Bulletin of the *Transilvania* University of Braşov • Vol. 2 (51) - 2009
Series I: Engineering Sciences

A NEW VERSION OF H-D DIAGRAM FOR HUMID AIR: THE CONSTRUCTION OF THE CONSTANT - QUALITY LINES IN THE MIST ZONE

D. ŞOVA[1] **W. LAURENZI[2]**

Abstract: *The paper presents the relationships for the construction of h-d diagram for humid air considering in addition new equations for the construction of the constant – quality curves and the constant- volume lines in the mist zone of humid air. For the graphical representation of h-d diagram, the program called H-d DIAGRAM was developed.*

Key words: *humid air, h-d diagram, mist zone.*

1. Introduction

The h-d diagram for humid air is a useful tool for the determination of the specific parameters of humid air during processes like air-conditioning or drying.

The Mollier diagram, also called the h-d (or h-x) diagram, is based on the relationship between heat content (enthalpy) and water vapor content of air. [1]

The diagram comprises two domains corresponding to unsaturated humid air and humid air in state of mist, separated by a borderline which is the saturation curve. Since the most processes are studied in the region of unsaturated air, a lesser interest was paid to the study of the mist zone and to the processes developed in this zone, such as cooling or drying in a closed circuit.

2. The Construction of H-d Diagram

The h-d diagram is constructed for the atmospheric pressure $p = 1\text{bar}$.

The network of isothermal lines in the domain of unsaturated humid air is plotted on the basis of the following relation:

$$h = c_{pa} t + \frac{d}{1000}\left(r_0 + c_{pv} t\right) \tag{1}$$

where: h is the enthalpy of unsaturated humid air $[\text{kJ/kg}]$, t - temperature $[0-90\,^{\circ}\text{C}]$, d - the moisture content of humid air $[0-50\,\text{g/kg}]$, r_0 - heat of vaporization $[\text{kJ/kg}]$, c_{pa} - constant-pressure specific heat of air $[\text{kJ/kgK}]$, c_{pv} - constant - pressure specific heat of water vapor $[\text{kJ/kgK}]$.

The construction of the network of constant - relative humidity curves, $\varphi = 0.1-1$, is made using the equation:

$$d = 622\frac{p_v}{p - p_v} = 622\frac{\varphi\, p_s(t)}{p - \varphi\, p_s(t)} \tag{2}$$

where: p_v is the partial pressure of the

[1] Dept. of Thermodynamics and Fluid Mechancis, *Transilvania* University of Braşov.
[2] Dept. of Machines for Wood Industry, *Transilvania* University of Braşov.

water vapor $[\text{bar}]$, φ- the relative humidity, $p_s(t)$- the saturation pressure at a given temperature of air $[\text{bar}]$.

The constant - volume lines in the zone of unsaturated humid air are represented according to the next relation:

$$v = v_a = \frac{622 + d}{622} \cdot \frac{R_a T}{p} \tag{3}$$

where: v is the specific volume of humid air, equal to the specific volume of dry air v_a $[\text{m}^3/\text{kg}]$, R_a- the gas constant of air $[\text{J/kgK}]$.

The line of the partial pressure of water vapor is based on equation:

$$p_v = \frac{pd}{622 + d} \tag{4}$$

The part of the diagram situated below the saturation curve corresponds to a mixture formed of dry air and moisture, which is held by air in form of vapor and tiny droplets of liquid at saturation (wet vapor). It represents the mist zone.

The network of isothermal lines in the mist zone is constructed on the basis of relation:

$$h = c_{pa} t + \frac{d_{vs}}{1000}\left(r_0 + c_{pv} t\right) + \frac{d_{ls}}{1000} c_{pl} t \tag{5}$$

where: d_{vs} is the moisture content of air in form of dry saturated vapor at temperature t $[\text{g/kg}]$, d_{ls} - the moisture content of air in form of saturated liquid at the same temperature $[\text{g/kg}]$, c_{pl}- the constant - pressure specific heat of liquid water $[\text{kJ/kgK}]$.

The construction of the constant - quality curves in the mist zone is performed according to the following equations:

$$d_m = 1000 \frac{m_{moist.}}{m_a} = 1000 \frac{m_{vs} + m_{ls}}{m_a} \frac{m_{vs}}{m_{vs}} = 1000 \frac{1}{x} \frac{m_{vs}}{m_a} = \frac{d_{vs}}{x} = 622 \frac{1}{x} \frac{p_s(t)}{p - p_s(t)} \tag{6}$$

where: d_m is the moisture content of the humid air in the mist zone at temperature t $[\text{g/kg}]$, $m_{moist.}$- the mass of moisture (vapor and liquid at saturation) $[\text{kg}]$, m_a- the mass of dry air $[\text{kg}]$, m_{vs} - the mass of saturated vapor at temperature t $[\text{kg}]$, m_{ls}- the mass of saturated liquid at temperature t $[\text{kg}]$, x – the quality of wet vapor.

From its definition, the quality of wet vapor is calculated from:

$$x = \frac{m_{vs}}{m_{vs} + m_{ls}} \tag{7}$$

Based on equation (6), the moisture content of humid air in the mist state, corresponding to temperature t, can be determined for a certain value of the vapor quality.

For $x = 1$, we have $d_m = d_{vs}$; this means that this constant - quality curve coincides with the maximum relative humidity curve $\varphi = 1$. For the quality values $x < 1$, the intersection points of the moisture content lines d_m with the isothermal lines t will be situated on curves placed in the mist zone of h-d diagram.

The constant - quality curves permit the determination of the state of wet vapor for each point from the mist zone and also the expression of the parameters of humid air in the mist state, such as specific volume, density or specific heat.

The construction of the constant-volume lines in the mist zone is made using the relation:

$$v = \frac{V_a + V_{ls}}{m_a} = v_a + \frac{m_{ls} v_{ls}}{m_a} =$$
$$v_a + (1-x)\frac{m_{vs} + m_{ls}}{m_a} v_{ls} = \quad (8)$$
$$v_a + (1-x)\frac{d_m}{1000} v_{ls}$$

which can be also written in the form:

$$v = \frac{R_a T}{p} \frac{622 + x d_m}{622} + (1-x)\frac{d_m}{1000} v_{ls} \quad (9)$$

where: v_{ls} is the specific volume of saturated liquid $\left[\mathrm{m}^3/\mathrm{kg}\right]$.

Equation (8) was determined with the consideration that the mass of wet vapor is:

$$m = m_{ls} + m_{vs} \quad (10)$$

and the volume of humid air in the mist state is:

$$V = V_a + V_{ls} \quad (11)$$

since in the mixture air - wet vapor, $V_{vs} = V_a$.

The constant - volume lines in the mist zone are represented in prolongation to the constant - volume lines from the zone of unsaturated humid air.

The enthalpy of humid air in the mist state can be also determined with respect to the quality of wet vapor as:

$$h = c_{pa} t + \frac{x d_m}{1000}\left(r_0 + c_{pv} t\right) + \frac{(1-x) d_m}{1000} c_{pl} t \quad (12)$$

since:

$$d_{ls} = d_m - d_{vs} = d_m - x d_m \quad (13)$$

The equations of the state properties of humid air have been determined with the assumptions that air and saturated vapor are ideal gases and the quantities are related to humid air that contains one kilogram of dry air.

3. The Representation of H-d Diagram

For the graphical representation of h-d diagram for humid air, the program called H-d DIAGRAM was developed. It is based on the equations indicated in the previous chapter. The graphical representation is accomplished through the simulation of these equations. H-d diagram comprises the following lines:

- isothermal lines in the zone of unsaturated humid air;
- constant - relative humidity curves;
- isothermal lines in the mist zone of humid air;
- the vapor partial pressure line;
- specific volume lines in the zone of unsaturated humid air;
- the constant - quality lines of wet vapor;
- specific volume lines in the mist zone of humid air;
- constant - enthalpy lines.

These lines can be represented either on the same diagram (Fig.2) or independent (Fig. 4, 7, 8, 10) or grouped according to different criteria (Fig. 3, 5, 6, 9, 11).

The program can be improved in order to determine a parameter value of humid air with respect to the displayed graph and the position of the cursor on the graph.

4. Conclusions

H-d diagram for humid air completed with the constant-quality curves and the constant-volume lines constructed in the mist zone allows the determination of the vapor quality for each point of this zone in

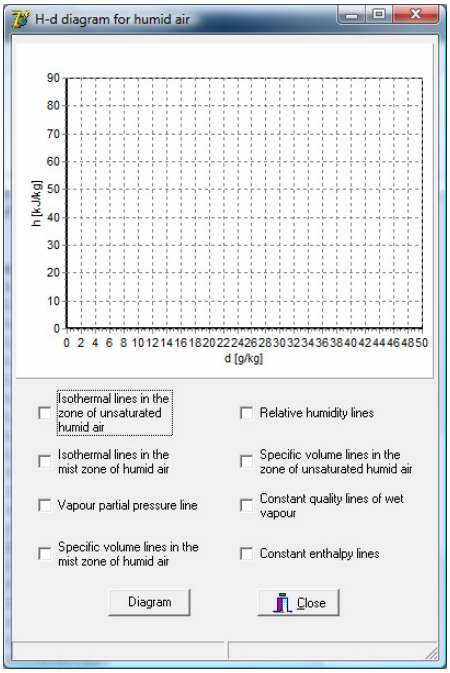

Fig. 1. *The main menu of the H- d diagram program*

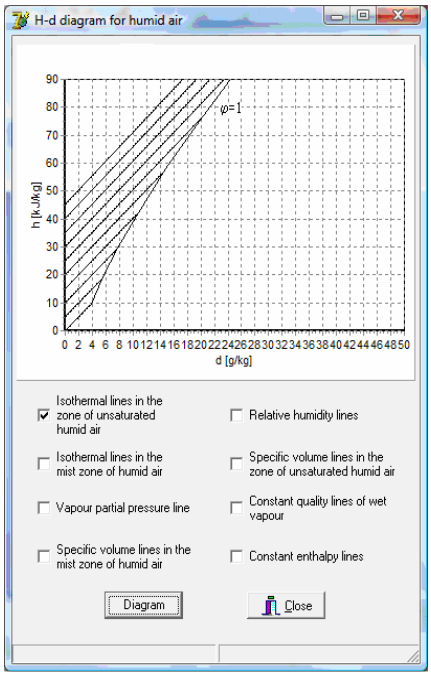

Fig. 3. *Isothermal lines in the zone of unsaturated humid air*

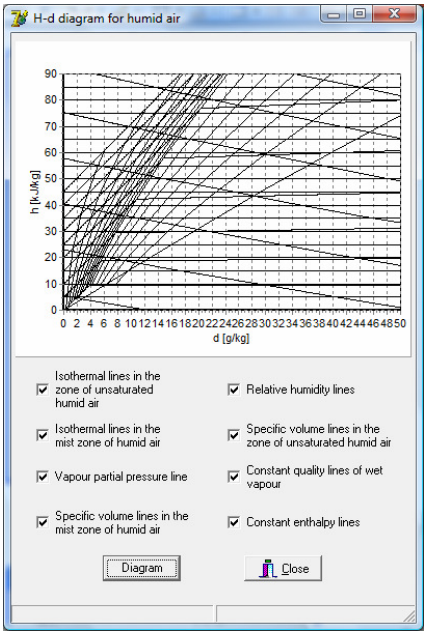

Fig. 2. *The h - d diagram respect with the moisture content of humid* air. Thus, the state of vapor in the humid air is more precisely specified.

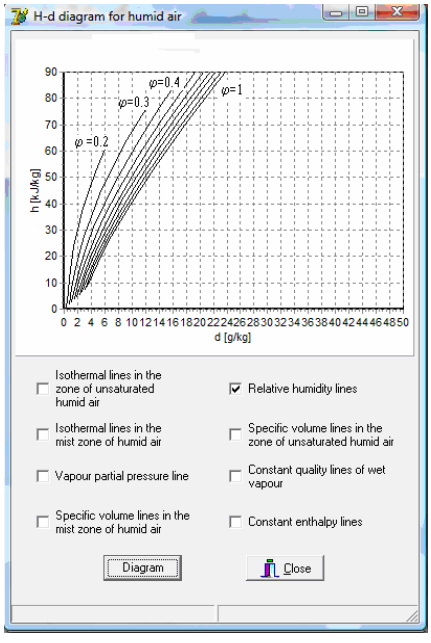

Fig. 4. *Relative humidity lines*

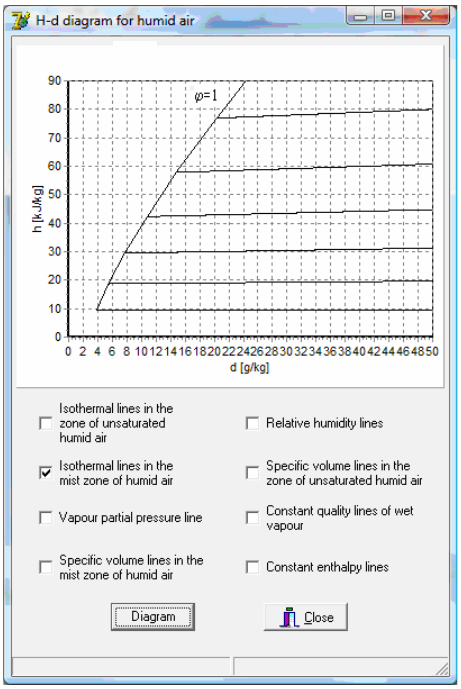

Fig. 5. *Isothermal lines in the mist zone of humid air*

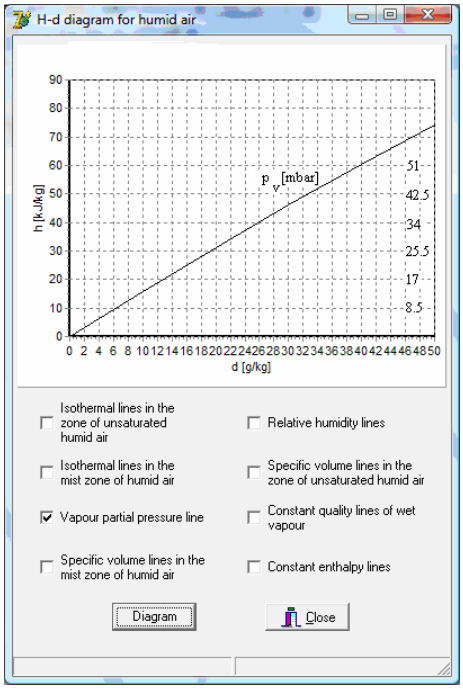

Fig. 7. *The vapor partial pressure line*

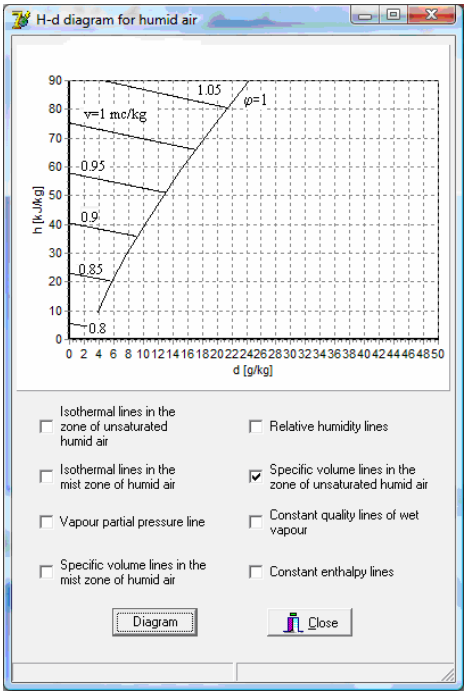

Fig. 6. *Specific volume lines in the zone of unsaturated humid air*

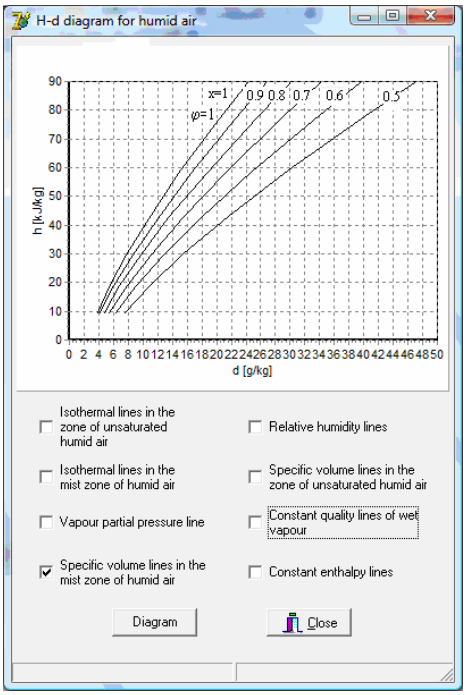

Fig. 8. *Constant - quality lines of wet vapor*

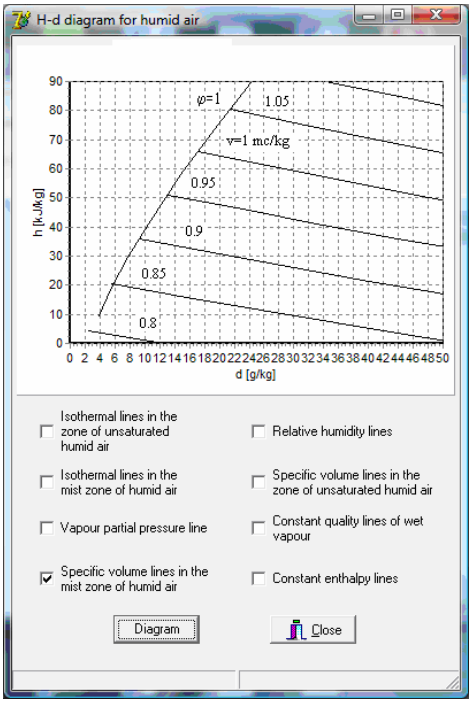

Fig. 9. *Specific volume lines in the mist zone of humid air*

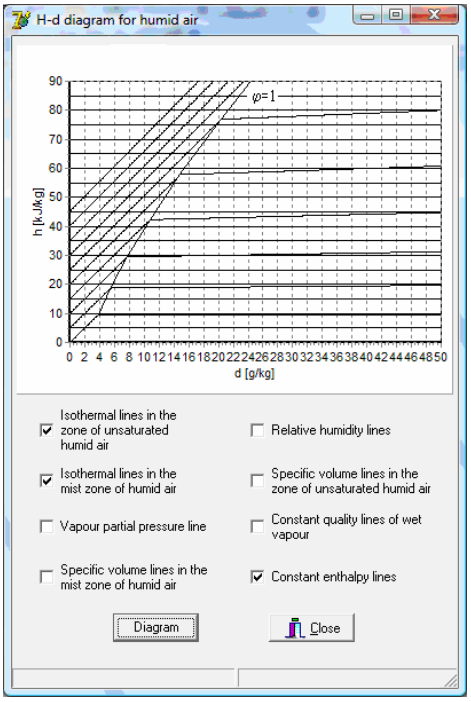

Fig. 11. *Isothermal lines in the zone of unsaturated and in the mist zone of humid air*

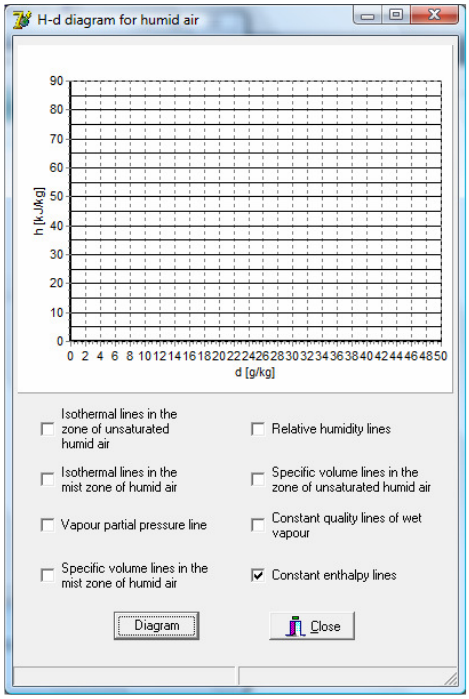

Fig. 10. *Constant enthalpy lines*

References

1. http://www.natmus.dk/cons/tp/mollier/moll1.htm.
2. Ražnjević, K.: *Tabele şi diagrame termodinamice*. Bucureşti. Editura Tehnică, 1978.
3. Shvets, I.T., Tolubinsky, V.I., Kirakovsky, N.F., Neduzhy, I.A., Sheludko, I.M.: *Heat Engineering*. Moscow. MIR Publishers, 1975.
4. Şova, M., Şova, V., Şova, D.: *Some Considerations Concerning the Construction and Application of the h-d Diagram for Humid Air in the Mist Zone*. In: Bulletin of the *Transilvania* University of Braşov, Vol. XXXV, Series A, 1993, p. 63-68.