BASIC THEORY OF THE MOLLIER'S CHART

1. What is Mollier's chart?

- the tool for determining of isobaric psychrometric processes of moist air
- suitable for steady conditions
- similar to psychrometric chart used mainly in Anglo-Saxon literature
- each chart is determined for specific pressure

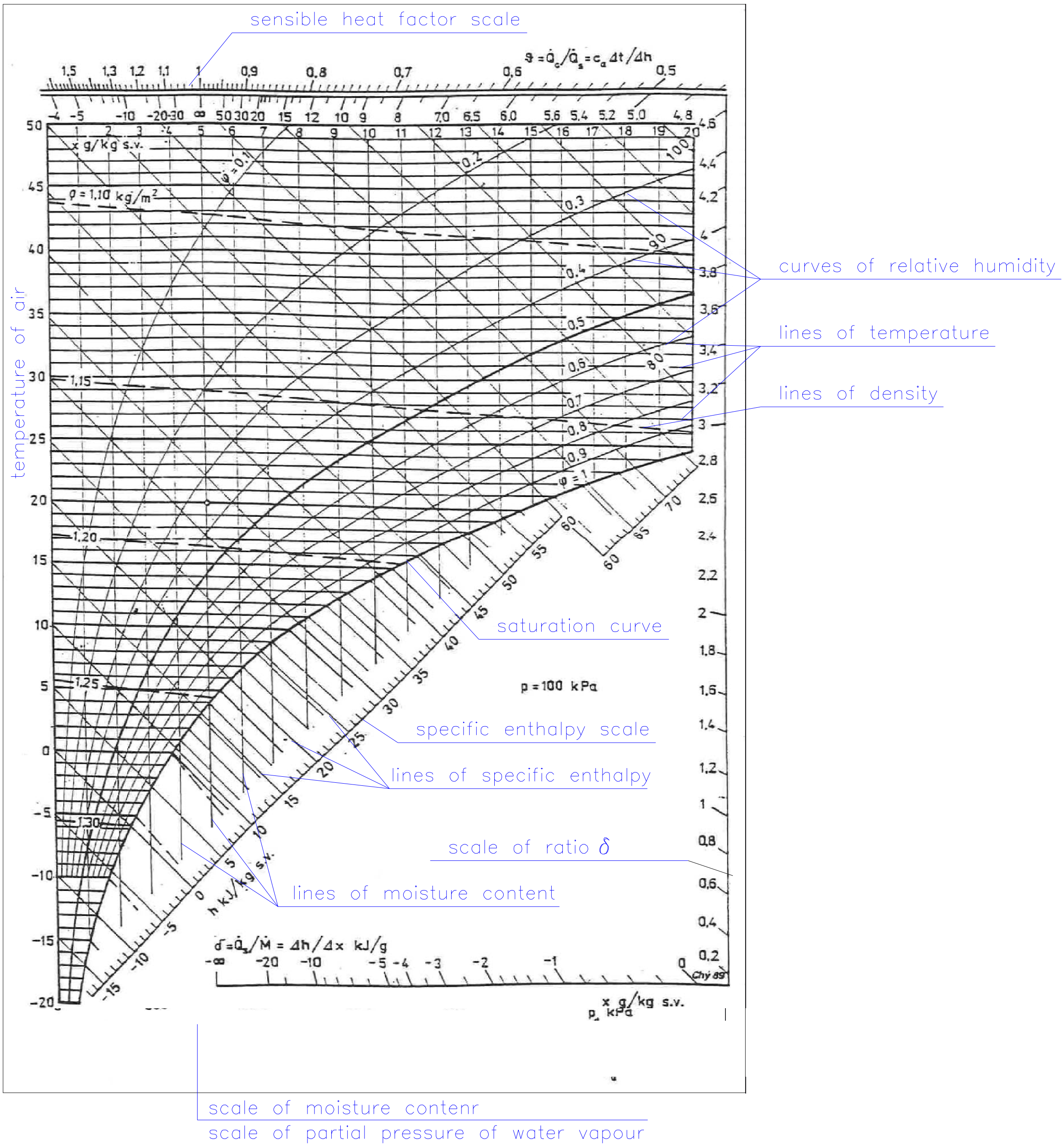


Figure 1- Descrtiption of Mollier´s chart

Determination of the dew point temperature and the wet-bulb temperature

- **dew point temperature td:**

The temperature of moist air saturated at the same pressure *p* and with the same moisture content *x* as the given state of moist air.

- **thermodynamic wet-bulb temperature t_w:**

The temperature at which water evaporating into moist air, can bring air to the adiabatic saturation. The lowest temperature of adiabatic cooling of air.

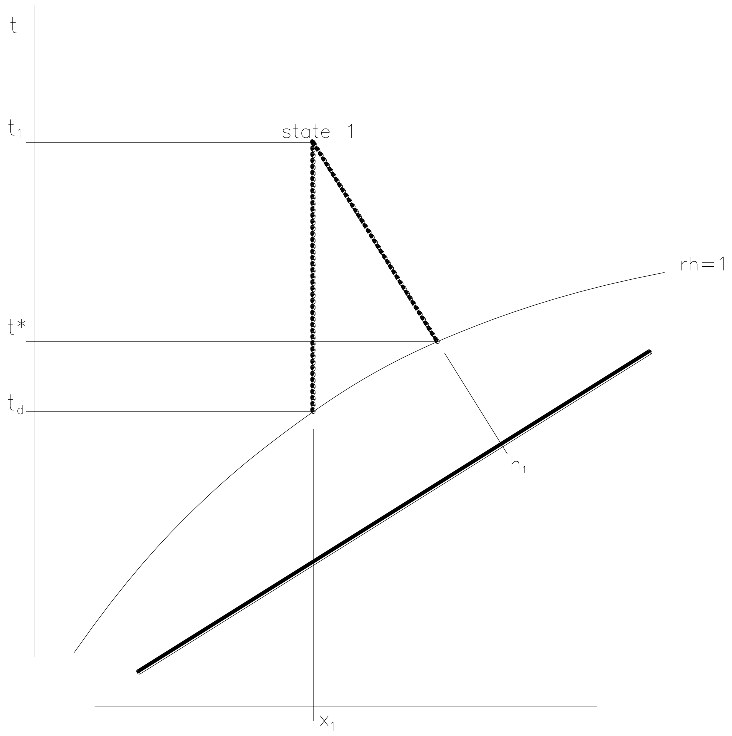


Figure 2 - Determination of the dew point temperature and the wet-bulb temperature

Training example for diagram use

Air state: dry-bulb temperature *t* = 15°C moisture content *x* = 7,8 g/kg d.a. barometric pressure *p* = 100 kPa	Find other moist air properties: specific enthalpy, relative humidity, dew point temperature, wet-bulb temperature
Results: specific enthalpy *h* = 35 kJ/kg, relative humidity rh = 73 %, dew point temperature t_d = 10 °C, wet-bulb temperature t_w = 12,5 °C	

Air state: specific enthalpy *h* = 55 kJ/kg relative humidity *rh* = 45 % barometric pressure *p* = 100 kPa	Find other moist air properties: dry-bulb temperature, moisture content, dew point temperature, wet-bulb temperature
Results: dry-bulb temperature t_d = 28 °C, moisture content *x* = 10,6 g/kg d.a., dew point temperature t_d = 15 °C, wet-bulb temperature t_w = 19 °C	

2. Basic psychrometric processes

3.1 Introduction

- any process has two heat components

- sensible heat S – moisture is constant
- latent heat L – temperature is constant

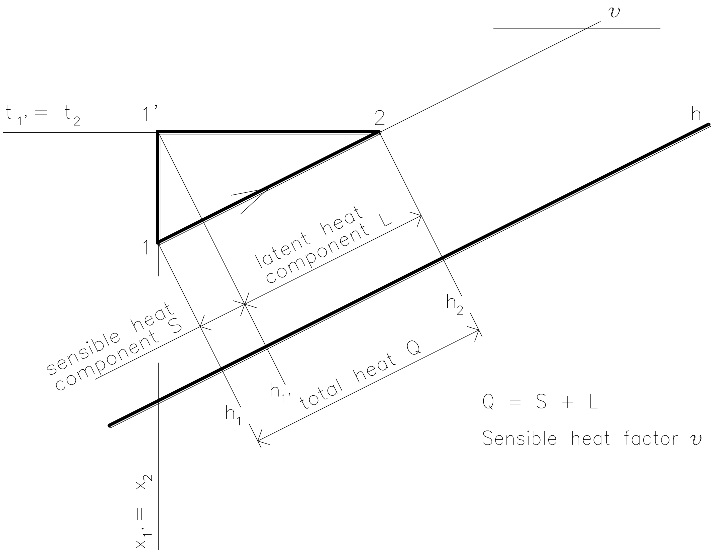


Figure 3 - Components of any process

1 – 2 is any process in Mollier's chart

total heat Q = L + S

where:

- latent heat component
  $L = m_a.(h_2 - h_{1'})$
- sensible heat component
  $S = m_a.(h_{1'} - h_1)$

sensible heat factor u:

- ratio of sensible heat component included in total heat

$$\vartheta = \frac{S}{Q} = \frac{c.\Delta t}{\Delta h}$$

2.2. Sensible heating and cooling

- the process with no changes of moisture content *x*
- the sensible cooling and the sensible heating are reversed processes
- in the case of sensible cooling the surface temperature of cooler must be higher than the dew point temperature of moist air

Properties of states:

$x_1 = x_2$

- sensible cooling
  $t_2 < t_1$
  $rh_2 > rh_1$
  $h_2 < h_1$
- heating
  $t_2 > t_1$
  $rh_2 < rh_1$
  $h_2 > h_1$

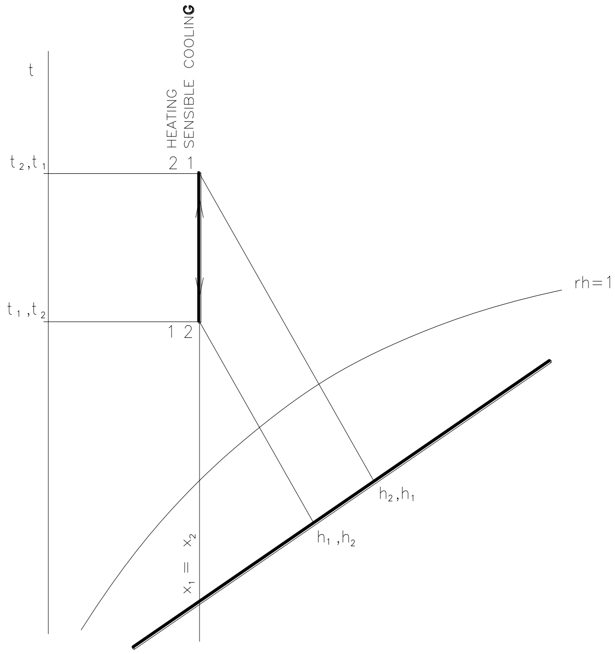


Figure 4- Sensible heating and cooling

The heat required for the process:

- sensible cooling

$Q = m_a.(h_1 - h_2) = m_a.c_d.(t_1 - t_2)$ [kW]

- heating

$Q = m_a.(h_2 - h_1) = m_a.c_d.(t_2 - t_1)$ [kW]

2.3. Cooling

- the process with change of moisture content *x*
- the surface temperature of cooler is lower than the dew point temperature of moist air
  → the condensation occurs

Properties of states:

$x_1 > x_2$

$t_2 < t_1$

$rh_2 > rh_1$

$h_2 < h_1$

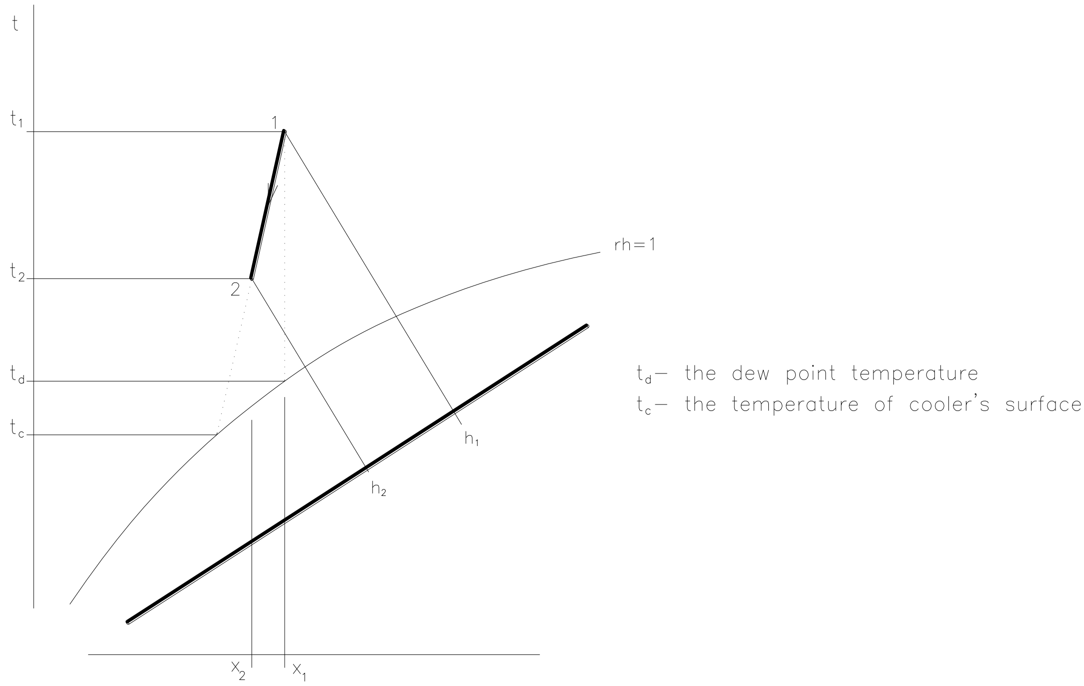


Figure 5 - Cooling process

The heat required for the process:

$Q = m_a.(h_1 - h_2)$ [kW]

The rate of condensing moisture:

$m_w = m_a.(x_1 - x_2)$ [kg/s]

2.4. The different between sensible cooling and cooling

- while the cooler's surface temperature is lower than the dew point temperature condensation of water vapour occurs.
  → a part of total heat is used for change from gaseous state to liquid state

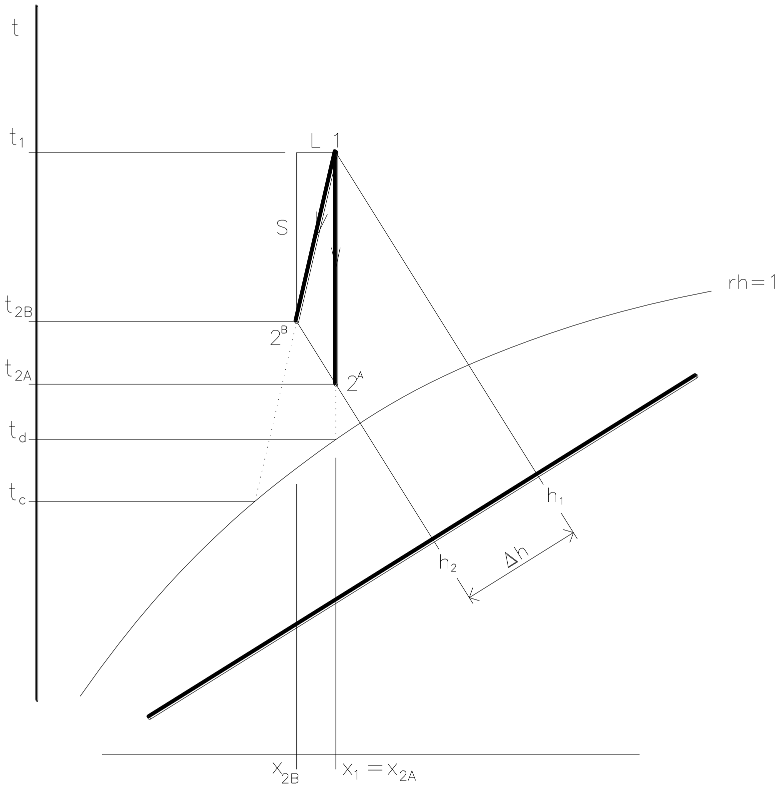


Figure 6 - The different between sensible cooling and cooling

$$Q = m.\Delta h;\ \Delta h = h_1 - h_2$$
$$A)\quad Q = S + L;\quad L = 0$$
$$B)\quad Q = S + L;\quad L \neq 0 \quad \Rightarrow \quad S_B < S_A \rightarrow t_{2B} > t_{2A}$$

2.5. Humidification

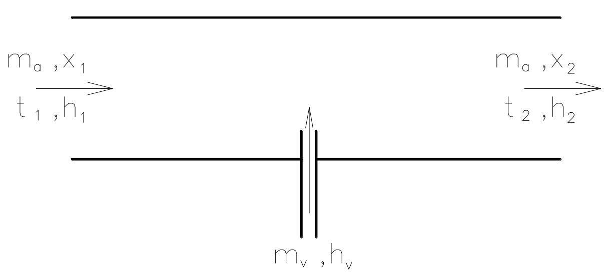
- the moisture content can be increased in two ways
  a) the direct injection of steam into the air stream
  b) passing the air through a spray chamber containing small water droplets

2.5.1. Steam injection

Definition

the mass balance: $m_{a1} = m_{a2} = m_a$

steady-flow energy equations:



$m_a.x_1 + m_v = m_a.x_2$

$m_a.h_1 + m_v.h_v = m_a.h_2$

$\Rightarrow m_v.h_v = m_a.(h_2 - h_1)$

$m_v \quad = m_a.(x_2 - x_1)$

$$\rightarrow \frac{h_2 - h_1}{x_2 - x_1} = h_v = q_{12} \rightarrow \text{specific heat of the proces}$$

Properties of states:

$x_1 < x_2$

$t_2 = t_1$

$rh_2 > rh_1$

$h_2 > h_1$

Mollier's chart:

ratio d

$$\delta = \frac{\Delta h}{\Delta x} = h_v$$

where:

h_v – specific enthalpy of injected steam (or any liquid)

h_v varies about *2,6 kJ/kg*

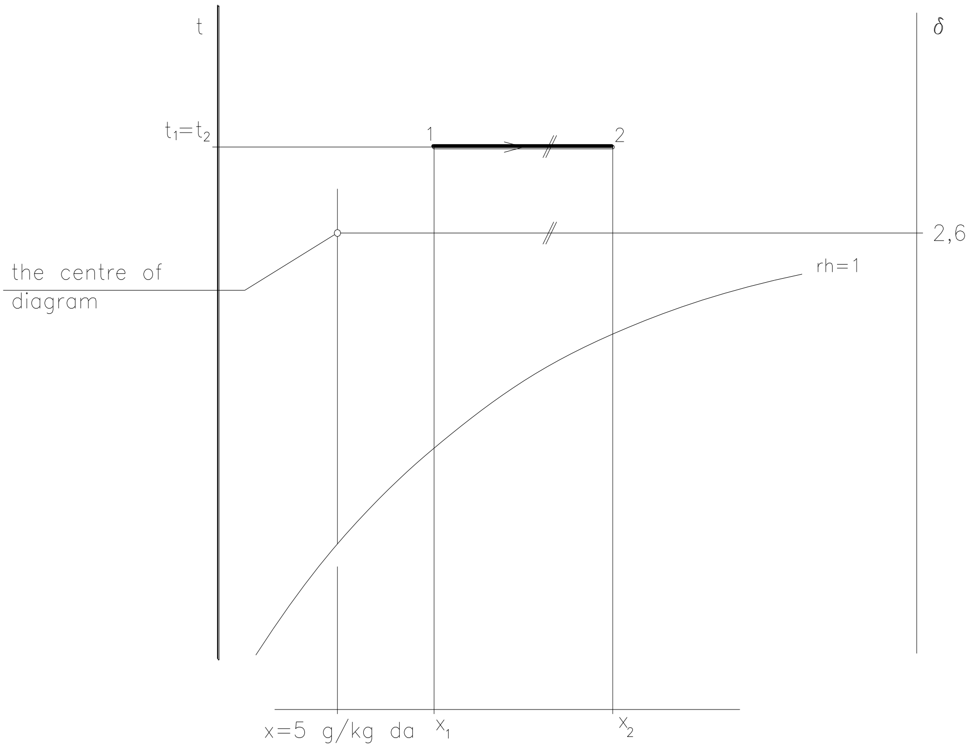
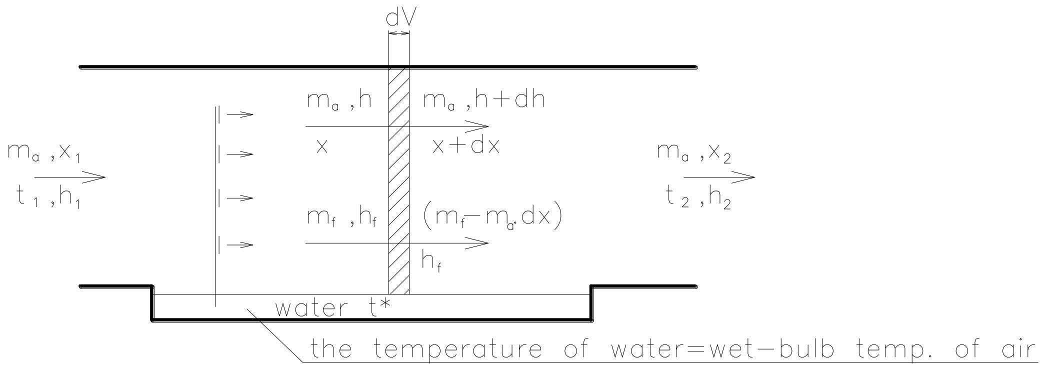


Figure 7 - Steam humidification

The process of steam injection in the air stream is taken with reasonable accuracy as isothermal.

2.5.2. b) Humidification in spray chamber

Definition



Energy balance:

$m_a.dh = m_a.dx.h_f$

$$m_a \cdot dh = m_a \cdot dx \cdot h_f \rightarrow \frac{dh}{dx} = h_f ;\text{the same equation as in the steam injection humidification}$$

h_f of water at temperature 10 to 15 °C varies between 0 to 0,42 kJ/kg

Properties of states:

$x_1 < x_2$

$t_2 < t_1$

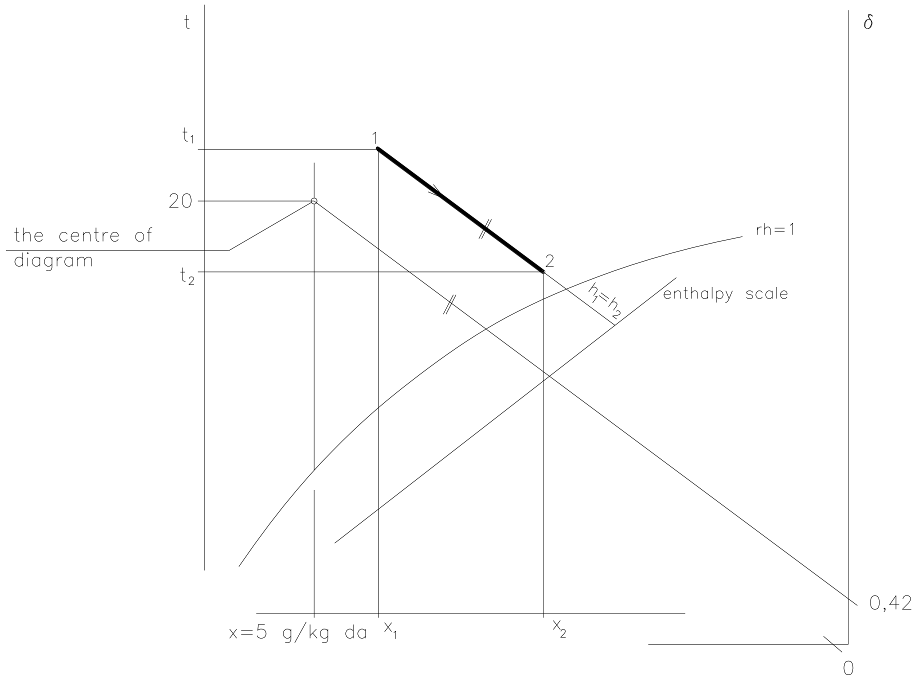
$rh_2 > rh_1$

$h_2 = h_1$

Equations:

$m_w = m_a.(x_2 - x_1)$ [kg/s]

m_w - **the rate of water transported into the air stream**



Humidification with water in spray chamber is taken with reasonable precision as <u>adiabatic</u> ⇒ specific enthalpy is constant

Figure 8 - Humidification with water in spray chamber

2.6. Mixing

Definition

- mix of two air streams

steady-flow energy equation:

$m_{a1}.h_1 + m_{a2}.h_2 = m_{a3}.h_3$

mass balance equation:

$m_{a1} + m_{a2} = m_{a3}$ for dry air

$m_{a1}.x_1 + m_{va2}.x_2 = m_{a3}.x_3$ for water vapour

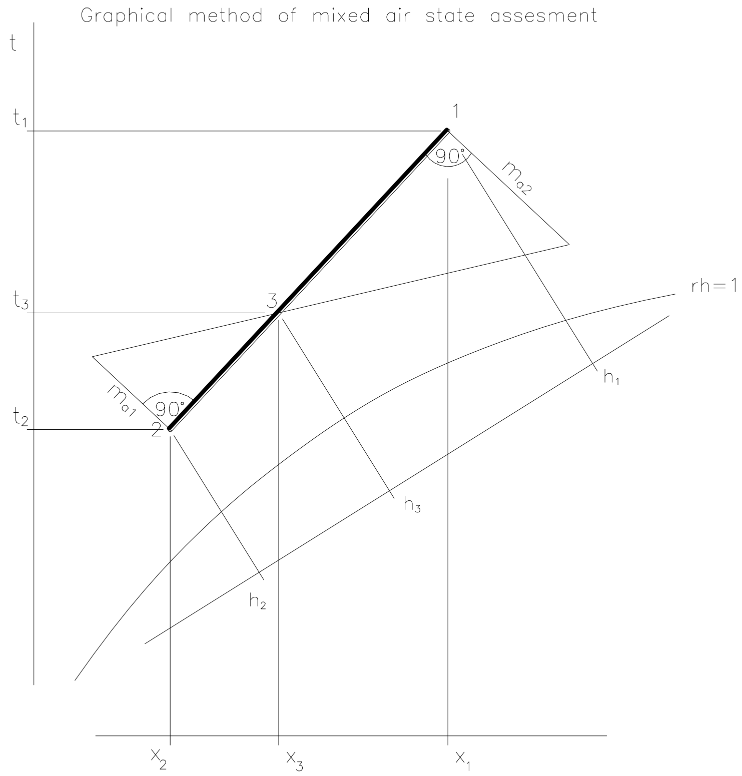


Figure 9- Mixing

from the equations ensues:

$$\frac{m_{a1}}{m_{a2}} = \frac{h_3 - h_2}{h_1 - h_3} = \frac{x_3 - x_2}{x_1 - x_3} \Rightarrow \frac{h_3 - h_2}{x_3 - x_2} = \frac{h_1 - n_3}{x_1 - x_3} = \delta_{13} = \delta_{23}$$

In the case of result state is below saturation curve:

state 3 is oversaturated air $\Rightarrow$ air immediately changes to the saturated air according to the line of constant temperature, *Dx* is amount of condensed water steam.

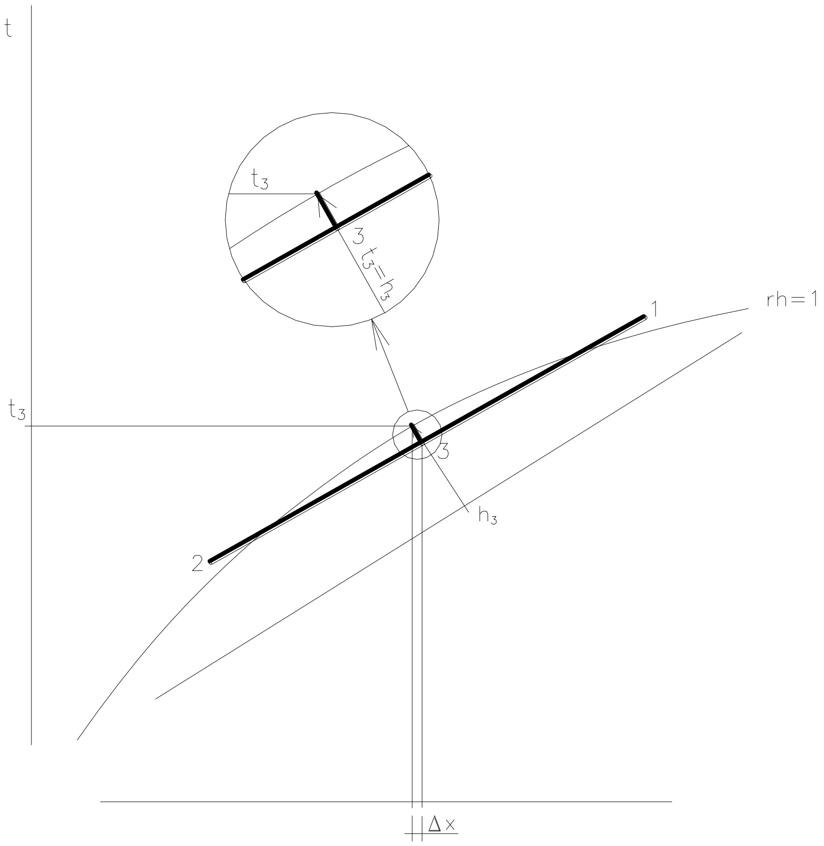


Figure 10 - State is below saturation curve