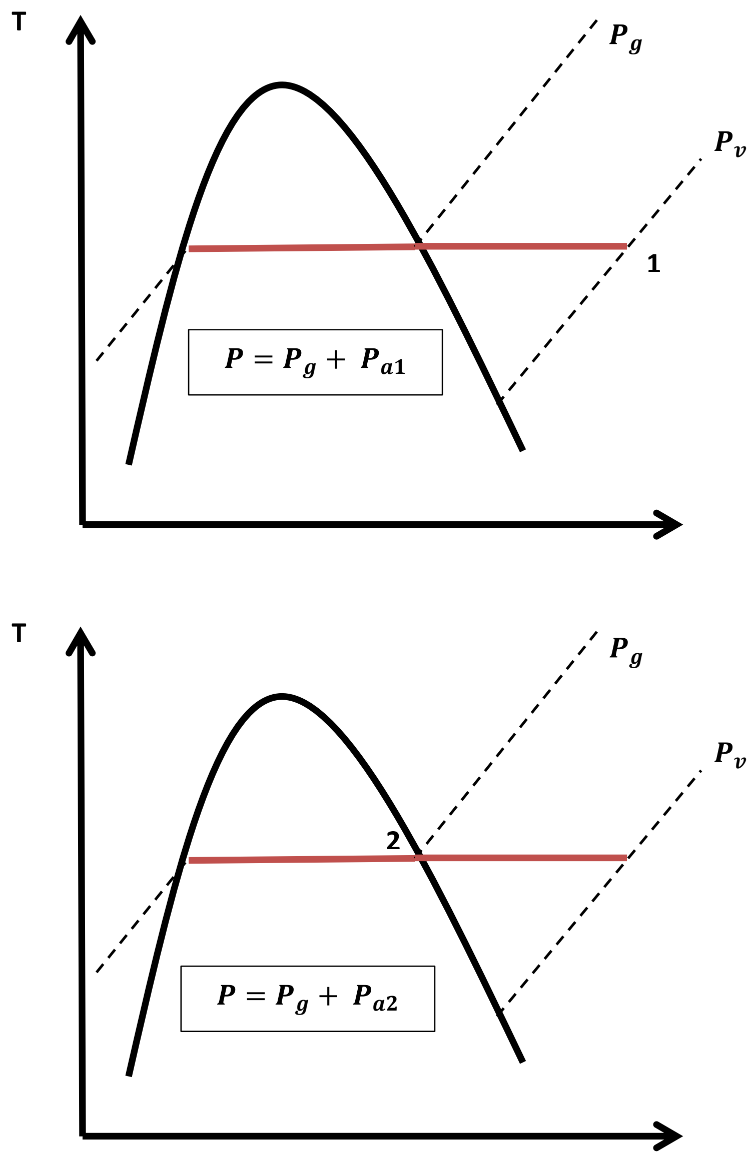


Fig. 3.3. State of vapor in moist air and in saturated mixture.

CHAPTER IV

Chapter4: Gas Compression

Classification of compression machines:

Compressors are used for many industrial applications: refrigeration, air conditioning, transportation of natural gas etc. A special mention must be made of air compressors, used as a source power for public and building works as well as in factories, pneumatic tools having many benefits.

Isentropic compression:

Compressors are compact machines, through which pass a gaseous fluid that stays there very briefly. Exchange surfaces are reduced and heat exchange coefficients are low. As a result, generally heat transfer between the working fluid and the outside is negligible compared to the compression work: the reference compression is therefore an adiabatic compression. If it is reversible, it is an isentropic.

Polytropic compression:

A polytropic process is a thermodynamic process that obeys the relation:

$$PV^n = constant$$

Where P Whereis the pressure,V is the volume, and n is the polytropic index. The polytropic process equation describes expansion and compression processes, which include heat transfer.

Piston compressors:

A reciprocating compressor or piston compressor is a positive-displacement compressor that uses pistons driven by a crankshaft to deliver gases at high pressure. The intake gas enters the suction manifold, then flows into the compression cylinder where it gets compressed by a piston driven in a reciprocating motion via a crankshaft, and is then discharged. Applications include railway and road vehicle air brake systems oil refineries, gas pipelines, oil and gas production drilling and well services, air and nitrogen injection, offshore platforms, chemical plants, natural gas processing plants, air conditioning, and refrigeration plants.

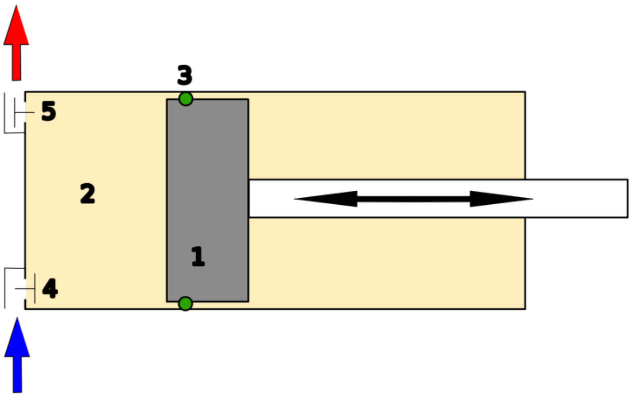


Fig. 4.1.reciprocating compressor or piston compressor

Rotary positive displacement compressor :

A rotary-screw compressor is a type of gas compressor, such as an air compressor, that uses a rotary-type positive-displacement mechanism. These compressors are common in industrial applications and replace more traditional piston compressors where larger volumes of compressed gas are needed, e.g. for large refrigeration cycles such as chillers, or for compressed air systems to operate air-driven tools such as jackhammers and impact wrenches. For smaller rotor sizes the inherent leakage in the rotors becomes much more significant, leading to this type of mechanism being less suitable for smaller compressors than piston compressors.

The screw compressor is identical to the screw pump except that the pockets of trapped material get progressively smaller along the screw, thus compressing the material held within the pockets. Thus the screw of a screw compressor is asymmetrical along its length, while a screw pump is symmetrical all the way.

The gas compression process of a rotary screw is a continuous sweeping motion, so there is very little pulsation or surging of flow, as occurs with piston compressors. This also allows screw compressors to be significantly quieter and produce much less vibration than piston compressors, even at large sizes, and produces some benefits in efficiency.

CHAPTER V

Chapter5: Gas relaxation

Adiabatic expansion

An adiabatic process is a type of thermodynamic process that occurs without transferring heat or mass between the thermodynamic system and its environment. Unlike an isothermal process, an adiabatic process transfers energy to the surroundings only as work. As a key concept in thermodynamics, the adiabatic process supports the theory that explains the first law of thermodynamics.

Some chemical and physical processes occur too rapidly for energy to enter or leave the system as heat, allowing a convenient "adiabatic approximation".

A process without transfer of heat to or from a system, so that Q = 0, is called adiabatic, and such a system is said to be adiabatically isolated. The simplifying assumption frequently made is that a process is adiabatic. For example, the compression of a gas within a cylinder of an engine is assumed to occur so rapidly that on the time scale of the compression process, little of the system's energy can be transferred out as heat to the surroundings. Even though the cylinders are not insulated and are quite conductive, that process is idealized to be adiabatic. The same can be said to be true for the expansion process of such a system.

The assumption of adiabatic isolation is useful and often combined with other such idealizations to calculate a good first approximation of a system's behaviour. For such an adiabatic process, the γ is the ratio of specific heats at constant pressure and at constant volume ($\gamma = Cp/Cv$) and P is the pressure of the gas.

$$PV^{\gamma} = constant$$

Work:

Reversible & Irreversible Work Reversible work means that the entire system (including the surrounding system) can be returned to the starting state. Irreversible work means that we can only bring the piston back to the starting state if we change the surrounding system.

$$W = -\int PdV$$

Efficiency and power produced:

Efficiency is expressed as a percentage and can be calculated using the equation:

$$\eta = (P_{out} - P_{in}) \times 100\%$$

Where P_{out} is the output power, and P_{in} is the input power, both measured in kW. In practice, the output power is always less than the input power due to energy losses caused by factors such as friction and heat.

Turbines:

Motor composed of a moving wheel to which the energy of a working fluid is applied. This motor transforms a linear force into a rotary force and recovers energy from water or steam to turn the rotor of an alternator.

Chapter 6: Engine cycles

Carnot Cycle :

The Carnot cycle have four processes:

1 – Two Constant temperature processes.

2 – Two isentropics processes.

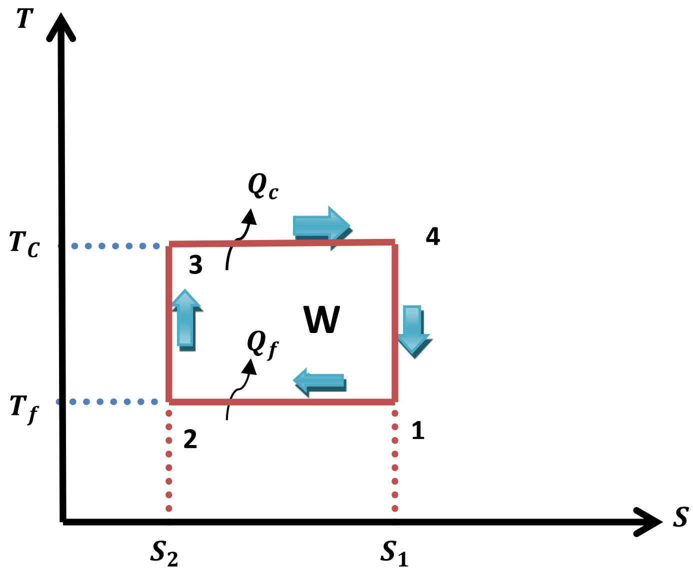


Fig. 5.1: Carnot Cycle in T-S diagram.

1.1 Efficiency of Carnot cycle:

Fiirst law :

$$W + Q_f + Q_c = 0 \quad (I.17)$$

Second law :

$$Q_f = T_f(S_1 - S_4) \quad (I.18)$$

$$Q_c = T_c(S_3 - S_2) \quad (I.19)$$

Or $S_3 = S_2$ et $S_1 = S_4$ soit :

$$W = -(Q_f + Q_c) \quad (I.20)$$

$$W = -[T_f(S_1 - S_2) + T_c(S_4 - S_3)] \quad (I.21)$$

$$W = -[T_f(S_1 - S_2) + T_c(S_1 - S_2)] \quad (I.22)$$

$$W = -(S_1 - S_2)(T_c - T_f) \qquad \text{(I.23)}$$

Or $S_2 < S_1$ and $T_f < T_c$ so $W < 0$

$$\eta_{Carnot} = \frac{W}{Q_C} = \frac{(T_c - T_f)(S_1 - S_2)}{T_c(S_1 - S_2)} = (T_c - T_f)/T_c \qquad \text{(I.24)}$$

The system receives work W, transfers the quantity of heat Q_c to the hot source and rejected heat Q_f to the cold source.

Q_f: Heat absorbed by the fluid during a cycle.

Q_c: Heat released by the fluid during a cycle.

Otto Cycle

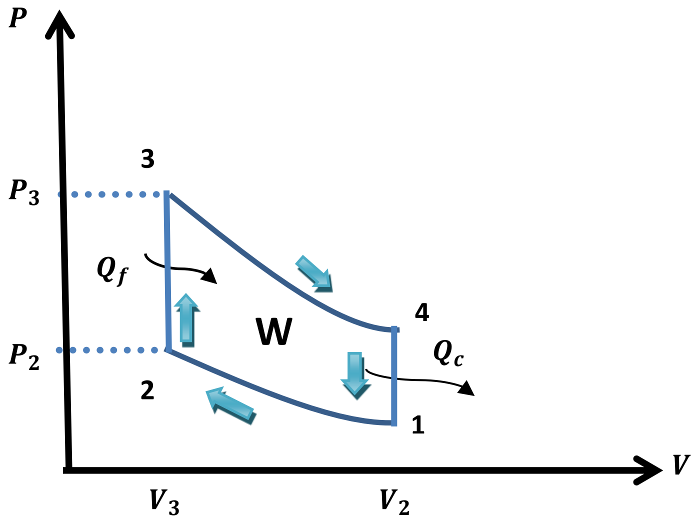


Fig. 5.2: Otto Cycle in T-S diagram.

Diesel Cycle

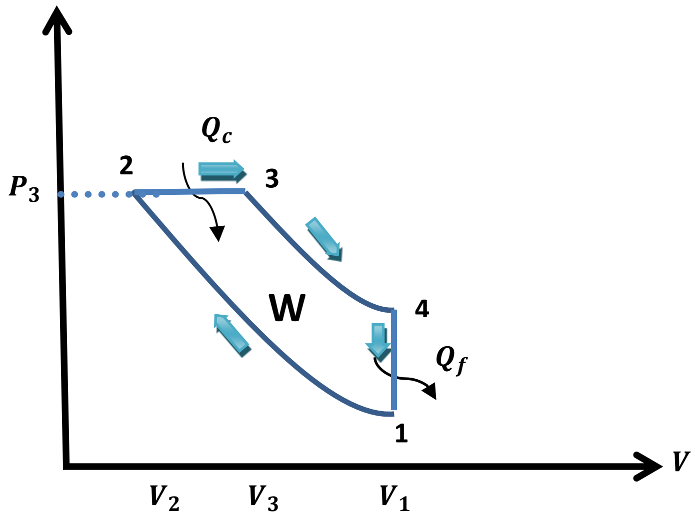


Fig. 5.3: Diesel Cycle in T-S diagram.

Brayton Cycle

The Brayton cycle, also known as the Joule cycle, is a thermodynamic cycle that describes the operation of certain heat engines that have air or some other gas as their working fluid. It is characterized by isentropic compression and expansion, and isobaric heat addition and rejection, though practical engines have adiabatic rather than isentropic steps.

The most common current application is in airbreathing jet engines and gas turbine engines.

Ideal Brayton cycle:

Isentropic process – ambient air is drawn into the compressor, where it is pressurized.

isobaric process – the compressed air then passes through a combustion chamber, where fuel is burned, heating that air—a constant-pressure process, since the chamber is open to flow in and out.

isentropic process – the heated, pressurized air then gives up its energy, expanding through a turbine (or series of turbines). Some of the work extracted by the turbine is used to drive the compressor.

isobaric process – heat rejection (in the atmosphere).

Actual Brayton cycle:

adiabatic process – compression

isobaric process – heat addition

adiabatic process – expansion

isobaric process – heat rejection

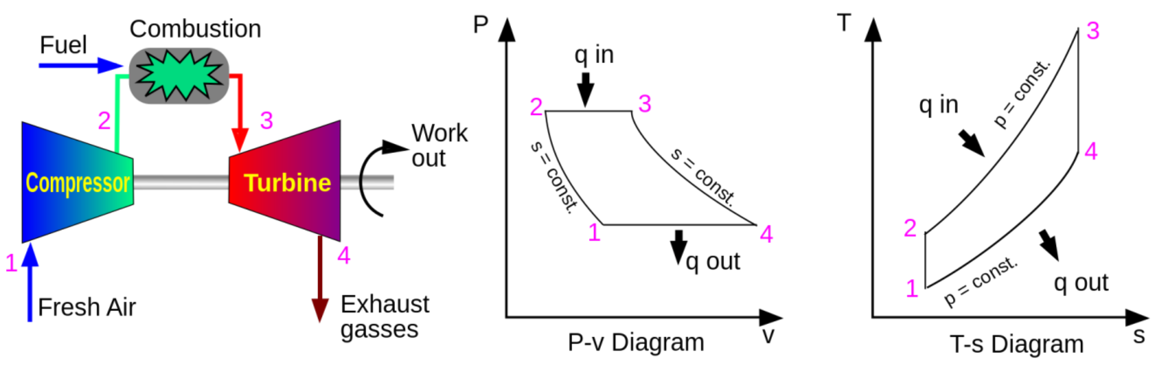


Fig. 5.4: Brayton cycle.

Steam turbines

A steam turbine is a machine that extracts thermal energy from pressurized steam and uses it to do mechanical work on a rotating output shaft. Its modern manifestation was invented by Charles Parsons in 1884.[1][2] Fabrication of a modern steam turbine involves advanced metalwork to form high-grade steel alloys into precision parts using technologies that first became available in the 20th century; continued advances in durability and efficiency of steam turbines remains central to the energy economics of the 21st century.

The steam turbine is a form of heat engine that derives much of its improvement in thermodynamic efficiency from the use of multiple stages in the expansion of the steam, which results in a closer approach to the ideal reversible expansion process.

Because the turbine generates rotary motion, it can be coupled to a generator to harness its motion into electricity. Such turbogenerators are the core of thermal power stations which can be fueled by fossil fuels, nuclear fuels, geothermal, or solar energy. About 42% of all electricity generation in the United States in the year 2022 was by use of steam turbines.[3]

Technical challenges include rotor imbalance, vibration, bearing wear, and uneven expansion (various forms of thermal shock). In large installations, even the sturdiest turbine will shake itself apart if operated out of trim.

Rankine Cycle

The Rankine cycle is an idealized thermodynamic cycle describing the process by which certain heat engines, such as steam turbines or reciprocating steam engines, allow mechanical work to be extracted from a fluid as it moves between a heat source and heat sink. The Rankine cycle is named after William John Macquorn Rankine, a Scottish polymath professor at Glasgow University.

Heat energy is supplied to the system via a boiler where the working fluid (typically water) is converted to a high-pressure gaseous state (steam) in order to turn a turbine. After passing over the turbine the fluid is allowed to condense back into a liquid state as waste heat energy is rejected before being returned to boiler, completing the cycle. Friction losses throughout the system are often neglected for the purpose of simplifying calculations as such losses are usually much less significant than thermodynamic losses, especially in larger systems.

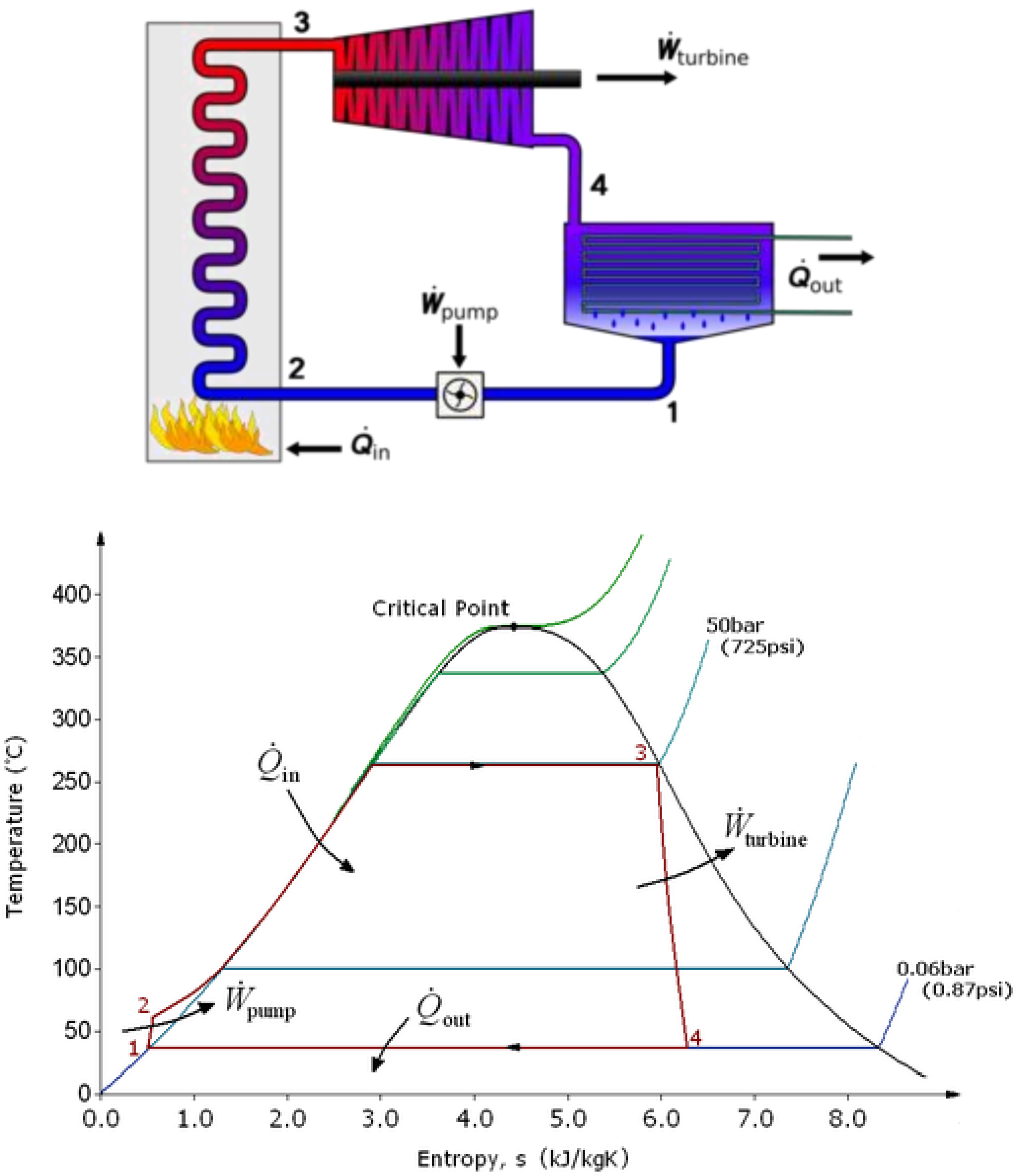


Fig. 5.5: Rankine cycle.

CHAPTER VII

Chapter 7: Refrigeration Cycles

Gas refrigeration cycle

Single stage vapor compression cycle

The ideal vapor compression refrigeration cycle is shown above.

It is made up of four transformations: adiabatic and reversible compression 1-2, isobaric cooling by condensation 2-3, irreversible expansion without work exchange 3-4, and finally isobaric heating by evaporation 4-1. This is essentially a reverse Rankine-Hirn cycle; except that a valve replaces the pump.

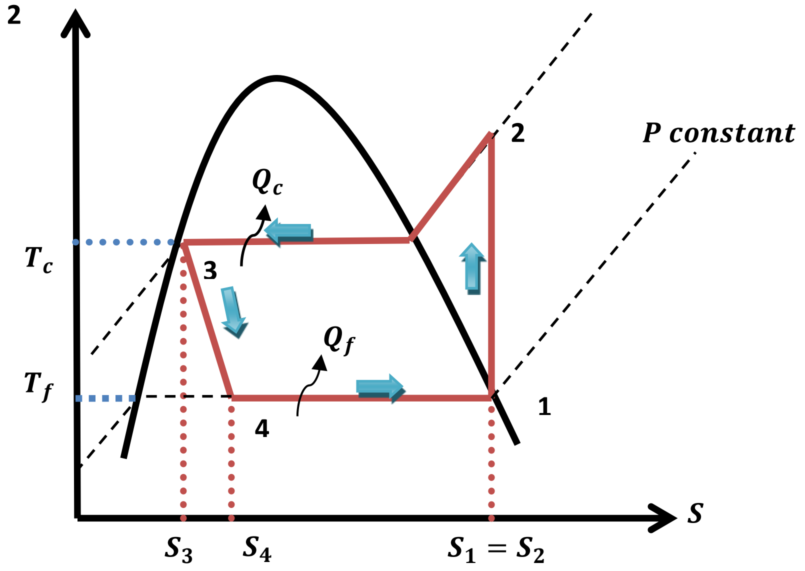


Fig. 7.1. Basic cycle of a refrigeration machine diagram (T-S).

The 1-2 isentropic transformation : ($S_1 = S_2$)

The 2-3 isobaric transformation : ($P_2 = P_3$)

The 3-4 isenthalpic transformation: ($h_3 = h_4$)

The 4-1 isobaric transformation (also isothermal): ($P_4 = P_1$ et $T_4 = T_1$)

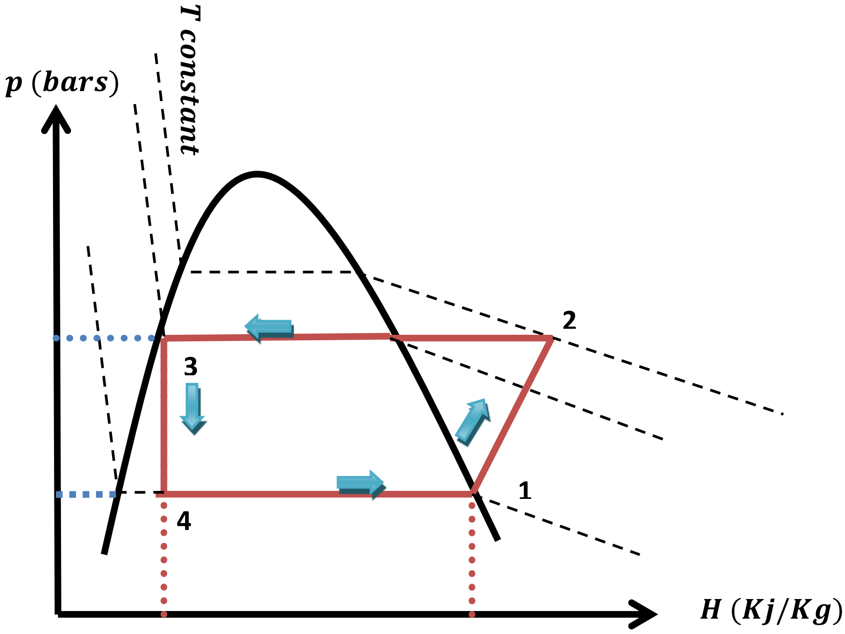


Fig. 7.2. Basic cycle of a refrigeration machine diagram (P-H).

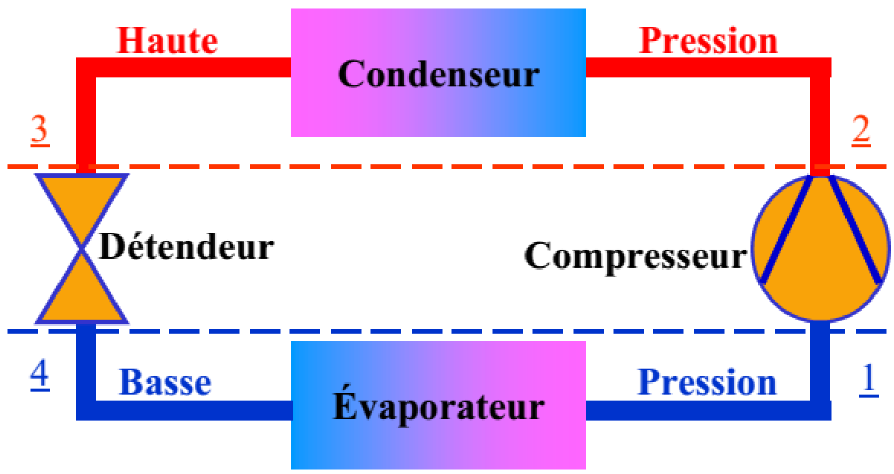


Fig. 7.3. Operating diagram of a basic cycle of a refrigeration machine.

To explain how it works, we will take the characteristics of R22 because it is the fluid most commonly used in air conditioning.

In the evaporator; The liquid refrigerant boils and evaporates, absorbing heat from the outside fluid. Secondly, the gas formed is further slightly heated by the external fluid, this is called the overheating phase.

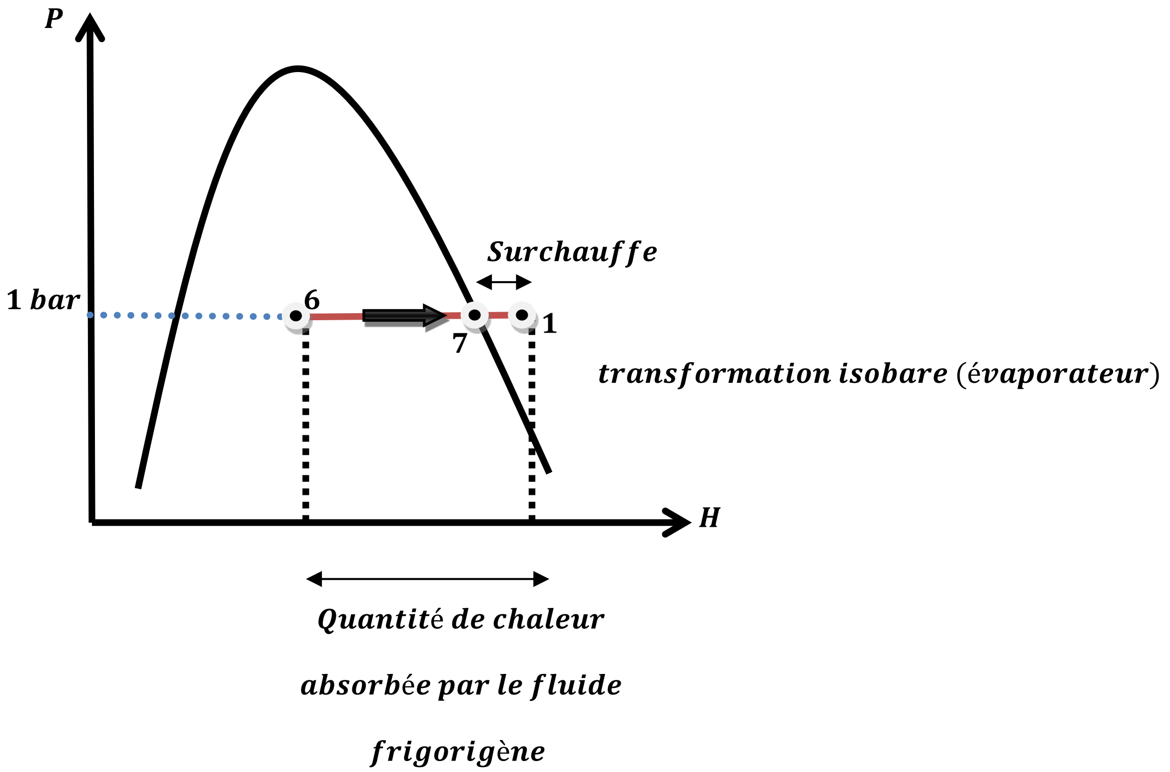


Fig. 7.4. Isobaric transformation in the evaporator.

In the compressor; The compressor will first suck in the refrigerant gas at low pressure and low temperature (1). The mechanical energy provided by the compressor will raise the pressure and temperature of the refrigerant gas. An increase in enthalpy will result.

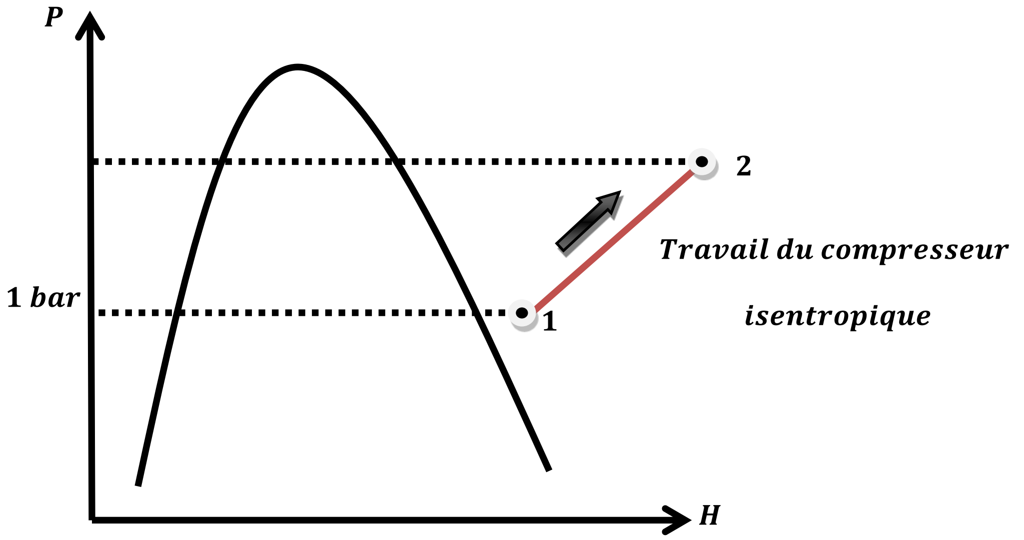


Fig. 7.5. Isentropic transformation in the compressor.

In the condenser; The hot gas coming from the compressor will transfer its heat to the external fluid. The refrigerant vapors cool "desuperheat" before the first drop of liquid appears (point 3). Then condensation takes place until the second vapor bubble disappears (point 5). The liquid fluid can then cool a few degrees (subcooling) before leaving the condenser.

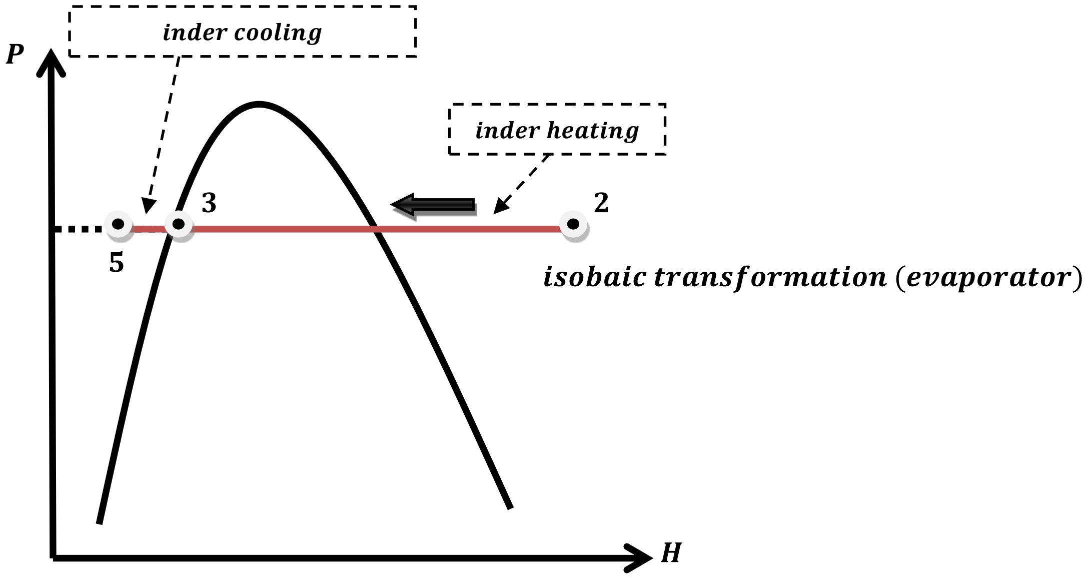


Fig. 7.6. Isobaric transformation in the condenser.

In the regulator;

The pressure difference between the condenser and the evaporator requires inserting a “pressure lowering” device into the circuit. This is the role of the regulator. The refrigerant partially vaporizes in the regulator to lower its temperature.

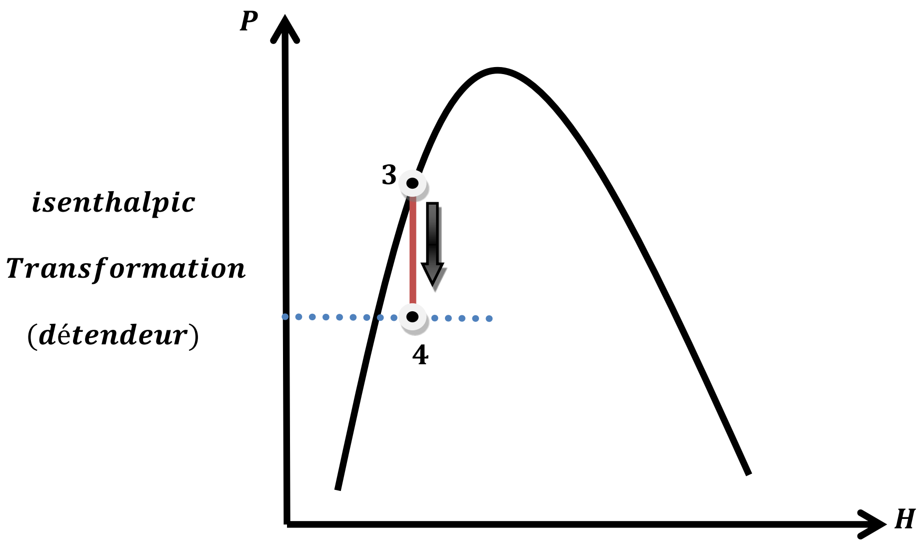


Fig. 7.7. Isenthalpic transformation in the expander.

Sign convention; What is received by the system will be counted positively, while what is given up or lost will be counted negative.

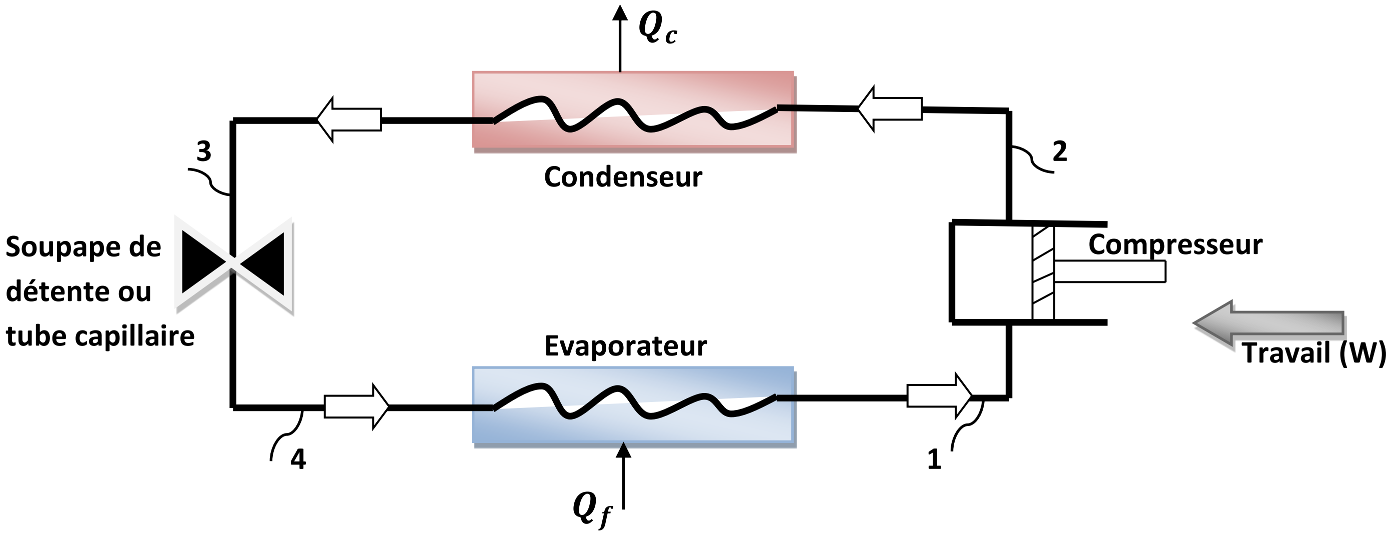


Fig. 7.8. Principle of operation.

2.2 Representation of the practical thermodynamic cycle (on T-S and P-H diagram):

For the practical cycle the transformation in the compressor is not isentropic at the 2s point.

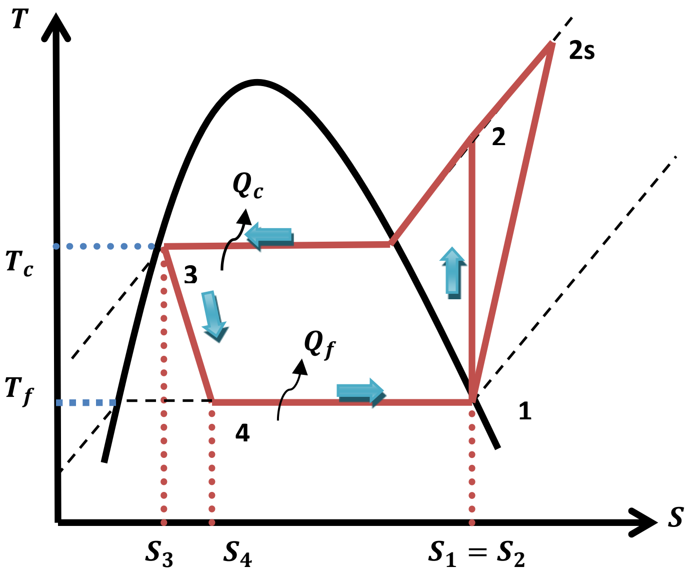


Fig. 7.9. Actual refrigeration cycle in diagram (T-S).

The non-isentropic 1-2s transformation

The 2s-3 isobaric transformation ($P_2= P_3$)

The 3-4 isenthalpic transformation ($h_3= h_4$)

The 4-1 isobaric transformation (also isothermal)($P_4= P_1$ and $T_4= T_1$)

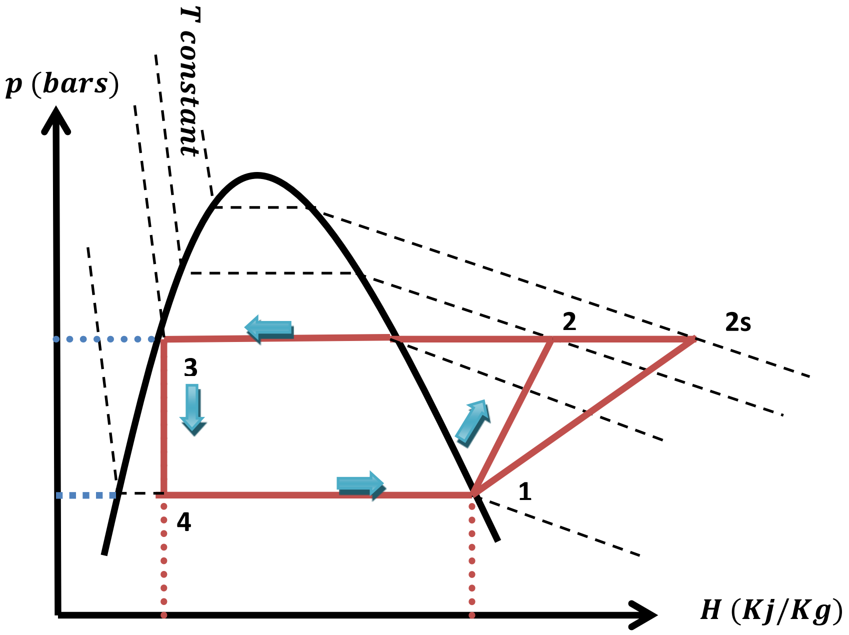


Fig. 7.10. Actual refrigeration cycle in diagram (P-H).

Heat balance of the thermodynamic cycle :

First principle :

$$W + Q_f + Q_c = 0$$

Second principle :

$$Q_f = h_4 - h_1$$

$$Q_c = h_3 - h_2$$

$$W = -(Q_f + Q_c)$$

$$W = h_2 - h_1$$

The system receives work W, takes heat Q_f from the cold source and transfers the quantity of heat Q_c to the hot source.

Q_f : heat absorbed by the fluid during a cycle.

Q_c : heat released by the fluid during a cycle.

Specific refrigeration efficiency :

$$\varepsilon_f = \frac{h_1 - h_4}{h_2 - h_1}$$

Specific heat efficiency :

$$\varepsilon_c = \frac{h_3 - h_2}{h_2 - h_1}$$

Where : τ is the duration in cycle

Frigorific power :

$$P_f = \left|\frac{Q_f}{\tau}\right| \text{ [W]}$$

Calorific power :

$$P_c = \left|\frac{Q_c}{\tau}\right| \text{ [W]}$$

Mechanic power :

$$p = \frac{W}{\tau} \text{ [W]}$$

Specific refrigeration production :

$$K_{fsp} = \frac{Q_f}{W} \text{ [J.Kw}h^{-1}\text{]}$$

Specific heat production :

$$K_{csp} = \frac{Q_c}{W} \text{ [J.Kw}h^{-1}\text{]}$$

<u>Refrigerants</u>

Refrigerants ; Have the form ; $C_xH_yF_zCL_k$

Whith ;

$$y + z + k = 2x + 2$$

They are caled ;

CFC ; Chlorofluorocarbures (Freons) if $y = 0$ (Very important Ozone)

HCFC ; Hydro-chlorofluorocarbures (Freons) if y $\neq$ 0 (important Ozone)

HFC ; Hydrofluorocarbures (Freons) if k = 0 (no Ozone)

Designations ;

$$R_{abc} = R_{(x-1)(y+1)(z)}$$

Exemple1 ;

$$R_{170}\begin{cases} x-1=1 \\ y+1=7 \\ z=0 \\ k=0 \end{cases} \rightarrow \begin{cases} x=2 \\ y=6 \end{cases} \rightarrow C_2H_6$$

If the symbol only has two digits ; $\mathrm{R_{bc}}$, it should be considered as a three-digit number of the form R_{0bc}

$$R_{12}\begin{cases} x-1=0 \\ y+1=1 \\ z=0 \end{cases} \rightarrow \begin{cases} x=1 \\ y=0 \end{cases} \rightarrow k=2x+2-z-y=2$$

The formula for freon is therefore ; CF_2CL_2

Exemple2 ; $R_{50}=CH_4$

Inorganic compound (Serie 700)

The rule consists of adding the molar mass of the fluid after the number 7 ;

$$NH_3; M=14+3=17 \qquad R717$$

$$H_2O; M=2+16=18 \qquad R718$$

$$CO_2; M=12+32=44 \qquad R744$$

Safety and environmental criteria :

- Toxicity

- Flammability

- Effect on the ozone layer

- Greenhouse effect.

Technological, operational and economic criteria :

- High liquid density = compactness

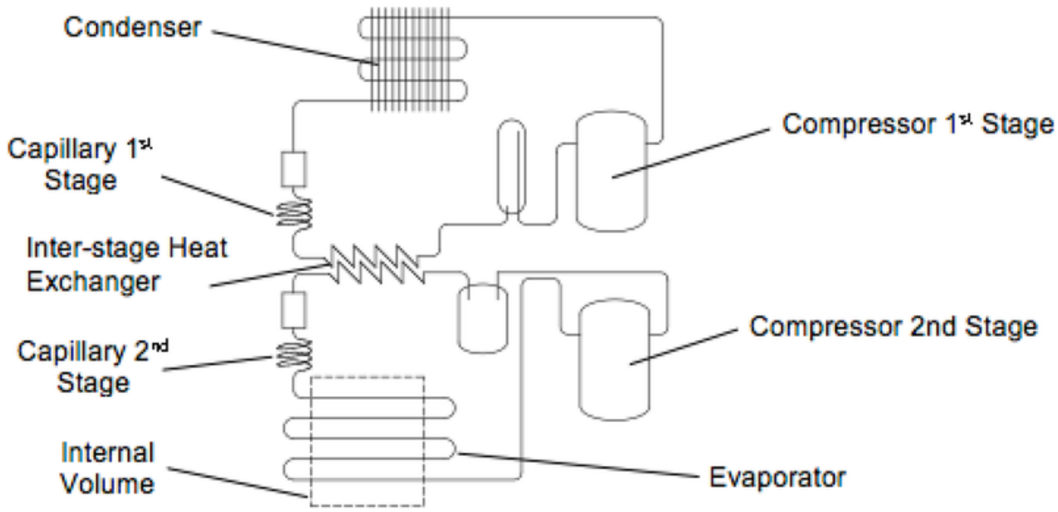
- Operating pressure ; pressure greater than atmospheric pressure.

- Low viscosity and high thermal conductivity

- Cost and availability.

Cascading cycle:

A cascade refrigeration cycle is a multi-stage thermodynamic cycle. An example two-stage process is shown at right. In a cascade refrigeration system, two or more vapor-compression cycles with different refrigerants are used. The evaporation-condensation temperatures of each cycle are sequentially lower with some overlap to cover the total temperature drop desired, with refrigerants selected to work efficiently in the temperature range they cover. The low temperature system removes heat from the space to be cooled using an evaporator, and transfers it to a heat exchanger that is cooled by the evaporation of the refrigerant of the high temperature system. Alternatively, a liquid to liquid or similar heat exchanger may be used instead. The high temperature system transfers heat to a conventional condenser that carries the entire heat output of the system and may be passively, fan, or water-cooled.



Heat pumps:

The heat pump pumps heat somewhere in a natural environment. It is a thermodynamic heating system called renewable energy. The heat pump commonly called heat pump extracts the calories present in the natural environment such as air, water, earth or soil, and transmits them through the amplifier to a space to be heated. The driving action of an electric compressor on a phase change refrigerant fluid carries out this thermodynamic operation.

The heat pump is mainly used as a residential heating solution. We then speak of geothermal energy (water-water or ground water heat pump) or air heater (air-water or air-air heat pump). In tertiary applications such as offices, the heat pump is often used all year round, either for heating or for cooling in summer. The range of heating powers is great for heat pumps since a heat pump can provide 2 kW of heating for a room just as it can deliver 400 kW or more for a building. It is also a geothermal energy called an air heater. The heat captured in the outside air is transferred not directly by direct expansion but via a hot water circuit. This network supplies a two-pipe radiator circuit, most often "low temperature", or a network of underfloor heating, or a series of fan coils, or even air heaters if the application is more industrial.

The heating temperature regime is often moderate, around 60°C maximum for a heat pump.

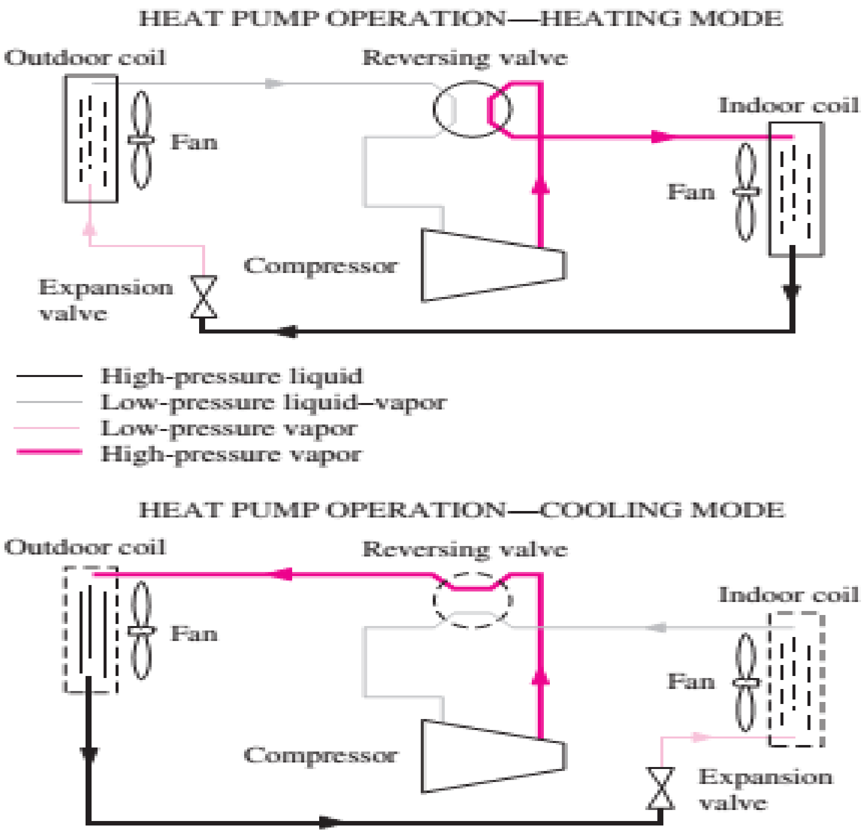


Fig. 7.11. Heat pump operations.[2].

EXERCICES :

EX 1: A gas compressed from an initial volume of 0.42 $m^3$to a final volume of 0.12m^3. During the quasi-equilibrium process, the pressure changes with volume according to the relation P = Av + b, where a = -1200 KPa/$m^3$and b= 600KPa. Calculate the work done during this process.

- **A) By plotting the process on P.V diagram and finding the area under the process curve and,**
- **B) By performing the necessary integration.**

EX 2: A frictionless piston cylinder device contains 2 Kg of nitrogen at 100 KPa and 300 K. Nitrogen compressed slowly according to the relation $PV^{1.4} = constant$ until it reaches a final temperature of 360 K. Calculate the work input this process.

EX 3: A piston cylinder device initially contains 0.25 Kg of nitrogen gas at 130 KPa and 120℃. The nitrogen expanded isothermally to a pressure of 100KPa. Determine the boundary work done during this process.

EX 4: A 1.8m^3 rigid tank contains steam at 220℃. one-third of the volume is in the liquid phase and the rest is in the vapor form. Determine:

- **a) The pressure of the steam,**
- **b) The quality of the saturated mixture, and,**
- **c) The density of the mixture.**

EX 5: A mass of 200 g of saturated liquid water completely vaporized at a constant pressure of 100KPa. Determine:

- **a) The volume charge and,**
- **b) The amount of energy transferred to the water.**

EX 6: A piston cylinder device contains 0.1$m^3$of liquid water and 0.9m^3 of water vapor in equilibrium at 800KPa. Heat transferred, at constant pressure until the temperature reaches 350℃.

- **A) What is the initial temperature of the water**
- **B) Determine the total mass of the water**
- **C) Calculate the final volume**
- **D) Show the process on a P-V diagram with respect to saturation lines.**

EX 7: A 1m^3 rigid tank contains 10 Kg of water (in any phase or phases) at 160℃. The pressure in the tank is:

a) **738 KPa,**
b) **618 KPa,**
c) **370KPa.**
d) **2000 KPa**
e) **1618 KPa**

EX 8: Consider a room that contains air at 1 atm, 35℃, and 40% relative humidity. Using the psychrometric chart, determine:ω, h, T_{wb}, $T_{dp}$and ϑ?

EX 11: An ideal Otto cycle has a compression ratio of 8. At the compression process, air is at 100 KPa and 17℃, and 800 Kj/Kg of heat is transfered to air during the constant volume of heat addition process. Accounting for the variation of specific heats of air with temperature, determine:

A) **The maximum temperature and pressure that occur during the cycle,**
B) **The network output,**
C) **The thermal efficiency, and**
D) **The mean effective pressure for the cycle.**

EX 12: An ideal Diesel cycle with air as the working fluid has a compression ratio of 18 and a cutoff ratio of 2. At the beginning of the compression process, the working fluid is at 1 Bar, 280 K. Utilizing the cold-air-standard assumptions, determine:

A) **The temperature and pressure of air at the end of each process,**
B) **The network and the thermal efficiency,**
C) **The mean effective pressure for the cycle.**

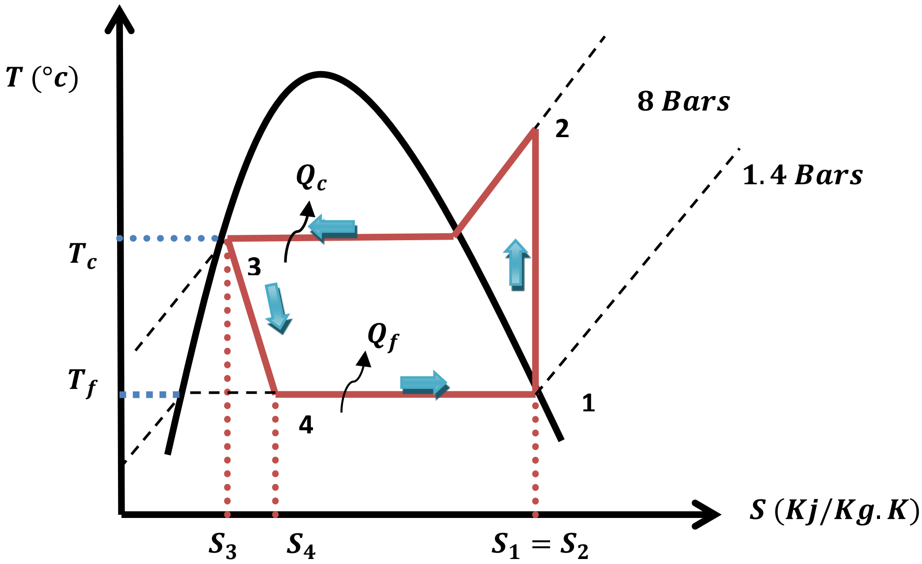
SOLUTION

EX 13 : Le cycle décrit par le R134 est représenté ci-contre. On donne

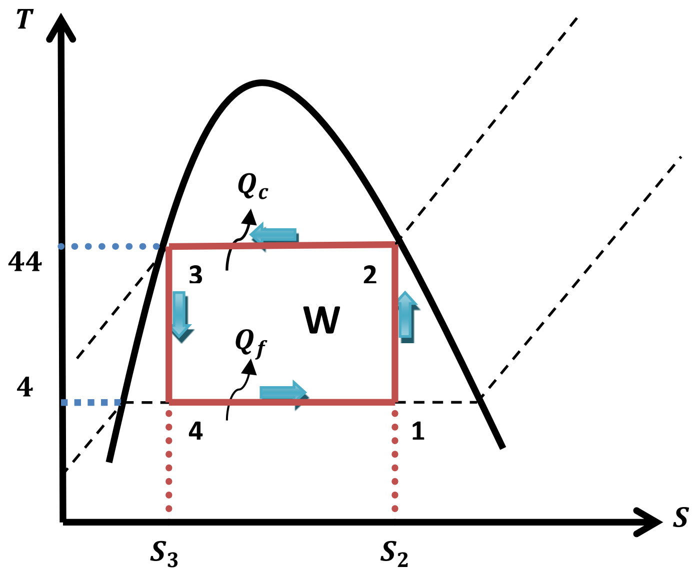
v_4= 0.04538 m^3/Kg : h_2= 284.39 Kj/Kg ; Calculer le COP ?

Si la masse d'eau est de 10 Kg, trouver la masse d'eau vapeur et le volume d'eau liquide ?

P(Bars)	v_l (m^3/Kg)	v_v (m^3/Kg)	h_l (Kj/Kg)	h_v (Kj/Kg)
1.4	0.0007381	0.1395	25.77	236.04
8	0.0008454	0.0255	-	264.15



Exercice N°14 : Pour fonctionner une machine frigorifique, on utilise le R134a avec un cycle de Carnot. Trouver le COP de cette machine.



SOLUTION

EX01 :

$v_i = 0.42\ m^3$;

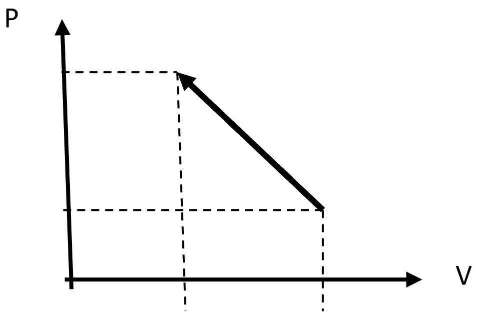
$v_f = 0.12\ m^3$;

$$P = aV + b$$

$P_i = a\,(0.42) + b = -1200(0.42) + 600 = 96\ KPa$

$P_f = a\,(0.12) + b = -1200(0.12) + 600 = 456\ KPa$

$W = \frac{1}{2}(0.42 - 0.12)x(456 - 96) + 96\,(0.42 - 0.12) = 82.8\ Kj$



$$W = -\int (aV + b) = -\int aV\,dV - \int b\,dV$$

$$W = -\frac{a}{2}\left({v_f}^2 - {v_i}^2\right) - b\left(v_f - v_i\right) = -\frac{1200}{2}\left((0.12)^2 - (0.42)^2\right) - 600\,(0.42 - 0.12) = 82.8\ Kj$$

EX 02:

$PV^\gamma = K$; $P = \frac{K}{V^\gamma}$

$$W = -\int PdV = -\int \frac{K}{V^\gamma}\,dV = -K\int \frac{dV}{V^\gamma} = -K\left[\frac{V^{1-\gamma}}{1-\gamma}\right]$$

$$W = -\frac{K}{1-\gamma}\left[{V_2}^{1-\gamma} - {V_1}^{1-\gamma}\right]$$

$P{V_2}^\gamma = P{V_1}^\gamma = K$

$$W = \frac{P_2V_2 - P_1V_1}{\gamma - 1} = \frac{nRT_2 - nRT_1}{\gamma - 1} = \frac{nR}{\gamma - 1}\left[T_2 - T_1\right]$$

$$W = \frac{\frac{2}{2.8}x8.314x(360 - 300)}{0.4}$$

$W = 89.08\ Kj$

EX 03 :

$m = 0.25\ Kg \quad ;\ P_1 = 130\ KPa \quad : T_1 = 120\ ℃\ ;\ P_2 = 100\ KPa$

$M = 28 \quad ;\ isothermally \quad PV = K$

$$W = -\int PdV = -\int \frac{K}{V}\, dV = -K\int \frac{dV}{V}$$

$$W = -K[\ln V] = -K\ ln(V_2/V_1)$$

$P_1V_1 = nRT_1\ ,\ \ V_1 = nRT_1/P_1 = 0.25 \ x\ 8.314\ x\ 393/\ 28\ x\ 130\ x\ 10^3 =\ 0.2244\ L$

$P_1V_1 = P_2V_2\ ,\ \ V_2 = V_1P_1/P_2 = 0.2244 x\ 130\ x\ 10^{-3}/\ 100 = 0.2917\ L$

$W = -P_1V_1 ln(V_2/V_1)$=130 x 0.2244 x 10^3 x$10^{-3} ln(0.2917/0.2244)$ = 7.65 Kj

EX 04 :

$V = 1.8\, m^3\ ;\ \ T = 220\ ℃\ ;\ \ V_f = V/3$

$V_f = 1.8/3 = 0.6\, m^3$

$V_f = V - V_g = 1.8 - 0.6 = 1.2\, m^3$

$m_g = \frac{V_g}{v_g} = \frac{1.2}{0.08619} = 13.9\ Kg$

$m_f = \frac{V_f}{v_f} = \frac{0.6}{0.00119} = 504.2\ Kg$

$$x = \frac{m_g}{m_g + m_f} = \frac{13.9}{504.2 + 13.9} = 0.026 = 2.6\ \%$$

$v = x\left(v_g - v_f\right) + v_f$

$v = 0.026\ (0.08619 - 0.001190) + 0.001190 = 0.0034\ m^3/Kg$

$\rho = 1/v = 1/0.0034 = 294.11\ Kg/m^3$

$P = 2.318\ MPa$

EX 05 :

The volume change per unit mass during a vaporization process isv_{fg} ; which is the difference between $v_g and v_f$. Reading these values from table at 100 KPa and substituting yield

$$v_{fg} = (v_g - v_f) = 1.6941 - 0.001043 = 1.6931\ m^3/Kg$$

$V = m\ v_{fg}(0.2\ Kg)(1.6931\ m^3/Kg) = 0.3386\ m^3$

The amount of energy needed to vaporize a unit mass of a substance at a given pressure is the enthalpy of vaporization at that pressure, which is h_{fg} = 2257.5 $\frac{Kj}{Kg}$ for water at 100 KPa. Thus the amount of energy transferred is:

$m\ h_{fg} = (0.2\ Kg)\left(2257.5\frac{Kj}{Kg}\right) = 451.5\ Kj$

EX 06 :

$V_f = 0.1m^3\ ; V_g = 0.9m^3$

$V_1 = V_f + V_g = 0.1 + 0.9 = 1m^3$

$P_1 = 800\ KPa\ So\ T_1 = 170.43$ ℃

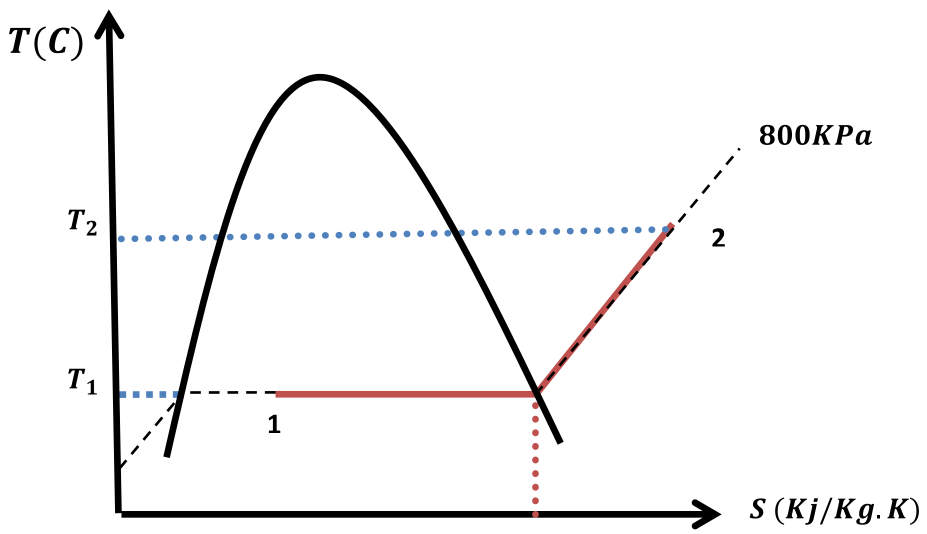
$v_f = 0.001115\ m^3/Kg\ And v_g = 0.2404\ m^3/Kg$

$m = \frac{V_f}{v_f} + \frac{V_g}{v_g} = \frac{0.1}{0.001115} + \frac{0.9}{0.2404} = 94.43\ Kg$

$P_1 = P_2 = 800\ KPa\ And T_2 = 350\ C$

$$v_g = 0.3544\ m^3/Kg$$

$$V_2 = m\ v_g(94.43\ Kg)(0.3544\ m^3/Kg) = 33.466\ m^3$$



EX 07:

$V = 1\, m^3\ ; m = 10\ Kg\ ; T = 160$℃

$v = V/m = 1/10 = 0.1\ Kg/m^3\ So\quad v_f \geq v\ \geq v_g$

$v_f\ = 0.001102\ m^3/Kg\ And v_g\ = 0.3071\ m^3/Kg$

$So\ \ P\ = 617.8\ KPa \cong 618\ KPa$

EX 08:

At a given total pressure, the state of atmospheric air is completely specified by two independent properties such as the dry-bulb temperature and the relative humidity; other properties are determined by directly reading their values at the specified state.

A) The specific humidity is determined by drawing a horizontal line from the specified state to the right until it intersects with the w axis. At the intersection point we read $\omega = 1\, 0.0142\ Kg \frac{H_2O}{Kg} dryair$

B) The enthalpy of air per unit mass of dry air is determined by drawing a line parallel to the h= constant lines from the specific state until it intersects the enthalpy scale, giving h= 71.5 Kj/Kg dry air

C) The wet-bulb temperature is determined by drawing a line parallel to the T_{wb}= constant lines from the specific state until it intersects the saturation line giving T_{wb}= 24 ℃

D) The dew-point temperature is determined by drawing a line from the specific state to the left until it intersects the saturation line giving T_{dp}= 19.4 ℃

E) The specific volume per unit mass of dry air is determined by noting the distances between the specified state and the v= constant lines on both sides of the point. The specific volume is determined by visual interpolation to be, v= 0.893m^3/Kg dry air

EX 9:

The saturation pressure of water is 1.7057 KPa at 15℃ and 3.1698 KPa at 25℃. The constant pressure specific heat of air at room temperature is C_p= 1.005 Kj/Kg. K.

The specific humidity $\boldsymbol{\omega}_1$ is determined from equation

$$\boldsymbol{\omega}_1 = (C_p(T_2 - T_1) + \boldsymbol{\omega}_2 h_{fg2})/h_{g2} - h_{f2}$$

Where T_2 is the wet-bulb temperature and $\boldsymbol{\omega}_2$ is

$\boldsymbol{\omega}_2 = 0.622 P_{g2}/\ (P_2 - P_{g2})$ = 0.622 (1.7057)/ (101.325 − 1.7057) = 0.01065 Kg $\frac{H_2O}{Kg} dryair$

Thus

$\boldsymbol{\omega}_1 = \left[\frac{1.005(15-25) + (0.01065)\ (2465.4)}{(2546.5-62.982)}\right]$ = 0.00653 Kg $\frac{H_2O}{Kg} dryair$

$\phi_1 = \omega_1 P_2/((0.622 + \omega_1)P_{g1})$ = $\left[\frac{(0.00653)\ (101.325)}{(0.622+0.00653)\ \ (3.1698)}\right] = 0.332 = 33.2\%$

$h_1 = h_{a1} + \omega_1 h_{v1} = C_p T_1 + \omega_1 h_{g1}$

= $1.005(25) + \ (0.00653)(2546.5) = \ 41.8 \frac{\text{Kj}}{\text{Kg}} drai\ air$

EX 10 :

$T_1 = 290\ K$; $u_1 = 206.91\ Kj/Kg$; $V_{r1} = 676.1$

Process 1-2: Isentropic compression of an ideal gas:

$$\frac{V_{r2}}{V_{r1}} = \frac{V_2}{V_1} = \frac{1}{r}$$

$V_{r2} = \frac{V_{r1}}{r} = \frac{676.1}{8}$= 84.51 ; $T_2 = 652.4\ K$; $u_1 = 475.11\ Kj/Kg$

$$\frac{P_2 V_2}{T_2} = \frac{P_1 V_1}{T_1}$$

$$P_2 = \frac{P_1 T_2 V_1}{T_1 V_2} = 100x\ 8\ x\frac{652.4}{290} = 1799.7\ KPa$$

Process 2-3: Constant volume heat addition:

$$q_{in} = u_3 - u_2$$

800 KJ/Kg = $u_3 - \ 475.11\ Kj/Kg$

$u_3 = 1275.11\ Kj/Kg$; $T_3 = 1575.1\ K$; $V_{r3} = 6.108$

$$\frac{P_2V_2}{T_2} = \frac{P_3V_3}{T_3}$$

$$P_3 = \frac{P_2T_3V_2}{T_2V_3} = 1.7997\ x\ 1\ x \frac{1575.1}{652.4} = 4.345\ KPa$$

$\frac{V_{r4}}{V_{r3}} = \frac{V_4}{V_3} = rV_{r4} = r\ x\ V_{r3} = 8\ x\ 6.108 = 48.864$; $T_4 = 795.6\ K$; $u_4 = 588.74\ Kj/Kg$

$q_{out} = u_4 - u_1 = 588.7 - 206.91 = 381.83\ Kj/Kg$

$$w_{net} = q_{net} = q_{in} - q_{out} = 800 - 381.83 = 418.17\ Kj/Kg$$

$\eta_{th} = w_{net}/q_{in} = 418.17/800 = 0.523 = 52.3\ \%$

$\eta_{th,Otto} = 1 - \frac{1}{r^{\gamma-1}} = 1 - r^{1-\gamma} = 1 - 8^{1-1.4} = 0.565 = 56.5\ \%$

MEP $= \frac{w_{net}}{V_2 - V_1} = \frac{w_{net}}{V_1 - V_{1/r}} = \frac{w_{net}}{V_1(1-\frac{1}{r})}$

Where

$$V_1 = \frac{RT_1}{P_1} = \frac{0.287/290}{100} = 0.832\ m^3/Kg$$

MEP $= \frac{418.17}{0.832\ (1-\frac{1}{8})} = 574\ KPa$

EX 11 :

$COP = \frac{h_1 - h_4}{h_2 - h_1}$

$x = \frac{v_4 - v_l}{v_v - v_l} = \frac{h_4 - h_l}{h_v - h_l}$

$h_4 = (h_v - h_l)\frac{(v_4 - v_l)}{v_v - v_l} + h_l = 93.41\ Kj/Kg$

$COP = \frac{236.04 - 93.41}{284.39 - 236.04} = 2.95$

$x = \frac{m_v}{m_t}$

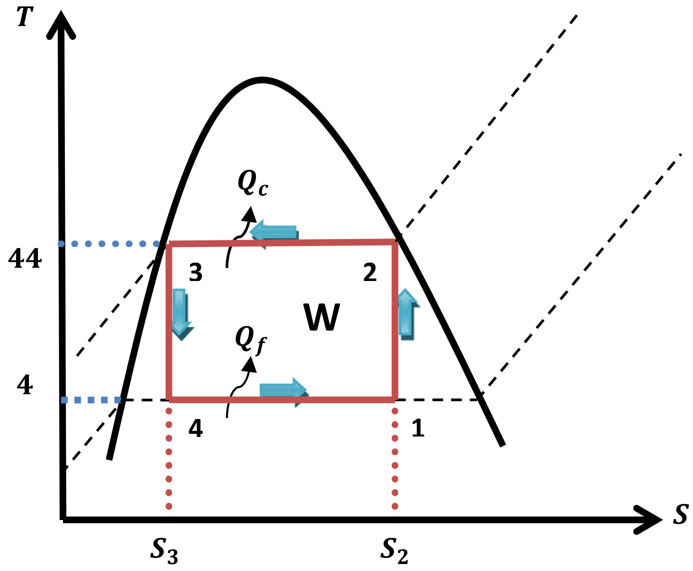
$m_v = x * m_t = \frac{v_4 - v_l}{v_v - v_l} * m_t = 0.3271 * 10 = 3.271\ Kg$

$m_t = m_v + m_l$

$m_l = m_t - m_v$

$V_l = m_l * v_l = (= m_t - m_v) * v_l = 0.005\ m^3$

EX 12 :



$$\varepsilon_{fr.Carnot} = \frac{T_{max}}{T_{max} - T_{min}} = \frac{44 + 273}{(44 - 4)} = 7.925$$

ANNEXE

Table.1. Saturated vapor (temperature)

Vapeur saturée: table de la température

		Volume massique m^3/kg		Énergie interne kJ/kg			Enthalpie kJ/kg			Entropie kJ/kg·K		
Temp. °C T	Pres. kPa P	Liquide sat. v_f	Vapeur sat. v_g	Liquide sat. u_f	Évap. u_{fg}	Vapeur sat. u_g	Liquide sat. h_f	Évap. h_{fg}	Vapeur sat. h_g	Liquide sat. s_f	Évap. s_{fg}	Vapeur sat. s_g
0.01	0.6113	0.001 000	206.14	.00	2375.3	2375.3	.01	2501.3	2501.4	.0000	9.1562	9.1562
5	0.8721	0.001 000	147.12	20.97	2361.3	2382.3	20.98	2489.6	2510.6	.0761	8.9496	9.0257
10	1.2276	0.001 000	106.38	42.00	2347.2	2389.2	42.01	2477.7	2519.8	.1510	8.7498	8.9008
15	1.7051	0.001 001	77.93	62.99	2333.1	2396.1	62.99	2465.9	2528.9	.2245	8.5569	8.7814
20	2.339	0.001 002	57.79	83.95	2319.0	2402.9	83.96	2454.1	2538.1	.2966	8.3706	8.6672
25	3.169	0.001 003	43.36	104.88	2304.9	2409.8	104.89	2442.3	2547.2	.3674	8.1905	8.5580
30	4.246	0.001 004	32.89	125.78	2290.8	2416.6	125.79	2430.5	2556.3	.4369	8.0164	8.4533
35	5.628	0.001 006	25.22	146.67	2276.7	2423.4	146.68	2418.6	2565.3	.5053	7.8478	8.3531
40	7.384	0.001 008	19.52	167.56	2262.6	2430.1	167.57	2406.7	2574.3	.5725	7.6845	8.2570
45	9.593	0.001 010	15.26	188.44	2248.4	2436.8	188.45	2394.8	2583.2	.6387	7.5261	8.1648
50	12.349	0.001 012	12.03	209.32	2234.2	2443.5	209.33	2382.7	2592.1	.7038	7.3725	8.0763
55	15.758	0.001 015	9.568	230.21	2219.9	2450.1	230.23	2370.7	2600.9	.7679	7.2234	7.9913
60	19.940	0.001 017	7.671	251.11	2205.5	2456.6	251.13	2358.5	2609.6	.8312	7.0784	7.9096
65	25.03	0.001 020	6.197	272.02	2191.1	2463.1	272.06	2346.2	2618.3	.8935	6.9375	7.8310
70	31.19	0.001 023	5.042	292.95	2176.6	2469.6	292.98	2333.8	2626.8	.9549	6.8004	7.7553
75	38.58	0.001 026	4.131	313.90	2162.0	2475.9	313.93	2321.4	2635.3	1.0155	6.6669	7.6824
80	47.39	0.001 029	3.407	334.86	2147.4	2482.2	334.91	2308.8	2643.7	1.0753	6.5369	7.6122
85	57.83	0.001 033	2.828	355.84	2132.6	2488.4	355.90	2296.0	2651.9	1.1343	6.4102	7.5445
90	70.14	0.001 036	2.361	376.85	2117.7	2494.5	376.92	2283.2	2660.1	1.1925	6.2866	7.4791
95	84.55	0.001 040	1.982	397.88	2102.7	2500.6	397.96	2270.2	2668.1	1.2500	6.1659	7.4159
100	Mpa ↓ 0.101 35	0.001 044	1.6729	418.94	2087.6	2506.5	419.04	2257.0	2676.1	1.3069	6.0480	7.3549
105	0.120 82	0.001 048	1.4194	440.02	2072.3	2512.4	440.15	2243.7	2683.8	1.3630	5.9328	7.2958
110	0.143 27	0.001 052	1.2102	461.14	2057.0	2518.1	461.30	2230.2	2691.5	1.4185	5.8202	7.2387
115	0.169 06	0.001 056	1.0366	482.30	2041.4	2523.7	482.48	2216.5	2699.0	1.4734	5.7100	7.1833
120	0.198 53	0.001 060	0.8919	503.50	2025.8	2529.3	503.71	2202.6	2706.3	1.5276	5.6020	7.1296
125	0.2321	0.001 065	0.7706	524.74	2009.9	2534.6	524.99	2188.5	2713.5	1.5813	5.4962	7.0775
130	0.2701	0.001 070	0.6685	546.02	1993.9	2539.9	546.31	2174.2	2720.5	1.6344	5.3925	7.0269
135	0.3130	0.001 075	0.5822	567.35	1977.7	2545.0	567.69	2159.6	2727.3	1.6870	5.2907	6.9777
140	0.3613	0.001 080	0.5089	588.74	1961.3	2550.0	589.13	2144.7	2733.9	1.7391	5.1908	6.9299
145	0.4154	0.001 085	0.4463	610.18	1944.7	2554.9	610.63	2129.6	2740.3	1.7907	5.0926	6.8833
150	0.4758	0.001 091	0.3928	631.68	1927.9	2559.5	632.20	2114.3	2746.5	1.8418	4.9960	6.8379
155	0.5431	0.001 096	0.3468	653.24	1910.8	2564.1	653.84	2098.6	2752.4	1.8925	4.9010	6.7935
160	0.6178	0.001 102	0.3071	674.87	1893.5	2568.4	675.55	2082.6	2758.1	1.9427	4.8075	6.7502
165	0.7005	0.001 108	0.2727	696.56	1876.0	2572.5	697.34	2066.2	2763.5	1.9925	4.7153	6.7078
170	0.7917	0.001 114	0.2428	718.33	1858.1	2576.5	719.21	2049.5	2768.7	2.0419	4.6244	6.6663
175	0.8920	0.001 121	0.2168	740.17	1840.0	2580.2	741.17	2032.4	2773.6	2.0909	4.5347	6.6256
180	1.0021	0.001 127	0.194 05	762.09	1821.6	2583.7	763.22	2015.0	2778.2	2.1396	4.4461	6.5857
185	1.1227	0.001 134	0.174 09	784.10	1802.9	2587.0	785.37	1997.1	2782.4	2.1879	4.3586	6.5465
190	1.2544	0.001 141	0.156 54	806.19	1783.8	2590.0	807.62	1978.8	2786.4	2.2359	4.2720	6.5079
195	1.3978	0.001 149	0.141 05	828.37	1764.4	2592.8	829.98	1960.0	2790.0	2.2835	4.1863	6.4698
200	1.5538	0.001 157	0.127 36	850.65	1744.7	2595.3	852.45	1940.7	2793.2	2.3309	4.1014	6.4323
205	1.7230	0.001 164	0.115 21	873.04	1724.5	2597.5	875.04	1921.0	2796.0	2.3780	4.0172	6.3952
210	1.9062	0.001 173	0.104 41	895.53	1703.9	2599.5	897.76	1900.7	2798.5	2.4248	3.9337	6.3585
215	2.104	0.001 181	0.094 79	918.14	1682.9	2601.1	920.62	1879.9	2800.5	2.4714	3.8507	6.3221
220	2.318	0.001 190	0.086 19	940.87	1661.5	2602.4	943.62	1858.5	2802.1	2.5178	3.7683	6.2861
225	2.548	0.001 199	0.078 49	963.73	1639.6	2603.3	966.78	1836.5	2803.3	2.5639	3.6863	6.2503
230	2.795	0.001 209	0.071 58	986.74	1617.2	2603.9	990.12	1813.8	2804.0	2.6099	3.6047	6.2146
235	3.060	0.001 219	0.065 37	1009.89	1594.2	2604.1	1013.62	1790.5	2804.2	2.6558	3.5233	6.1791
240	3.344	0.001 229	0.059 76	1033.21	1570.8	2604.0	1037.32	1766.5	2803.8	2.7015	3.4422	6.1437
245	3.648	0.001 240	0.054 71	1056.71	1546.7	2603.4	1061.23	1741.7	2803.0	2.7472	3.3612	6.1083
250	3.973	0.001 251	0.050 13	1080.39	1522.0	2602.4	1085.36	1716.2	2801.5	2.7927	3.2802	6.0730
255	4.319	0.001 263	0.045 98	1104.28	1496.7	2600.9	1109.73	1689.8	2799.5	2.8383	3.1992	6.0375
260	4.688	0.001 276	0.042 21	1128.39	1470.6	2599.0	1134.37	1662.5	2796.9	2.8838	3.1181	6.0019
265	5.081	0.001 289	0.038 77	1152.74	1443.9	2596.6	1159.28	1634.4	2793.6	2.9294	3.0368	5.9662
270	5.499	0.001 302	0.035 64	1177.36	1416.3	2593.7	1184.51	1605.2	2789.7	2.9751	2.9551	5.9301
275	5.942	0.001 317	0.032 79	1202.25	1387.9	2590.2	1210.07	1574.9	2785.0	3.0208	2.8730	5.8938
280	6.412	0.001 332	0.030 17	1227.46	1358.7	2586.1	1235.99	1543.6	2779.6	3.0668	2.7903	5.8571
285	6.909	0.001 348	0.027 77	1253.00	1328.4	2581.4	1262.31	1511.0	2773.3	3.1130	2.7070	5.8199
290	7.436	0.001 366	0.025 57	1278.92	1297.1	2576.0	1289.07	1477.1	2766.2	3.1594	2.6227	5.7821
295	7.993	0.001 384	0.023 54	1305.2	1264.7	2569.9	1316.3	1441.8	2758.1	3.2062	2.5375	5.7437
300	8.581	0.001 404	0.021 67	1332.0	1231.0	2563.0	1344.0	1404.9	2749.0	3.2534	2.4511	5.7045
305	9.202	0.001 425	0.019 948	1359.3	1195.9	2555.2	1372.4	1366.4	2738.7	3.3010	2.3633	5.6643
310	9.856	0.001 447	0.018 350	1387.1	1159.4	2546.4	1401.3	1326.0	2727.3	3.3493	2.2737	5.6230
315	10.547	0.001 472	0.016 867	1415.5	1121.1	2536.6	1431.0	1283.5	2714.5	3.3982	2.1821	5.5804
320	11.274	0.001 499	0.015 488	1444.6	1080.9	2525.5	1461.5	1238.6	2700.1	3.4480	2.0882	5.5362
330	12.845	0.001 561	0.012 996	1505.3	993.7	2498.9	1525.3	1140.6	2665.9	3.5507	1.8909	5.4417
340	14.586	0.001 638	0.010 797	1570.3	894.3	2464.6	1594.2	1027.9	2622.0	3.6594	1.6763	5.3357
350	16.513	0.001 740	0.008 813	1641.9	776.6	2418.4	1670.6	893.4	2563.9	3.7777	1.4335	5.2112
360	18.651	0.001 893	0.006 945	1725.2	626.3	2351.5	1760.5	720.5	2481.0	3.9147	1.1379	5.0526
370	21.03	0.002 213	0.004 925	1844.0	384.5	2228.5	1890.5	441.6	2332.1	4.1106	.6865	4.7971
374.14	22.09	0.003 155	0.003 155	2029.6	0	2029.6	2099.3	0	2099.3	4.4298	0	4.4298

Table.2. Saturated vapor (pressure)

Vapeur saturée: table de la pression

		Volume massique m³/kg		Énergie interne kJ/kg			Enthalpie kJ/kg			Entropie kJ/kg·K		
Pres. kPa P	Temp. °C T	Liquide sat. v_f	Vapeur sat. v_g	Liquide sat. u_f	Évap. u_{fg}	Vapeur sat. u_g	Liquide sat. h_f	Évap. h_{fg}	Vapeur sat. h_g	Liquide sat. s_f	Évap. s_{fg}	Vapeur sat. s_g
0.6113	0.01	0.001 000	206.14	.00	2375.3	2375.3	.01	2501.3	2501.4	.0000	9.1562	9.1562
1.0	6.98	0.001 000	129.21	29.30	2355.7	2385.0	29.30	2484.9	2514.2	.1059	8.8697	8.9756
1.5	13.03	0.001 001	87.98	54.71	2338.6	2393.3	54.71	2470.6	2525.3	.1957	8.6322	8.8279
2.0	17.50	0.001 001	67.00	73.48	2326.0	2399.5	73.48	2460.0	2533.5	.2607	8.4629	8.7237
2.5	21.08	0.001 002	54.25	88.48	2315.9	2404.4	88.49	2451.6	2540.0	.3120	8.3311	8.6432
3.0	24.08	0.001 003	45.67	101.04	2307.5	2408.5	101.05	2444.5	2545.5	.3545	8.2231	8.5776
4.0	28.96	0.001 004	34.80	121.45	2293.7	2415.2	121.46	2432.9	2554.4	.4226	8.0520	8.4746
5.0	32.88	0.001 005	28.19	137.81	2282.7	2420.5	137.82	2423.7	2561.5	.4764	7.9187	8.3951
7.5	40.29	0.001 008	19.24	168.78	2261.7	2430.5	168.79	2406.0	2574.8	.5764	7.6750	8.2515
10	45.81	0.001 010	14.67	191.82	2246.1	2437.9	191.83	2392.8	2584.7	.6493	7.5009	8.1502
15	53.97	0.001 014	10.02	225.92	2222.8	2448.7	225.94	2373.1	2599.1	.7549	7.2536	8.0085
20	60.06	0.001 017	7.649	251.38	2205.4	2456.7	251.40	2358.3	2609.7	.8320	7.0766	7.9085
25	64.97	0.001 020	6.204	271.90	2191.2	2463.1	271.93	2346.3	2618.2	.8931	6.9383	7.8314
30	69.10	0.001 022	5.229	289.20	2179.2	2468.4	289.23	2336.1	2625.3	.9439	6.8247	7.7686
40	75.87	0.001 027	3.993	317.53	2159.5	2477.0	317.58	2319.2	2636.8	1.0259	6.6441	7.6700
50	81.33	0.001 030	3.240	340.44	2143.4	2483.9	340.49	2305.4	2645.9	1.0910	6.5029	7.5939
75	91.78	0.001 037	2.217	384.31	2112.4	2496.7	384.39	2278.6	2663.0	1.2130	6.2434	7.4564
MPa												
0.100	99.63	0.001 043	1.6940	417.36	2088.7	2506.1	417.46	2258.0	2675.5	1.3026	6.0568	7.3594
0.125	105.99	0.001 048	1.3749	444.19	2069.3	2513.5	444.32	2241.0	2685.4	1.3740	5.9104	7.2844
0.150	111.37	0.001 053	1.1593	466.94	2052.7	2519.7	467.11	2226.5	2693.6	1.4336	5.7897	7.2233
0.175	116.06	0.001 057	1.0036	486.80	2038.1	2524.9	486.99	2213.6	2700.6	1.4849	5.6868	7.1717
0.200	120.23	0.001 061	0.8857	504.49	2025.0	2529.5	504.70	2201.9	2706.7	1.5301	5.5970	7.1271
0.225	124.00	0.001 064	0.7933	520.47	2013.1	2533.6	520.72	2191.3	2712.1	1.5706	5.5173	7.0878
0.250	127.44	0.001 067	0.7187	535.10	2002.1	2537.2	535.37	2181.5	2716.9	1.6072	5.4455	7.0527
0.275	130.60	0.001 070	0.6573	548.59	1991.9	2540.5	548.89	2172.4	2721.3	1.6408	5.3801	7.0209
0.300	133.55	0.001 073	0.6058	561.15	1982.4	2543.6	561.47	2163.8	2725.3	1.6718	5.3201	6.9919
0.325	136.30	0.001 076	0.5620	572.90	1973.5	2546.4	573.25	2155.8	2729.0	1.7006	5.2646	6.9652
0.350	138.88	0.001 079	0.5243	583.95	1965.0	2548.9	584.33	2148.1	2732.4	1.7275	5.2130	6.9405
0.375	141.32	0.001 081	0.4914	594.40	1956.9	2551.3	594.81	2140.8	2735.6	1.7528	5.1647	6.9175
0.40	143.63	0.001 084	0.4625	604.31	1949.3	2553.6	604.74	2133.8	2738.6	1.7766	5.1193	6.8959
0.45	147.93	0.001 088	0.4140	622.77	1934.9	2557.6	623.25	2120.7	2743.9	1.8207	5.0359	6.8565
0.50	151.86	0.001 093	0.3749	639.68	1921.6	2561.2	640.23	2108.5	2748.7	1.8607	4.9606	6.8213
0.55	155.48	0.001 097	0.3427	655.32	1909.2	2564.5	655.93	2097.0	2753.0	1.8973	4.8920	6.7893
0.60	158.85	0.001 101	0.3157	669.90	1897.5	2567.4	670.56	2086.3	2756.8	1.9312	4.8288	6.7600
0.65	162.01	0.001 104	0.2927	683.56	1886.5	2570.1	684.28	2076.0	2760.3	1.9627	4.7703	6.7331
0.70	164.97	0.001 108	0.2729	696.44	1876.1	2572.5	697.22	2066.3	2763.5	1.9922	4.7158	6.7080
0.75	167.78	0.001 112	0.2556	708.64	1866.1	2574.7	709.47	2057.0	2766.4	2.0200	4.6647	6.6847
0.80	170.43	0.001 115	0.2404	720.22	1856.6	2576.8	721.11	2048.0	2769.1	2.0462	4.6166	6.6628
0.85	172.96	0.001 118	0.2270	731.27	1847.4	2578.7	732.22	2039.4	2771.6	2.0710	4.5711	6.6421
0.90	175.38	0.001 121	0.2150	741.83	1838.6	2580.5	742.83	2031.1	2773.9	2.0946	4.5280	6.6226
0.95	177.69	0.001 124	0.2042	751.95	1830.2	2582.1	753.02	2023.1	2776.1	2.1172	4.4869	6.6041
1.00	179.91	0.001 127	0.194 44	761.68	1822.0	2583.6	762.81	2015.3	2778.1	2.1387	4.4478	6.5865
1.10	184.09	0.001 133	0.177 53	780.09	1806.3	2586.4	781.34	2000.4	2781.7	2.1792	4.3744	6.5536
1.20	187.99	0.001 139	0.163 33	797.29	1791.5	2588.8	798.65	1986.2	2784.8	2.2166	4.3067	6.5233
1.30	191.64	0.001 144	0.151 25	813.44	1777.5	2591.0	814.93	1972.7	2787.6	2.2515	4.2438	6.4953
1.40	195.07	0.001 149	0.140 84	828.70	1764.1	2592.8	830.30	1959.7	2790.0	2.2842	4.1850	6.4693
1.50	198.32	0.001 154	0.131 77	843.16	1751.3	2594.5	844.89	1947.3	2792.2	2.3150	4.1298	6.4448
1.75	205.76	0.001 166	0.113 49	876.46	1721.4	2597.8	878.50	1917.9	2796.4	2.3851	4.0044	6.3896
2.00	212.42	0.001 177	0.099 63	906.44	1693.8	2600.3	908.79	1890.7	2799.5	2.4474	3.8935	6.3409
2.25	218.45	0.001 187	0.088 75	933.83	1668.2	2602.0	936.49	1865.2	2801.7	2.5035	3.7937	6.2972
2.5	223.99	0.001 197	0.079 98	959.11	1644.0	2603.1	962.11	1841.0	2803.1	2.5547	3.7028	6.2575
3.0	233.90	0.001 217	0.066 68	1004.78	1599.3	2604.1	1008.42	1795.7	2804.2	2.6457	3.5412	6.1869
3.5	242.60	0.001 235	0.057 07	1045.43	1558.3	2603.7	1049.75	1753.7	2803.4	2.7253	3.4000	6.1253
4	250.40	0.001 252	0.049 78	1082.31	1520.0	2602.3	1087.31	1714.1	2801.4	27964	3.2737	6.0701
5	263.99	0.001 286	0.039 44	1147.81	1449.3	2597.1	1154.23	1640.1	2794.3	2.9202	3.0532	5.9734
6	275.64	0.001 319	0.032 44	1205.44	1384.3	2589.7	1213.35	1571.0	2784.3	3.0267	2.8625	5.8892
7	285.88	0.001 351	0.027 37	1257.55	1323.0	2580.5	1267.00	1505.1	2772.1	3.1211	2.6922	5.8133
8	295.06	0.001 384	0.023 52	1305.57	1264.2	2569.8	1316.64	1441.3	2758.0	3.2068	2.5364	5.7432
9	303.40	0.001 418	0.020 48	1350.51	1207.3	2557.8	1363.26	1378.9	2742.1	3.2858	2.3915	5.6772
10	311.06	0.001 452	0.018 026	1393.04	1151.4	2544.4	1407.56	1317.1	2724.7	3.3596	2.2544	5.6141
11	318.15	0.001 489	0.015 987	1433.7	1096.0	2529.8	1450.1	1255.5	2705.6	3.4295	2.1233	5.5527
12	324.75	0.001 527	0.014 263	1473.0	1040.7	2513.7	1491.3	1193.6	2684.9	3.4962	1.9962	5.4924
13	330.93	0.001 567	0.012 780	1511.1	985.0	2496.1	1531.5	1130.7	2662.2	3.5606	1.8718	5.4323
14	336.75	0.001 611	0.011 485	1548.6	928.2	2476.8	1571.1	1066.5	2637.6	3.6232	1.7485	5.3717
15	342.24	0.001 658	0.010 337	1585.6	869.8	2455.5	1610.5	1000.0	2610.5	3.6848	1.6249	5.3098
16	347.44	0.001 711	0.009 306	1622.7	809.0	2431.7	1650.1	930.6	2580.6	3.7461	1.4994	5.2455
17	352.37	0.001 770	0.008 364	1660.2	744.8	2405.0	1690.3	856.9	2547.2	3.8079	1.3698	5.1777
18	357.06	0.001 840	0.007 489	1698.9	675.4	2374.3	1732.0	777.1	2509.1	3.8715	1.2329	5.1044
19	361.54	0.001 924	0.006 657	1739.9	598.1	2338.1	1776.5	688.0	2464.5	3.9388	1.0839	5.0228
20	365.81	0.002 036	0.005 834	1785.6	507.5	2293.0	1826.3	583.4	2409.7	4.0139	.9130	4.9269
21	369.89	0.002 207	0.004 952	1842.1	388.5	2230.6	1888.4	446.2	2334.6	4.1075	.6938	4.8013
22	373.80	0.002 742	0.003 568	1961.9	125.2	2087.1	2022.2	143.4	2165.6	4.3110	.2216	4.5327
22.09	374.14	0.003 155	0.003 155	2029.6	0	2029.6	2099.3	0	2099.3	4.4298	0	4.4298

Table.3. Super heated vapor

Vapeur surchauffée

T	v	u	h	s	v	u	h	s	v	u	h	s
	P = .010 MPa (45.81)				P = .050 MPa (81.33)				P = .10 MPa (99.63)			
Sat.	14.674	2437.9	2584.7	8.1502	3.240	2483.9	2645.9	7.5939	1.6940	2506.1	2675.5	7.3594
50	14.869	2443.9	2592.6	8.1749								
100	17.196	2515.5	2687.5	8.4479	3.418	2511.6	2682.5	7.6947	1.6958	2506.7	2676.2	7.3614
150	19.512	2587.9	2783.0	8.6882	3.889	2585.6	2780.1	7.9401	1.9364	2582.8	2776.4	7.6134
200	21.825	2661.3	2879.5	8.9038	4.356	2659.9	2877.7	8.1580	2.172	2658.1	2875.3	7.8343
250	24.136	2736.0	2977.3	9.1002	4.820	2735.0	2976.0	8.3556	2.406	2733.7	2974.3	8.0333
300	26.445	2812.1	3076.5	9.2813	5.284	2811.3	3075.5	8.5373	2.639	2810.4	3074.3	8.2158
400	31.063	2968.9	3279.6	9.6077	6.209	2968.5	3278.9	8.8642	3.103	2967.9	3278.2	8.5435
500	35.679	3132.3	3489.1	9.8978	7.134	3132.0	3488.7	9.1546	3.565	3131.6	3488.1	8.8342
600	40.295	3302.5	3705.4	10.1608	8.057	3302.2	3705.1	9.4178	4.028	3301.9	3704.7	9.0976
700	44.911	3479.6	3928.7	10.4028	8.981	3479.4	3928.5	9.6599	4.490	3479.2	3928.2	9.3398
800	49.526	3663.8	4159.0	10.6281	9.904	3663.6	4158.9	9.8852	4.952	3663.5	4158.6	9.5652
900	54.141	3855.0	4396.4	10.8396	10.828	3854.9	4396.3	10.0967	5.414	3854.8	4396.1	9.7767
1000	58.757	4053.0	4640.6	11.0393	11.751	4052.9	4640.5	10.2964	5.875	4052.8	4640.3	9.9764
1100	63.372	4257.5	4891.2	11.2287	12.674	4257.4	4891.1	10.4859	6.337	4257.3	4891.0	10.1659
1200	67.987	4467.9	5147.8	11.4091	13.597	4467.8	5147.7	10.6662	6.799	4467.7	5147.6	10.3463
1300	72.602	4683.7	5409.7	11.5811	14.521	4683.6	5409.6	10.8382	7.260	4683.5	5409.5	10.5183
	P = .20 MPa (120.23)				P = .30 MPa (133.55)				P = .40 MPa (143.63)			
Sat.	.8857	2529.5	2706.7	7.1272	.6058	2543.6	2725.3	6.9919	.4625	2553.6	2738.6	6.8959
150	.9596	2576.9	2768.8	7.2795	.6339	2570.8	2761.0	7.0778	.4708	2564.5	2752.8	6.9299
200	1.0803	2654.4	2870.5	7.5066	.7163	2650.7	2865.6	7.3115	.5342	2646.8	2860.5	7.1706
250	1.1988	2731.2	2971.0	7.7086	.7964	2728.7	2967.6	7.5166	.5951	2726.1	2964.2	7.3789
300	1.3162	2808.6	3071.8	7.8926	.8753	2806.7	3069.3	7.7022	.6548	2804.8	3066.8	7.5662
400	1.5493	2966.7	3276.6	8.2218	1.0315	2965.6	3275.0	8.0330	.7726	2964.4	3273.4	7.8985
500	1.7814	3130.8	3487.1	8.5133	1.1867	3130.0	3486.0	8.3251	.8893	3129.2	3484.9	8.1913
600	2.013	3301.4	3704.0	8.7770	1.3414	3300.8	3703.2	8.5892	1.0055	3300.2	3702.4	8.4558
700	2.244	3478.8	3927.6	9.0194	1.4957	3478.4	3927.1	8.8319	1.1215	3477.9	3926.5	8.6987
800	2.475	3663.1	4158.2	9.2449	1.6499	3662.9	4157.8	9.0576	1.2372	3662.4	4157.3	8.9244
900	2.706	3854.5	4395.8	9.4566	1.8041	3854.2	4395.4	9.2692	1.3529	3853.9	4395.1	9.1362
1000	2.937	4052.5	4640.0	9.6563	1.9581	4052.3	4639.7	9.4690	1.4685	4052.0	4639.4	9.3360
1100	3.168	4257.0	4890.7	9.8458	2.1121	4256.8	4890.4	9.6585	1.5840	4256.5	4890.2	9.5256
1200	3.399	4467.5	5147.3	10.0262	2.2661	4467.2	5147.1	9.8389	1.6996	4467.0	5146.8	9.7060
1300	3.630	4683.2	5409.3	10.1982	2.4201	4683.0	5409.0	10.0110	1.8151	4682.8	5408.8	9.8780
	P = .50 MPa (151.86)				P = .60 MPa (158.85)				P = .80 MPa (170.43)			
Sat.	.3749	2561.2	2748.7	6.8213	.3157	2567.4	2756.8	6.7600	.2404	2576.8	2769.1	6.6628
200	.4249	2642.9	2855.4	7.0592	.3520	2638.9	2850.1	6.9665	.2608	2630.6	2839.3	6.8158
250	.4744	2723.5	2960.7	7.2709	.3938	2720.9	2957.2	7.1816	.2931	2715.5	2950.0	7.0384
300	.5226	2802.9	3064.2	7.4599	.4344	2801.0	3061.6	7.3724	.3241	2797.2	3056.5	7.2328
350	.5701	2882.6	3167.7	7.6329	.4742	2881.2	3165.7	7.5464	.3544	2878.2	3161.7	7.4089
400	.6173	2963.2	3271.9	7.7938	.5137	2962.1	3270.3	7.7079	.3843	2959.7	3267.1	7.5716
500	.7109	3128.4	3483.9	8.0873	.5920	3127.6	3482.8	8.0021	.4433	3126.0	3480.6	7.8673
600	.8041	3299.6	3701.7	8.3522	.6697	3299.1	3700.9	8.2674	.5018	3297.9	3699.4	8.1333
700	.8969	3477.5	3925.9	8.5952	.7472	3477.0	3925.3	8.5107	.5601	3476.2	3924.2	8.3770
800	.9896	3662.1	4156.9	8.8211	.8245	3661.8	4156.5	8.7367	.6181	3661.1	4155.6	8.6033
900	1.0822	3853.6	4394.7	9.0329	.9017	3853.4	4394.4	8.9486	.6761	3852.8	4393.7	8.8153
1000	1.1747	4051.8	4639.1	9.2328	.9788	4051.5	4638.8	9.1485	.7340	4051.0	4638.2	9.0153
1100	1.2672	4256.3	4889.9	9.4224	1.0559	4256.1	4889.6	9.3381	.7919	4255.6	4889.1	9.2050
1200	1.3596	4466.8	5146.6	9.6029	1.1330	4466.5	5146.3	9.5185	.8497	4466.1	5145.9	9.3855
1300	1.4521	4682.5	5408.6	9.7749	1.2101	4682.3	5408.3	9.6906	.9076	4681.8	5407.9	9.5575
	P = 1.00 MPa (179.91)				P = 1.20 MPa (187.99)				P = 1.40 MPa (195.07)			
Sat.	.194 44	2583.6	2778.1	6.5865	.163 33	2588.8	2784.8	6.5233	.140 84	2592.8	2790.0	6.4693
200	.2060	2621.9	2827.9	6.6940	.169 30	2612.8	2815.9	6.5898	.143 02	2603.1	2803.3	6.4975
250	.2327	2709.9	2942.6	6.9247	.192 34	2704.2	2935.0	6.8294	.163 50	2698.3	2927.2	6.7467
300	.2579	2793.2	3051.2	7.1229	.2138	2789.2	3045.8	7.0317	.182 28	2785.2	3040.4	6.9534
350	.2825	2875.2	3157.7	7.3011	.2345	2872.2	3153.6	7.2121	.2003	2869.2	3149.5	7.1360
400	.3066	2957.3	3263.9	7.4651	.2548	2954.9	3260.7	7.3774	.2178	2952.5	3257.5	7.3026
500	.3541	3124.4	3478.5	7.7622	.2946	3122.8	3476.3	7.6759	.2521	3121.1	3474.1	7.6027
600	.4011	3296.8	3697.9	8.0290	.3339	3295.6	3696.3	7.9435	.2860	3294.4	3694.8	7.8710
700	.4478	3475.3	3923.1	8.2731	.3729	3474.4	3922.0	8.1881	.3195	3473.6	3920.8	8.1160
800	.4943	3660.4	4154.7	8.4996	.4118	3659.7	4153.8	8.4148	.3528	3659.0	4153.0	8.3431
900	.5407	3852.2	4392.9	8.7118	.4505	3851.6	4392.2	8.6272	.3861	3851.1	4391.5	8.5556
1000	.5871	4050.5	4637.6	8.9119	.4892	4050.0	4637.0	8.8274	.4192	4049.5	4636.4	8.7559
1100	.6335	4255.1	4888.6	9.1017	.5278	4254.6	4888.0	9.0172	.4524	4254.1	4887.5	8.9457
1200	.6798	4465.6	5145.4	9.2822	.5665	4465.1	5144.9	9.1977	.4855	4464.7	5144.4	9.1262
1300	.7261	4681.3	5407.4	9.4543	.6051	4680.9	5407.0	9.3698	.5186	4680.4	5406.5	9.2984
	P = 1.60 MPa (201.41)				P = 1.80 MPa (207.15)				P = 2.00 MPa (212.42)			
Sat.	.123 80	2596.0	2794.0	6.4218	.110 42	2598.4	2797.1	6.3794	.099 63	2600.3	2799.5	6.3409
225	.132 87	2644.7	2857.3	6.5518	.116 73	2636.6	2846.7	6.4808	.103 77	2628.3	2835.8	6.4147
250	.141 84	2692.3	2919.2	6.6732	.124 97	2686.0	2911.0	6.6066	.111 44	2679.6	2902.5	6.5453
300	.158 62	2781.1	3034.8	6.8844	.140 21	2776.9	3029.2	6.8226	.125 47	2772.6	3023.5	6.7664
350	.174 56	2866.1	3145.4	7.0694	.154 57	2863.0	3141.2	7.0100	.138 57	2859.8	3137.0	6.9563
400	.190 05	2950.1	3254.2	7.2374	.168 47	2947.7	3250.9	7.1794	.151 20	2945.2	3247.6	7.1271
500	.2203	3119.5	3472.0	7.5390	.195 50	3117.9	3469.8	7.4825	.175 68	3116.2	3467.6	7.4317
600	.2500	3293.3	3693.2	7.8080	.2220	3292.1	3691.7	7.7523	.199 60	3290.9	3690.1	7.7024
700	.2794	3472.7	3919.7	8.0535	.2482	3471.8	3918.5	7.9983	.2232	3470.9	3917.4	7.9487
800	.3086	3658.3	4152.1	8.2808	.2742	3657.6	4151.2	8.2258	.2467	3657.0	4150.3	8.1765
900	.3377	3850.5	4390.8	8.4935	.3001	3849.9	4390.1	8.4386	.2700	3849.3	4389.4	8.3895
1000	.3668	4049.0	4635.8	8.6938	.3260	4048.5	4635.2	8.6391	.2933	4048.0	4634.6	8.5901
1100	.3958	4253.7	4887.0	8.8837	.3518	4253.2	4886.4	8.8290	.3166	4252.7	4885.9	8.7800
1200	.4248	4464.2	5143.9	9.0643	.3776	4463.7	5143.4	9.0096	.3398	4463.3	5142.9	8.9607
1300	.4538	4679.9	5406.0	9.2364	.4034	4679.5	5405.6	9.1818	.3631	4679.0	5405.1	9.1329

Vapeur surchauffée

T	v	u	h	s	v	u	h	s	v	u	h	s
	P = 2.50 MPa (223.99)				**P = 3.00 MPa (233.90)**				**P = 3.50 MPa (242.60)**			
Sat.	.079 98	2603.1	2803.1	6.2575	.066 68	2604.1	2804.2	6.1869	.057 07	2603.7	2803.4	6.1253
225	.080 27	2605.6	2806.3	6.2639								
250	.087 00	2662.6	2880.1	6.4085	.070 58	2644.0	2855.8	6.2872	.058 72	2623.7	2829.2	6.1749
300	.098 90	2761.6	3008.8	6.6438	.081 14	2750.1	2993.5	6.5390	.068 42	2738.0	2977.5	6.4461
350	.109 76	2851.9	3126.3	6.8403	.090 53	2843.7	3115.3	6.7428	.076 78	2835.3	3104.0	6.6579
400	.120 10	2939.1	3239.3	7.0148	.099 36	2932.8	3230.9	6.9212	.084 53	2926.4	3222.3	6.8405
450	.130 14	3025.5	3350.8	7.1746	.107 87	3020.4	3344.0	7.0834	.091 96	3015.3	3337.2	7.0052
500	.139 98	3112.1	3462.1	7.3234	.116 19	3108.0	3456.5	7.2338	.099 18	3103.0	3450.9	7.1572
600	.159 30	3288.0	3686.3	7.5960	.132 43	3285.0	3682.3	7.5085	.113 24	3282.1	3678.4	7.4339
700	.178 32	3468.7	3914.5	7.8435	.148 38	3466.5	3911.7	7.7571	.126 99	3464.3	3908.8	7.6837
800	.197 16	3655.3	4148.2	8.0720	.164 14	3653.5	4145.9	7.9862	.140 56	3651.8	4143.7	7.9134
900	.215 90	3847.9	4387.6	8.2853	.179 80	3846.5	4385.9	8.1999	.154 02	3845.0	4384.1	8.1276
1000	.2346	4046.7	4633.1	8.4861	.195 41	4045.4	4631.6	8.4009	.167 43	4044.1	4630.1	8.3288
1100	.2532	4251.5	4884.6	8.6762	.210 98	4250.3	4883.3	8.5912	.180 80	4249.2	4881.9	8.5192
1200	.2718	4462.1	5141.7	8.8569	.226 52	4460.9	5140.5	8.7720	.194 15	4459.8	5139.3	8.7000
1300	.2905	4677.8	5404.0	9.0291	.242 06	4676.6	5402.8	8.9442	.207 49	4675.5	5401.7	8.8723
	P = 4.0 MPa (250.40)				**P = 4.5 MPa (257.49)**				**P = 5.0 MPa (263.99)**			
Sat.	.049 78	2602.3	2801.4	6.0701	.044 06	2600.1	2798.3	6.0198	.039 44	2597.1	2794.3	5.9734
275	.054 57	2667.9	2886.2	6.2285	.047 30	2650.3	2863.2	6.1401	.041 41	2631.3	2838.3	6.0544
300	.058 84	2725.3	2960.7	6.3615	.051 35	2712.0	2943.1	6.2828	.045 32	2698.0	2924.5	6.2084
350	.066 45	2826.7	3092.5	6.5821	.058 40	2817.8	3080.6	6.5131	.051 94	2808.7	3068.4	6.4493
400	.073 41	2919.9	3213.6	6.7690	.064 75	2913.3	3204.7	6.7047	.057 81	2906.6	3195.7	6.6459
450	.080 02	3010.2	3330.3	6.9363	.070 74	3005.0	3323.3	6.8746	.063 30	2999.7	3316.2	6.8186
500	.086 43	3099.5	3445.3	7.0901	.076 51	3095.3	3439.6	7.0301	.068 57	3091.0	3433.8	6.9759
600	.098 85	3279.1	3674.4	7.3688	.087 65	3276.0	3670.5	7.3110	.078 69	3273.0	3666.5	7.2589
700	.110 95	3462.1	3905.9	7.6198	.098 47	3459.9	3903.0	7.5631	.088 49	3457.6	3900.1	7.5122
800	.122 87	3650.0	4141.5	7.8502	.109 11	3648.3	4139.3	7.7942	.098 11	3646.6	4137.1	7.7440
900	.134 69	3843.6	4382.3	8.0647	.119 65	3842.2	4380.6	8.0091	.107 62	3840.7	4378.8	7.9593
1000	.146 45	4042.9	4628.7	8.2662	.130 13	4041.6	4627.2	8.2108	.117 07	4040.4	4625.7	8.1612
1100	.158 17	4248.0	4880.6	8.4567	.140 56	4246.8	4879.3	8.4015	.126 48	4245.6	4878.0	8.3520
1200	.169 87	4458.6	5138.1	8.6376	.150 98	4457.5	5136.9	8.5825	.135 87	4456.3	5135.7	8.5331
1300	.181 56	4674.3	5400.5	8.8100	.161 39	4673.1	5399.4	8.7549	.145 26	4672.0	5398.2	8.7055
	P = 6.0 MPa (275.64)				**P = 7.0 MPa (285.88)**				**P = 8.0 MPa (295.06)**			
Sat.	.032 44	2589.7	2784.3	5.8892	.027 37	2580.5	2772.1	5.8133	.023 52	2569.8	2758.0	5.7432
300	.036 16	2667.2	2884.2	6.0674	.029 47	2632.2	2838.4	5.9305	.024 26	2590.9	2785.0	5.7906
350	.042 23	2789.6	3043.0	6.3335	.035 24	2769.4	3016.0	6.2283	.029 95	2747.7	2987.3	6.1301
400	.047 39	2892.9	3177.2	6.5408	.039 93	2878.6	3158.1	6.4478	.034 32	2863.8	3138.3	6.3634
450	.052 14	2988.9	3301.8	6.7193	.044 16	2978.0	3287.1	6.6327	.038 17	2966.7	3272.0	6.5551
500	.056 65	3082.2	3422.2	6.8803	.048 14	3073.4	3410.3	6.7975	.041 75	3064.3	3398.3	6.7240
550	.061 01	3174.6	3540.6	7.0288	.051 95	3167.2	3530.9	6.9486	.045 16	3159.8	3521.0	6.8778
600	.065 25	3266.9	3658.4	7.1677	.055 65	3260.7	3650.3	7.0894	.048 45	3254.4	3642.0	7.0206
700	.073 52	3453.1	3894.2	7.4234	.062 83	3448.5	3888.3	7.3476	.054 81	3443.9	3882.4	7.2812
800	.081 60	3643.1	4132.7	7.6566	.069 81	3639.5	4128.2	7.5822	.060 97	3636.0	4123.8	7.5173
900	.089 58	3837.8	4375.3	7.8727	.076 69	3835.0	4371.8	7.7991	.067 02	3832.1	4368.3	7.7351
1000	.097 49	4037.8	4622.7	8.0751	.083 50	4035.3	4619.8	8.0020	.073 01	4032.8	4616.9	7.9384
1100	.105 36	4243.3	4875.4	8.2661	.090 27	4240.9	4872.8	8.1933	.078 96	4238.6	4870.3	8.1300
1200	.113 21	4454.0	5133.3	8.4474	.097 03	4451.7	5130.9	8.3747	.084 89	4449.5	5128.5	8.3115
1300	.121 06	4669.6	5396.0	8.6199	.103 77	4667.3	5393.7	8.5473	.090 80	4665.0	5391.5	8.4842
	P = 9.0 MPa (303.40)				**P = 10.0 MPa (311.06)**				**P = 12.5 MPa (327.89)**			
Sat.	.020 48	2557.8	2742.1	5.6772	.018 026	2544.4	2724.7	5.6141	.013 495	2505.1	2673.8	5.4624
325	.023 27	2646.6	2856.0	5.8712	.019 861	2610.4	2809.1	5.7568				
350	.025 80	2724.4	2956.6	6.0361	.022 42	2699.2	2923.4	5.9443	.016 126	2624.6	2826.2	5.7118
400	.029 93	2848.4	3117.8	6.2854	.026 41	2832.4	3096.5	6.2120	.020 00	2789.3	3039.3	6.0417
450	.033 50	2955.2	3256.6	6.4844	.029 75	2943.4	3240.9	6.4190	.022 99	2912.5	3199.8	6.2719
500	.036 77	3055.2	3386.1	6.6576	.032 79	3045.8	3373.7	6.5966	.025 60	3021.7	3341.8	6.4618
550	.039 87	3152.2	3511.0	6.8142	.035 64	3144.6	3500.9	6.7561	.028 01	3125.0	3475.2	6.6290
600	.042 85	3248.1	3633.7	6.9589	.038 37	3241.7	3625.3	6.9029	.030 29	3225.4	3604.0	6.7810
650	.045 74	3343.6	3755.3	7.0943	.041 01	3338.2	3748.2	7.0398	.032 48	3324.4	3730.4	6.9218
700	.048 57	3439.3	3876.5	7.2221	.043 58	3434.7	3870.5	7.1687	.034 60	3422.9	3855.3	7.0536
800	.054 09	3632.5	4119.3	7.4596	.048 59	3628.9	4114.8	7.4077	.038 69	3620.0	4103.6	7.2965
900	.059 50	3829.2	4364.8	7.6783	.053 49	3826.3	4361.2	7.6272	.042 67	3819.1	4352.5	7.5182
1000	.064 85	4030.3	4614.0	7.8821	.058 32	4027.8	4611.0	7.8315	.046 58	4021.6	4603.8	7.7237
1100	.070 16	4236.3	4867.7	8.0740	.063 12	4234.0	4865.1	8.0237	.050 45	4228.2	4858.8	7.9165
1200	.075 44	4447.2	5126.2	8.2556	.067 89	4444.9	5123.8	8.2055	.054 30	4439.3	5118.0	8.0987
1300	.080 72	4662.7	5389.2	8.4284	.072 65	4460.5	5387.0	8.3783	.058 13	4654.8	5381.4	8.2717
	P = 15.0 MPa (342.24)				**P = 17.5 MPa (354.75)**				**P = 20.0 MPa (365.81)**			
Sat.	.010 337	2455.5	2610.5	5.3098	.007 920	2390.2	2528.8	5.1419	.005 834	2293.0	2409.7	4.9269
350	.011 470	2520.4	2692.4	5.4421								
400	.015 649	2740.7	2975.5	5.8811	.012 447	2685.0	2902.9	5.7213	.009 942	2619.3	2818.1	5.5540
450	.018 445	2879.5	3156.2	6.1404	.015 174	2844.2	3109.7	6.0184	.012 695	2806.2	3060.1	5.9017
500	.020 80	2996.6	3308.6	6.3443	.017 358	2970.3	3274.1	6.2383	.014 768	2942.9	3238.2	6.1401
550	.022 93	3104.7	3448.6	6.5199	.019 288	3083.9	3421.4	6.4230	.016 555	3062.4	3393.5	6.3348
600	.024 91	3208.6	3582.3	6.6776	.021 06	3191.5	3560.1	6.5866	.018 178	3174.0	3537.6	6.5048
650	.026 80	3310.3	3712.3	6.8224	.022 74	3296.0	3693.9	6.7357	.019 693	3281.4	3675.3	6.6582
700	.028 61	3410.9	3840.1	6.9572	.024 34	3398.7	3824.6	6.8736	.021 13	3386.4	3809.0	6.7993
800	.032 10	3610.9	4092.4	7.2040	.027 38	3601.8	4081.1	7.1244	.023 85	3592.7	4069.7	7.0544
900	.035 46	3811.9	4343.8	7.4279	.030 31	3804.7	4335.1	7.3507	.026 45	3797.5	4326.4	7.2830
1000	.038 75	4015.4	4596.6	7.6348	.033 16	4009.3	4589.5	7.5589	.028 97	4003.1	4582.5	7.4925
1100	.042 00	4222.6	4852.6	7.8283	.035 97	4216.9	4846.4	7.7531	.031 45	4211.3	4840.2	7.6874
1200	.045 23	4433.8	5112.3	8.0108	.038 76	4428.3	5106.6	7.9360	.033 91	4422.8	5101.0	7.8707
1300	.048 45	4649.1	5376.0	8.1840	.041 54	4643.5	5370.5	8.1093	.036 36	4638.0	5365.1	8.0442

Vapeur surchauffée

T	v	u	h	s	v	u	h	s	v	u	h	s
	P = 25.0 MPa				P = 30.0 MPa				P = 35.0 MPa			
375	.001 973 1	1798.7	1848.0	4.0320	.001 789 2	1737.8	1791.5	3.9305	.001 700 3	1702.9	1762.4	3.8722
400	.006 004	2430.1	2580.2	5.1418	.002 790	2067.4	2151.1	4.4728	.002 100	1914.1	1987.6	4.2126
425	.007 881	2609.2	2806.3	5.4723	.005 303	2455.1	2614.2	5.1504	.003 428	2253.4	2373.4	4.7747
450	.009 162	2720.7	2949.7	5.6744	.006 735	2619.3	2821.4	5.4424	.004 961	2498.7	2672.4	5.1962
500	.011 123	2884.3	3162.4	5.9592	.008 678	2820.7	3081.1	5.7905	.006 927	2751.9	2994.4	5.6282
550	.012 724	3017.5	3335.6	6.1765	.010 168	2970.3	3275.4	6.0342	.008 345	2921.0	3213.0	5.9026
600	.014 137	3137.9	3491.4	6.3602	.011 446	3100.5	3443.9	6.2331	.009 527	3062.0	3395.5	6.1179
650	.015 433	3251.6	3637.4	6.5229	.012 596	3221.0	3598.9	6.4058	.010 575	3189.8	3559.9	6.3010
700	.016 646	3361.3	3777.5	6.6707	.013 661	3335.8	3745.6	6.5606	.011 533	3309.8	3713.5	6.4631
800	.018 912	3574.3	4047.1	6.9345	.015 623	3555.5	4024.2	6.8332	.013 278	3536.7	4001.5	6.7450
900	.021 045	3783.0	4309.1	7.1680	.017 448	3768.5	4291.9	7.0718	.014 883	3754.0	4274.9	6.9886
1000	.023 10	3990.9	4568.5	7.3802	.019 196	3978.8	4554.7	7.2867	.016 410	3966.7	4541.1	7.2064
1100	.025 12	4200.2	4828.2	7.5765	.020 903	4189.2	4816.3	7.4845	.017 895	4178.3	4804.6	7.4057
1200	.027 11	4412.0	5089.9	7.7605	.022 589	4401.3	5079.0	7.6692	.019 360	4390.7	5068.3	7.5910
1300	.029 10	4626.9	5354.4	7.9342	.024 266	4616.0	5344.0	7.8432	.020 815	4605.1	5333.6	7.7653
	P = 40.0 MPa				P = 50.0 MPa				P = 60.0 MPa			
375	.001 640 7	1677.1	1742.8	3.8290	.001 559 4	1638.6	1716.6	3.7639	.001 502 8	1609.4	1699.5	3.7141
400	.001 907 7	1854.6	1930.9	4.1135	.001 730 9	1788.1	1874.6	4.0031	.001 633 5	1745.4	1843.4	3.9318
425	.002 532	2096.9	2198.1	4.5029	.002 007	1959.7	2060.0	4.2734	.001 816 5	1892.7	2001.7	4.1626
450	.003 693	2365.1	2512.8	4.9459	.002 486	2159.6	2284.0	4.5884	.002 085	2053.9	2179.0	4.4121
500	.005 622	2678.4	2903.3	5.4700	.003 892	2525.5	2720.1	5.1726	.002 956	2390.6	2567.9	4.9321
550	.006 984	2869.7	3149.1	5.7785	.005 118	2763.6	3019.5	5.5485	.003 956	2658.8	2896.2	5.3441
600	.008 094	3022.6	3346.4	6.0114	.006 112	2942.0	3247.6	5.8178	.004 834	2861.1	3151.2	5.6452
650	.009 063	3158.0	3520.6	6.2054	.006 966	3093.5	3441.8	6.0342	.005 595	3028.8	3364.5	5.8829
700	.009 941	3283.6	3681.2	6.3750	.007 727	3230.5	3616.8	6.2189	.006 272	3177.2	3553.5	6.0824
800	.011 523	3517.8	3978.7	6.6662	.009 076	3479.8	3933.6	6.5290	.007 459	3441.5	3889.1	6.4109
900	.012 962	3739.4	4257.9	6.9150	.010 283	3710.3	4224.4	6.7882	.008 508	3681.0	4191.5	6.6805
1000	.014 324	3954.6	4527.6	7.1356	.011 411	3930.5	4501.1	7.0146	.009 480	3906.4	4475.2	6.9127
1100	.015 642	4167.4	4793.1	7.3364	.012 496	4145.7	4770.5	7.2184	.010 409	4124.1	4748.6	7.1195
1200	.016 940	4380.1	5057.7	7.5224	.013 561	4359.1	5037.2	7.4058	.011 317	4338.2	5017.2	7.3083
1300	.018 229	4594.3	5323.5	7.6969	.014 616	4572.8	5303.6	7.5808	.012 215	4551.4	5284.3	7.4837

Liquide comprimé

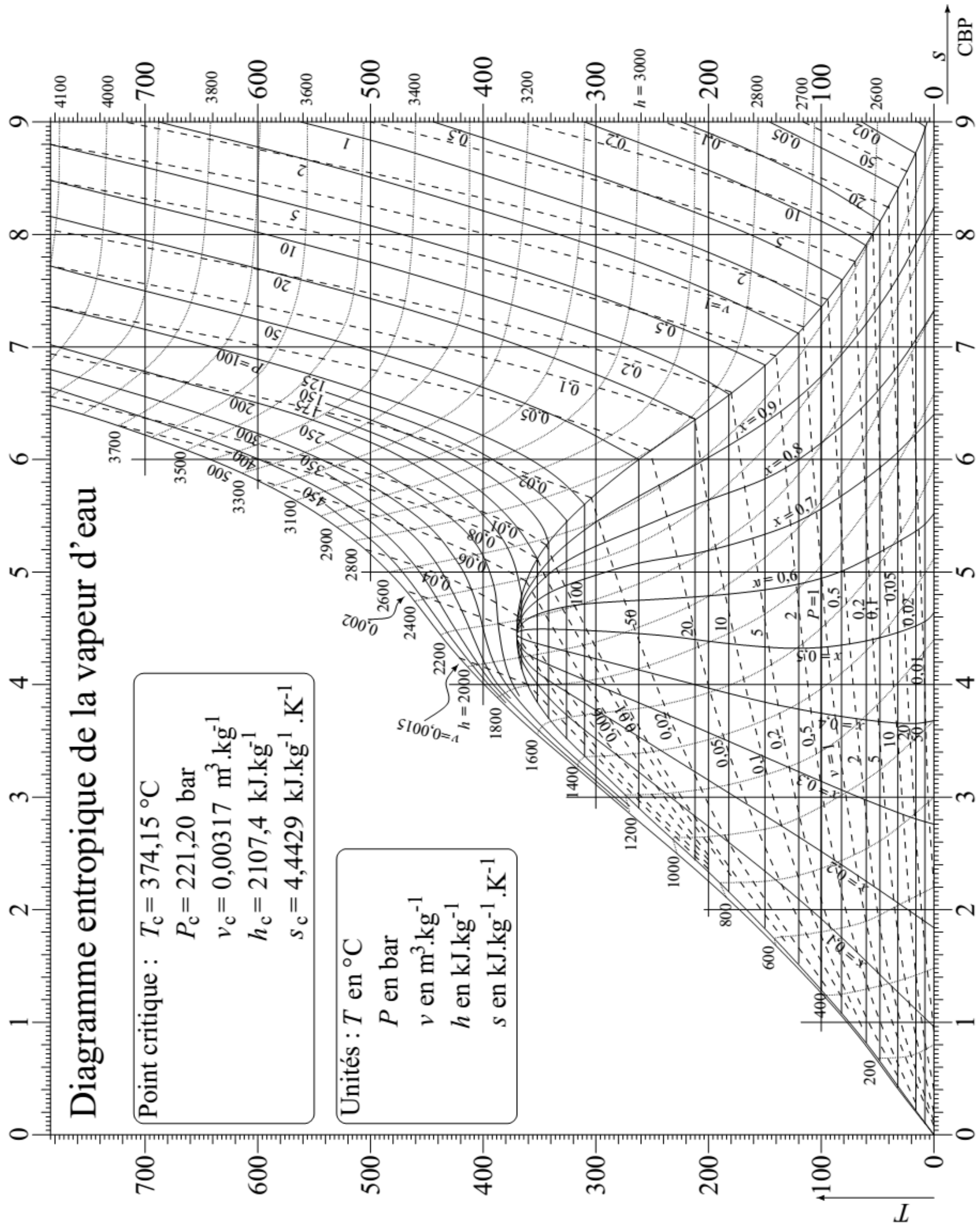
T	v	u	h	s	v	u	h	s	v	u	h	s
	P = 5 MPa (263.99)				P = 10 MPa (311.06)				P = 15 MPa (342.24)			
Sat.	.001 285 9	1147.8	1154.2	2.9202	.001 452 4	1393.0	1407.6	3.3596	.001 658 1	1585.6	1610.5	3.6848
0	.000 997 7	.04	5.04	.0001	.000 995 2	.09	10.04	.0002	.000 992 8	.15	15.05	.0004
20	.000 999 5	83.65	88.65	.2956	.000 997 2	83.36	93.33	.2945	.000 995 0	83.06	97.99	.2934
40	.001 005 6	166.95	171.97	.5705	.001 003 4	166.35	176.38	.5686	.001 001 3	165.76	180.78	.5666
60	.001 014 9	250.23	255.30	.8285	.001 012 7	249.36	259.49	.8258	.001 010 5	248.51	263.67	.8232
80	.001 026 8	333.72	338.85	1.0720	.001 024 5	332.59	342.83	1.0688	.001 022 2	331.48	346.81	1.0656
100	.001 041 0	417.52	422.72	1.3030	.001 038 5	416.12	426.50	1.2992	.001 036 1	414.74	430.28	1.2955
120	.001 057 6	501.80	507.09	1.5233	.001 054 9	500.08	510.64	1.5189	.001 052 2	498.40	514.19	1.5145
140	.001 076 8	586.76	592.15	1.7343	.001 073 7	584.68	595.42	1.7292	.001 070 7	582.66	598.72	1.7242
160	.001 098 8	672.62	678.12	1.9375	.001 095 3	670.13	681.08	1.9317	.001 091 8	667.71	684.09	1.9260
180	.001 124 0	759.63	765.25	2.1341	.001 119 9	756.65	767.84	2.1275	.001 115 9	753.76	770.50	2.1210
200	.001 153 0	848.1	853.9	2.3255	.001 148 0	844.5	856.0	2.3178	.001 143 3	841.0	858.2	2.3104
220	.001 186 6	938.4	944.4	2.5128	.001 180 5	934.1	945.9	2.5039	.001 174 8	929.9	947.5	2.4953
240	.001 226 4	1031.4	1037.5	2.6979	.001 218 7	1026.0	1038.1	2.6872	.001 211 4	1020.8	1039.0	2.6771
260	.001 274 9	1127.9	1134.3	2.8830	.001 264 5	1121.1	1133.7	2.8699	.001 255 0	1114.6	1133.4	2.8576
280					.001 321 6	1220.9	1234.1	3.0548	.001 308 4	1212.5	1232.1	3.0393
300					.001 397 2	1328.4	1342.3	3.2469	.001 377 0	1316.6	1337.3	3.2260
320									.001 472 4	1431.1	1453.2	3.4247
340									.001 631 1	1567.5	1591.9	3.6546
	P = 20 MPa (365.81)				P = 30 MPa				P = 50 MPa			
Sat.	.002 036	1785.6	1826.3	4.0139								
0	.000 990 4	.19	20.01	.0004	.000 985 6	.25	29.82	.0001	.000 976 6	.20	49.03	.0014
20	.000 992 8	82.77	102.62	.2923	.000 988 6	82.17	111.84	.2899	.000 980 4	81.00	130.02	.2848
40	.000 999 2	165.17	185.16	.5646	.000 995 1	164.04	193.89	.5607	.000 987 2	161.86	211.21	.5527
60	.001 008 4	247.68	267.85	.8206	.001 004 2	246.06	276.19	.8154	.000 996 2	242.98	292.79	.8052
80	.001 019 9	330.40	350.80	1.0624	.001 015 6	328.30	358.77	1.0561	.001 007 3	324.34	374.70	1.0440
100	.001 033 7	413.39	434.06	1.2917	.001 029 0	410.78	441.66	1.2844	.001 020 1	405.88	456.89	1.2703
120	.001 049 6	496.76	517.76	1.5102	.001 044 5	493.59	524.93	1.5018	.001 034 8	487.65	539.39	1.4857
140	.001 067 8	580.69	602.04	1.7193	.001 062 1	576.88	608.75	1.7098	.001 051 5	569.77	622.35	1.6915
160	.001 088 5	665.35	687.12	1.9204	.001 082 1	660.82	693.28	1.9096	.001 070 3	652.41	705.92	1.8891
180	.001 112 0	750.95	773.20	2.1147	.001 104 7	745.59	778.73	2.1024	.001 091 2	735.69	790.25	2.0794
200	.001 138 8	837.7	860.5	2.3031	.001 130 2	831.4	865.3	2.2893	.001 114 6	819.7	875.5	2.2634
220	.001 169 3	925.9	949.3	2.4870	.001 159 0	918.3	953.1	2.4711	.001 140 8	904.7	961.7	2.4419
240	.001 204 6	1016.0	1040.0	2.6674	.001 192 0	1006.9	1042.6	2.6490	.001 170 2	990.7	1049.2	2.6158
260	.001 246 2	1108.6	1133.5	2.8459	.001 230 3	1097.4	1134.3	2.8243	.001 203 4	1078.1	1138.2	2.7860
280	.001 296 5	1204.7	1230.6	3.0248	.001 275 5	1190.7	1229.0	2.9986	.001 241 5	1167.2	1229.3	2.9537
300	.001 359 6	1306.1	1333.3	3.2071	.001 330 4	1287.9	1327.8	3.1741	.001 286 0	1258.7	1323.0	3.1200
320	.001 443 7	1415.7	1444.6	3.3979	.001 399 7	1390.7	1432.7	3.3539	.001 338 8	1353.3	1420.2	3.2868
340	.001 568 4	1539.7	1571.0	3.6075	.001 492 0	1501.7	1546.5	3.5426	.001 403 2	1452.0	1522.1	3.4557
360	.001 822 6	1702.8	1739.3	3.8772	.001 626 5	1626.6	1675.4	3.7494	.001 483 8	1556.0	1630.2	3.6291
380					.001 869 1	1781.4	1837.5	4.0012	.001 588 4	1667.2	1746.6	3.8101

Table.4. Solid and saturated vapor

Solide et vapeur saturés

	Volume massique m³/kg			Énergie interne kJ/kg			Enthalpie kJ/kg			Entropie kJ/kg·K		
Temp. °C T	Pres. kPa P	Solide sat. $v_i \times 10^3$	Vapeur sat. v_g	Solide sat. u_i	Subl. u_{ig}	Vapeur sat. u_g	Solide sat. h_i	Subl. h_{ig}	Vapeur sat. h_g	Solide sat. s_i	Subl. s_{ig}	Vapeur sat. s_g
.01	.6113	1.0908	206.1	−333.40	2708.7	2375.3	−333.40	2834.8	2501.4	−1.221	10.378	9.156
0	.6108	1.0908	206.3	−333.43	2708.8	2375.3	−333.43	2834.8	2501.3	−1.221	10.378	9.157
−2	.5176	1.0904	241.7	−337.62	2710.2	2372.6	−337.62	2835.3	2497.7	−1.237	10.456	9.219
−4	.4375	1.0901	283.8	−341.78	2711.6	2369.8	−341.78	2835.7	2494.0	−1.253	10.536	9.283
−6	.3689	1.0898	334.2	−345.91	2712.9	2367.0	−345.91	2836.2	2490.3	−1.268	10.616	9.348
−8	.3102	1.0894	394.4	−350.02	2714.2	2364.2	−350.02	2836.6	2486.6	−1.284	10.698	9.414
−10	.2602	1.0891	466.7	−354.09	2715.5	2361.4	−354.09	2837.0	2482.9	−1.299	10.781	9.481
−12	.2176	1.0888	553.7	−358.14	2716.8	2358.7	−358.14	2837.3	2479.2	−1.315	10.865	9.550
−14	.1815	1.0884	658.8	−362.15	2718.0	2355.9	−362.15	2837.6	2475.5	−1.331	10.950	9.619
−16	.1510	1.0881	786.0	−366.14	2719.2	2353.1	−366.14	2837.9	2471.8	−1.346	11.036	9.690
−18	.1252	1.0878	940.5	−370.10	2720.4	2350.3	−370.10	2838.2	2468.1	−1.362	11.123	9.762
−20	.1035	1.0874	1128.6	−374.03	2721.6	2347.5	−374.03	2838.4	2464.3	−1.377	11.212	9.835
−22	.0853	1.0871	1358.4	−377.93	2722.7	2344.7	−377.93	2838.6	2460.6	−1.393	11.302	9.909
−24	.0701	1.0868	1640.1	−381.80	2723.7	2342.0	−381.80	2838.7	2456.9	−1.408	11.394	9.985
−26	.0574	1.0864	1986.4	−385.64	2724.8	2339.2	−385.64	2838.9	2453.2	−1.424	11.486	10.062
−28	.0469	1.0861	2413.7	−389.45	2725.8	2336.4	−389.45	2839.0	2449.5	−1.439	11.580	10.141
−30	.0381	1.0858	2943	−393.23	2726.8	2333.6	−393.23	2839.0	2445.8	−1.455	11.676	10.221
−32	.0309	1.0854	3600	−396.98	2727.8	2330.8	−396.98	2839.1	2442.1	−1.471	11.773	10.303
−34	.0250	1.0851	4419	−400.71	2728.7	2328.0	−400.71	2839.1	2438.4	−1.486	11.872	10.386
−36	.0201	1.0848	5444	−404.40	2729.6	2325.2	−404.40	2839.1	2434.7	−1.501	11.972	10.470
−38	.0161	1.0844	6731	−408.06	2730.5	2322.4	−408.06	2839.0	2430.9	−1.517	12.073	10.556
−40	.0129	1.0841	8354	−411.70	2731.3	2319.6	−411.70	2838.9	2427.2	−1.532	12.176	10.644

Diagram.1. Diagram Entropic water vapor



References

[1].Mohammed YoubiIdrissi « Technique du froid & composants frigorifiques » Cours ; Cemagref. 2006.

[2].YunusA.Cengelet Michel A. Boles « Thermodynamics An Engineering Approach", 5 Edition.

[3].Maxime Duminil, « Théorie des machines frigorifiques, machine à compression mécanique » B 9730, traité Génie énergétiquen Techniques de l'ingénieur. 1996.

[4].H.Recknagel, E-R.Schramek, E.Sprenger, « Génie climatique", Dunod, 2013

[5].W.Maake ; H.-J.Eckert ; J-L.Cauchepin ; « Le Pohlmann- Manuel technique du froid », PYC Livres.

[6].J.Desmons, « Aide-mémoire de l'ingénieur ; Génie climatique », Dunod.

[7].F.Meunier, D. Mugnier, « la climatisation solaire ; Thermique ou photovoltaïque » ; Dunod. 2013.

[8].F.Meunier, P.Rivet, M-F. Terrier, « Froid industriel- 2 éme édition » ; Dunod. 2010.

[9].Horst Herr ; « Génie énergétique et climatique chauffage, froid, climatisation » Dunod Tech. 2014.