PROPERTIES OF REAL GASES

Properties of Real Gases

In contrast to ideal gas, **real gas** consists of molecules of specified dimensions which interact at a distance, and the dependence of this interaction on gas density is very complicated.

This leads to the complexity of the differences in properties of real gas from those of ideal gas.

Properties of Real Gases

The thermal equation of state of real gas can be represented in the form:

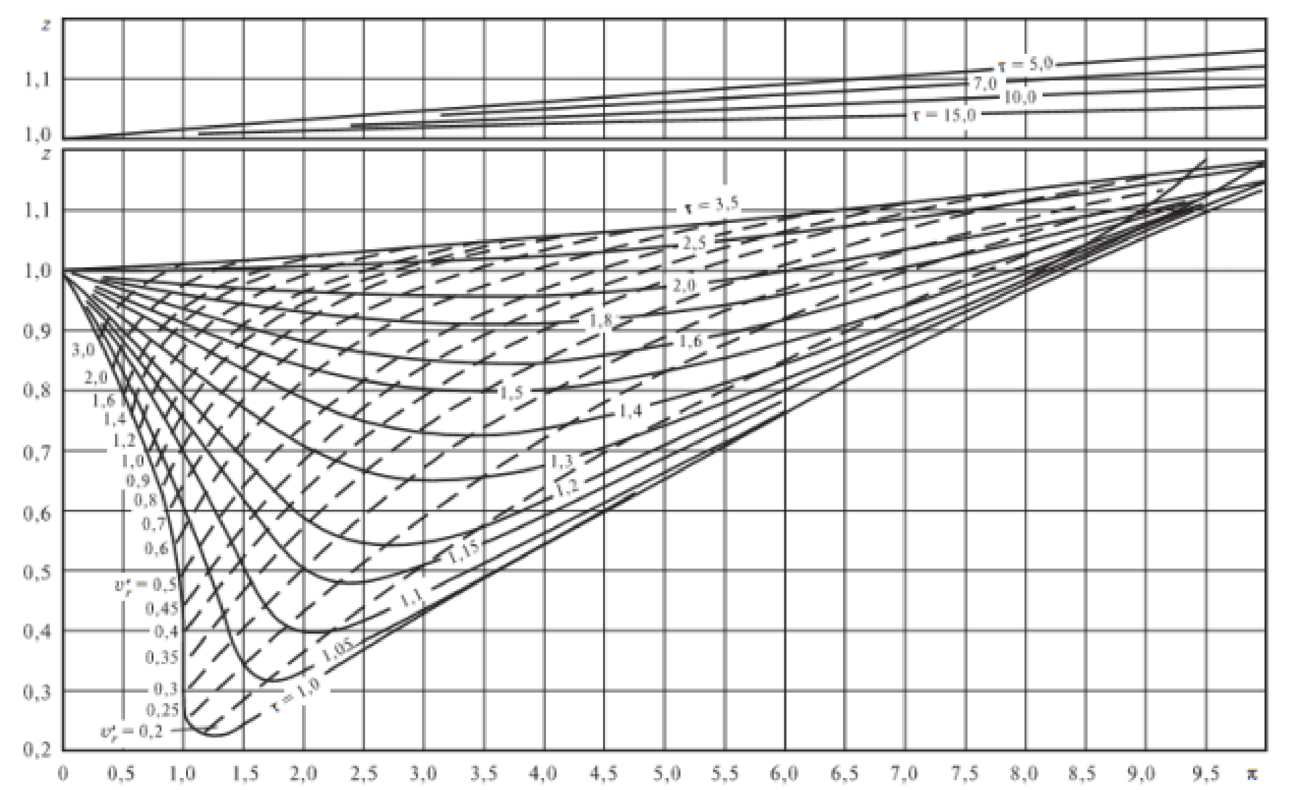
$$pv = zRT$$

where z is the compressibility factor, which is a complex function of temperature and density (or pressure).

In the next slide, the form of this function is presented in figure

Properties of Real Gases

z



pk are the parameters of the substance at critical point

$$\pi = \frac{p}{p_k}$$

Properties of Real Gases

An empirical equation of state for real gas takes into account the quality of physical performance:

$$\left(p + \frac{a}{v^2}\right) \cdot (v - b) = RT$$

van der Waals equation

where b is the value to account for the volume (the maximum volume of the compression)

a/v^2 is the correction for internal pressure due to forces of molecular attraction

a и b are physical constants determined experimentally for a particular gas.

Vapor

A vapor is a gaseous substance at temperature when it ordinarily should be a liquid or a gas

Vaporization is the process of converting liquid into vapor

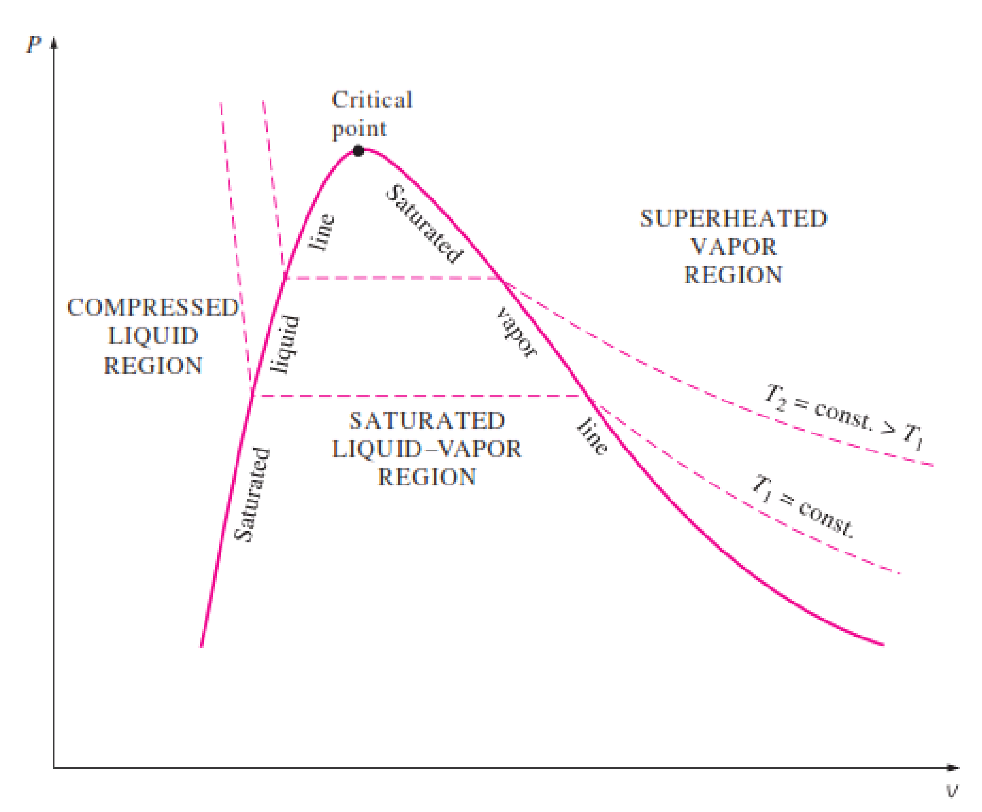
Condensation is the process of converting gas into liquid

Vapor

- ***Unsaturated steam*** is the steam that did not reach dynamic equilibrium with its liquid. At a given temperature, the pressure of the steam is always less than the pressure of the saturated steam ($p<ps$)

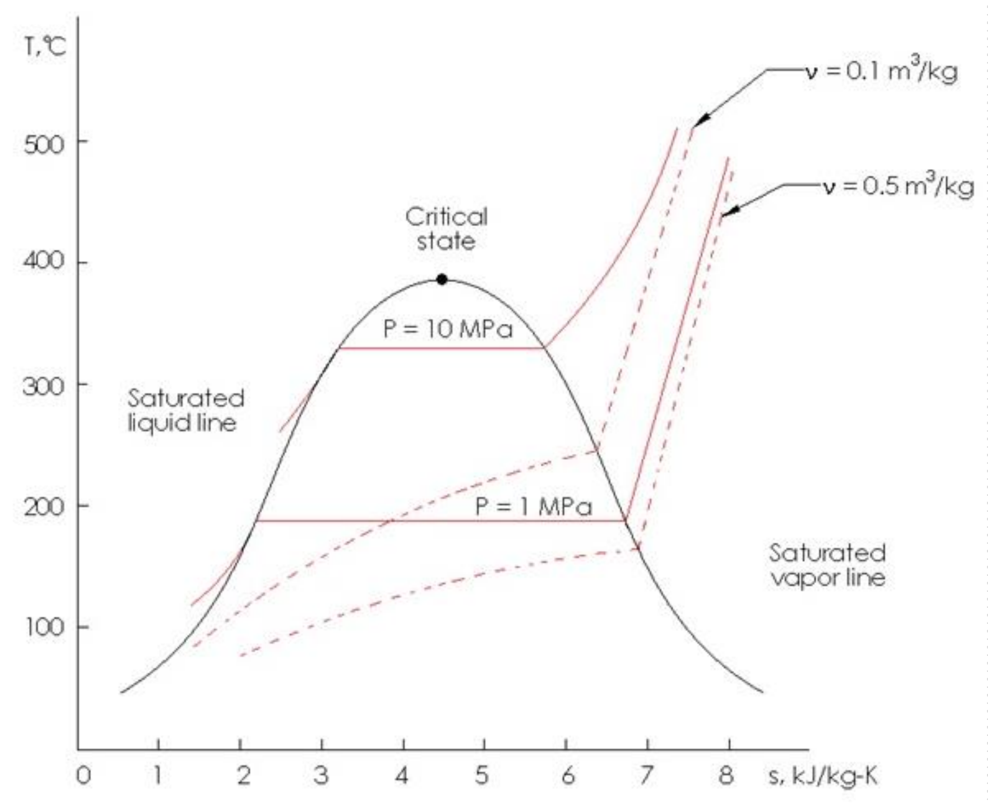
- ***Saturated steam*** is the steam that is in dynamic equilibrium with its liquid (evaporation = condensation). This means that at this temperature the amount of vapor in this volume is not large

Vapor



p,v diagram for vapors

Vapor



T,s diagram for vapors

Water vapor

Water vapor is a gaseous state of water

$$p = 0.1013 \text{ MPa} = 760 \text{ mm Hg} \rightarrow T \text{ (boiling water)} = 100°C = 373.15 \text{ K}$$

Water vapor is **real gas** and it is widely used as the working fluid in engineering and, especially, in the heat power system

Water vapor obtained through vaporization when heat is supplied to water in heat exchangers and units, for example, in boilers or nuclear reactors

Water vapor

Vaporization occurs in two-phase region, the liquid is in a saturation state. Vapor in the two-phase region is humid saturated steam, it is a two-phase mixture (vapor and suspended liquid droplets).

Wet steam is characterized by the dryness factor :

$$x = \frac{m_{\text{п}}}{m_{\text{п}} + m_{\text{в}}}$$

where m_s, m_w are the mass of steam and boiling water, respectively

The degree of humidity:

$$y = 1 - x$$

Novikov–Vukalovich equation

A universal equation describing the state of water vapor. It takes into account the phenomenon of interaction of molecules:

$$\left(p+\frac{a}{v^2}\right)\cdot(v-b)=\left[RT-\frac{C}{vT^{\frac{3+2m}{2}}}\right]$$

where a, b are constants in the van der Waals equation
m, c are constants, which are calculated empirically
R is the universal gas constant.

$$R=8{,}3144\ \frac{m^2\cdot kg}{s^2\cdot K\cdot mol}$$

Thermodynamic tables for water and water vapor

To determine the values of the parameters you need to know the aggregate state of water:

- water subcooled to the boiling point
- boiling liquid
- saturated steam
- superheated steam

Saturated steam can be:

- dry
- wet
- a mixture of dry steam and boiling liquid

Calculation of thermodynamic processes using tables

1) The parameters of **the boiling liquid** and the dry saturated steam are uniquely determined if at least one parameter is known.

2) The parameters of **the wet steam** is calculated from the values of temperature or pressure and dryness factor of steam reflecting the vapor mass to the mass of the working fluid.

3) The parameters of **subcooled boiling water** and superheated steam are found by at least two parameters.

4) If there are no parameter values in the tables, data is interpolation.

Calculation of thermodynamic processes of water vapor using tables

An example of a table of thermodynamic processes for water and water vapor

t_S	p	v'	v''	h'	h''	r	s'	s''
48	11,161	0,0010112	13,236	200,89	2588,3	2387,4	0,6776	8,1121
49	11,735	0,0010116	12,626	205,07	2590,1	2385,0	0,6906	8,0945
50	12,335	0,0010121	12,048	209,26	2382,5	2382,5	0,7035	8,0771
51	12,960	0,0010126	11,501	213,44	2593,6	2380,2	0,7164	8,0598
52	13,612	0,0010131	10,982	217,62	2595,4	2377,8	0,7293	8,0427
53	14,292	0,0010136	10,490	221,80	2597,2	2375,4	0,7422	8,0258
54	15,001	0,0010140	10,024	225,98	2598,9	2372,9	0,7550	8,0089
55	15,740	0,0010145	9,5812	230,17	2600,7	2370,5	0,7677	7,9922
56	16,510	0,0010150	9,1609	234,35	2602,4	2368,1	0,7804	7,9756
57	17,312	0,0010156	8,7618	238,54	2604,2	2365,7	0,7931	7,9591
58	18,146	0,0010161	8,3831	242,72	2606,0	2363,3	0,8058	7,9428

R is the specific heat of vaporization, kJ/kg

$'$ is saturated liquid
$''$ is dry steam
s is saturation

Calculation of thermodynamic processes of water vapor using tables

- for *superheated steam* at a given pressure *p*

  $$t > t_s,\quad \upsilon > \upsilon'',\quad h > h'',\quad s > s'';$$

- for *subcooled water* at a given pressure *p*

  $$t < t_s,\quad \upsilon < \upsilon',\quad h < h',\quad s < s';$$

- for *wet steam* at a given pressure *p*

  $$t = t_s,\quad \upsilon' < \upsilon < \upsilon'',\quad h' < h < h'',\quad s' < s < s'';$$

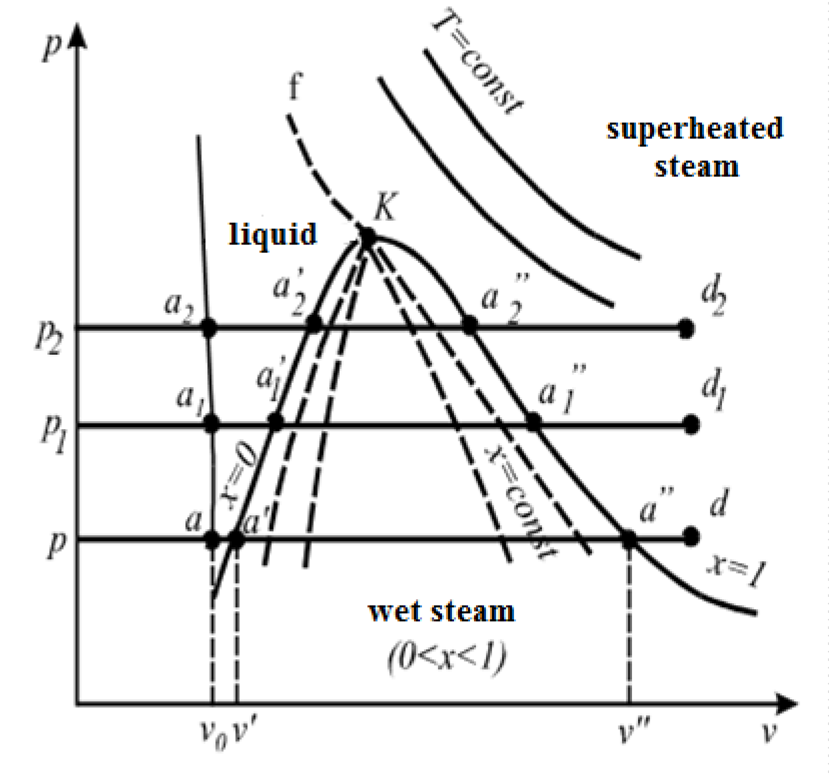
- for *boiling water* at a given pressure *p*

  $$t = t_s,\quad \upsilon = \upsilon',\quad h = h',\quad s = s';$$

- for *wet saturated steam* at a given pressure *p*

  $$t = t_s,\quad \upsilon = \upsilon'',\quad h = h'',\quad s = s''.$$

Diagram of water vapor



p, v – diagram of water vapor

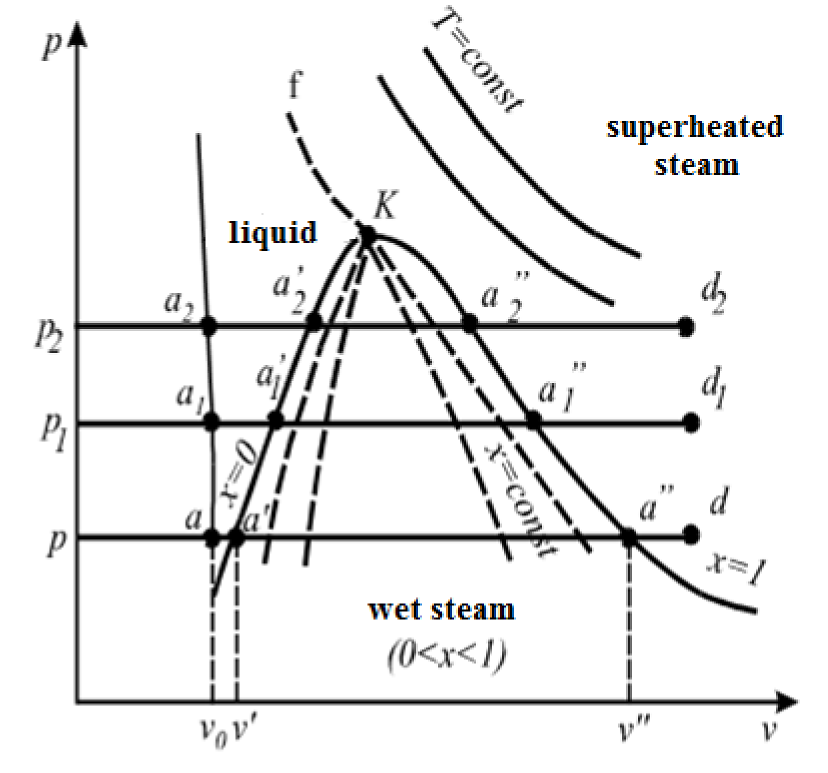
$a, a1, a2$ indicate liquid

$a', a1', a2'$ indicate boiling water

$a'', a1'', a2''$ indicate wet saturated steam

$d, d1, d2$ indicate superheated steam

Diagram of water vapor



p, ν – diagram of water vapor

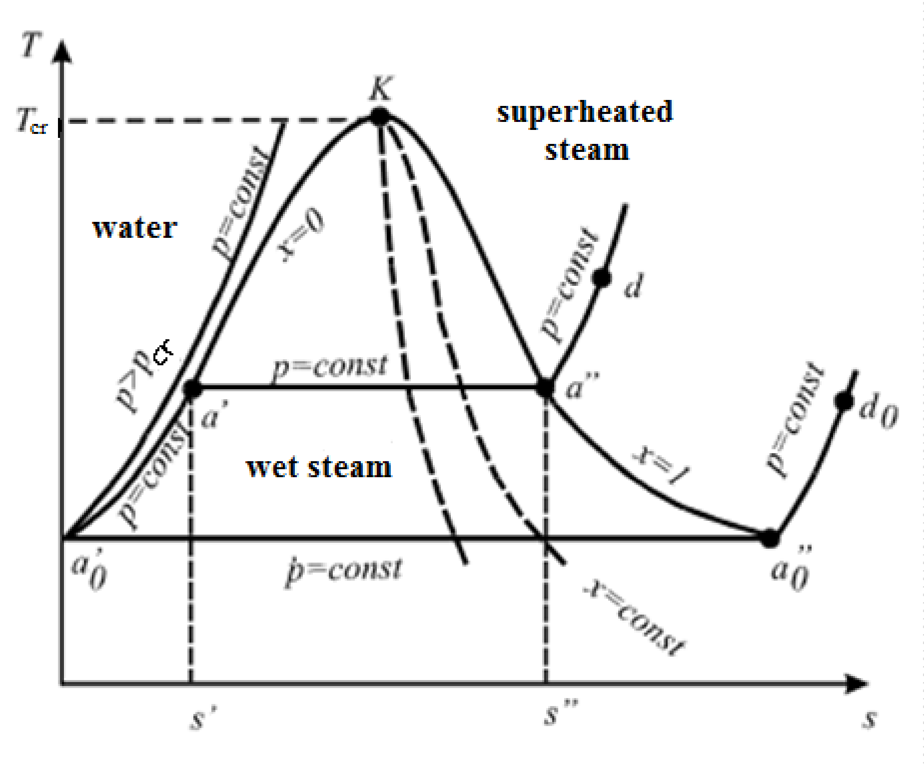
Boundary curves are matched at point «*K*» referred to as a critical point of water and water vapor. At this point, the properties of the liquid and gas become identical.

$$p_{cr} = 221,29 \cdot 10^5 \ Pa$$

$$t_{cr} = 374,15 \ °C$$

$$\nu_{cr} = 0,00326 \ m^3 / kg$$

Diagram of water vapor



T, s – diagram of water vapor

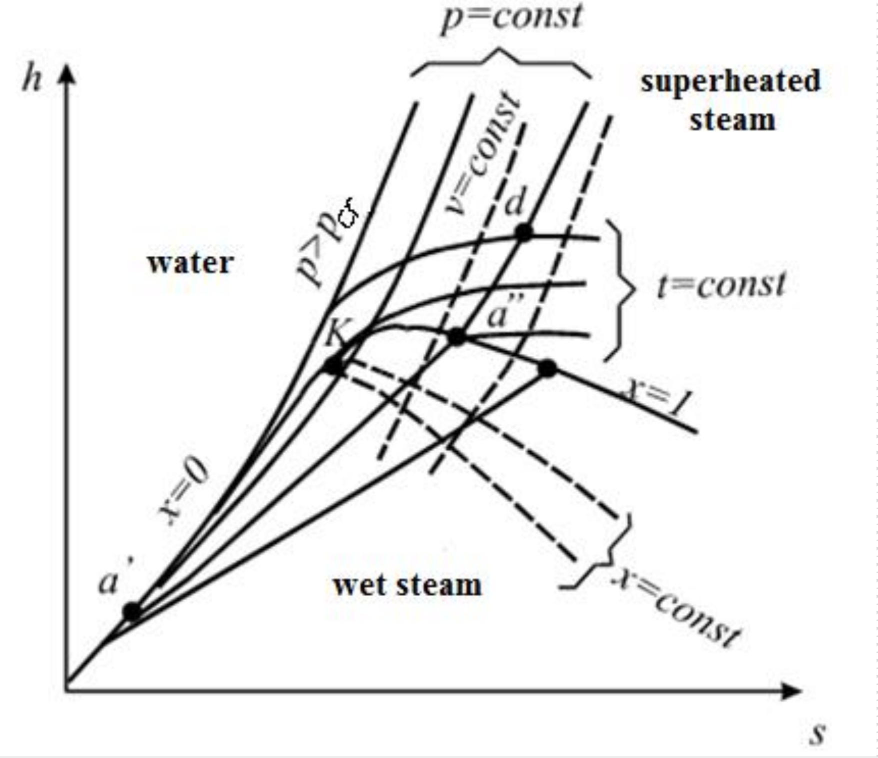
Triple point:

$$s_0 = 0,\ T_0 = 273\ °C \rightarrow \alpha_0^{'}$$

The diagram contains Isobars, isochors (have a logarithmic character) and lines of constant degree of dryness.

In the T,s – diagram, the area under the curve of the process is the equivalent of the quantity supplied or removed heat.

Diagram of water vapor



h, s – diagram of water vapor

Triple point:

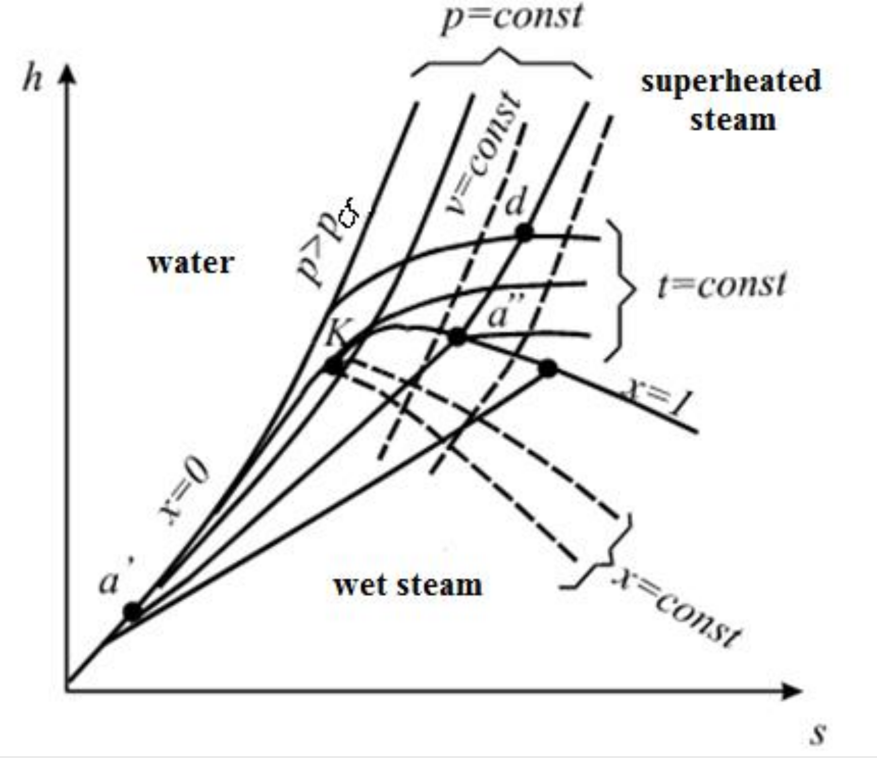
$$s_0 = 0,\ h_0 = 0 \rightarrow \alpha_0'$$

The critical point is not at the top of the boundary curve.

The h, s – diagram, clearly depicts isoentropic process of water vapor.

Only the upper part of the h, s – diagram is used for calculations

Calculation of thermodynamic processes of water vapor using h, s - diagram



h, s – diagram of water vapor

For different pressures (temperatures) put it on the h, s – diagram the values of s' for water at the boiling point, and s'' and h'' for dry saturated steam, we obtain the lower and upper boundary curves.

Isobars in the region of wet steam are a bundle of divergent lines. The bigger the pressure, the higher the isobar.

Calculation of thermodynamic processes of water vapor using h, s - diagram

If independent parameters that specify the state of the working fluid, to take entropy s and enthalpy h, each state can be represented by a point in the h, s – diagram for which can be found any of the parameters p, v, t, h, s, and for wet steam and also the degree of dryness x.

h, s – diagram of water vapor enables you to find the parameters with sufficient accuracy for engineering calculations. The difference between the enthalpies determined in the form of segments that allows easily calculation of the work of water vapor and the amount of heat in isobaric processes.