GRAPSI_DRAW DIGITAL PSYCHROMETRIC CHART

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Abstract: Knowledge of psychrometric properties is the basic requirement for environmental measurements and drying processes. The software GRAPSI_DRAW is capable of calculating the psychrometric properties and simulating the basic psychrometric processes with the precision of analytical methods, also showing the results in charts plotted on the computer screen.

Keywords: psychrometry, engineering, graphical interface

1. INTRODUCTION

Psychrometry or hygrometry is the study of the thermodynamic properties of gas-vapor mixtures. Despite their numerous applications, psychrometric properties of the air are useful in heating, ventilating, air-conditioning, meteorology and grain storage (Zolnier, 1994).

A psychrometric chart is a graph of the physical properties of moist air at a constant atmospheric pressure. It expresses how various properties relate to each other, and is thus a graphical equation of state. The thermophysical properties found on most psychrometric charts are the dry bulb temperature, the wet bulb temperature, the dew point temperature, the relative humidity, the humidity ratio, the partial pressure, the saturation pressure, the enthalpy and the specific volume. The versatility of the psychrometric chart lies in the fact that by knowing two independent properties of some moist air, the other properties can be determined. The most widely used combinations are dry bulb temperature and relative humidity, dry and wet bulb temperatures and dry bulb and dew point temperatures (Navarro and Noyes, 2001; Wilhelm, 1976).

Since the atmosphere can be considered as a mixture of dry air and water vapor, at any given temperature, the pressure of the water vapor in the mixture can be any value equal to or less than the saturation pressure at that temperature. The vapor pressure is also called partial pressure and most often is used to describe the tendency of molecules and atoms to escape from a liquid or a solid. Saturation pressure corresponds to the pressure at which moist air starts boiling, at a given temperature. So, saturation pressure is the highest possible pressure at any given temperature (Brooker et al., 1992).

The dry bulb, wet bulb and dew point temperatures are important to determine the state of humid air. The dry bulb temperature is the most common used property of air. Its value refers basically to the ambient air and is measured by a normal thermometer freely exposed to the air but shielded from radiation and moisture (Zolnier, 1994). Wet bulb temperature is that of adiabatic saturation. This property is indicated by a moistened thermometer bulb exposed to the airflow. The adiabatic evaporation of water from the thermometer and the cooling effect is indicated by the wet bulb temperature lower or equal to the dry bulb temperature of the air. The rate of evaporation from the wet bandage on the bulb and the temperature difference between the dry bulb and wet bulb depend on the humidity of the air. The evaporation is reduced when the air contains more water vapor (Navarro and Noyes, 2001). The dew point temperature is that at which water vapor starts to condense out of the air or the temperature at which air becomes completely saturated. If the dew point temperature is close to the air temperature, the relative humidity is high and if it is well below the air temperature, the relative humidity is low (Brooker et al., 1992).

Humidity is the quantity of water vapor present in air. Relative humidity is the ratio of the mole fraction of water vapor to the mole fraction of saturated moist air at the same temperature and pressure. It is dimensionless and is usually expressed as a percentage. Humidity ratio, moisture content or humidity of air refer to the same quantity. This property differs from relative humidity in that it is the amount of water vapor by weight in the air. Generally it is defined as the mass of water contained in one kilogram of dry air (Wilhelm, 1976).

Enthalpy is the measure of the total energy in the air or the energy content per unit air weight. That is, enthalpy is the sum of the internal energy of the moist air in question, including the heat of the air and water vapor within. This property is read from where the appropriate wet-bulb line crosses the diagonal scale above the saturation curve. Air with same amount of energy may either be dry hot air (high sensible heat) or cool moist air (high latent heat) (Brooker et al., 1992).

Specific volume is the volume per unit mass of the air sample. In other words, this property represents the space occupied by a unit weight of dry air and is the reciprocal of the density (Navarro and Noyes, 2001).

Basic psychrometric processes are heating, cooling, adiabatic humidification and air mixing, which can be combined according to different applications or equipment (Leal et al., 2000). Heating of the air occurs when energy is absorbed from a heat source and cooling occurs when the air loses its heat energy. Neither heating nor cooling change the humidity ratio and the partial pressure. However, if cooling occurs beyond the dew point, the air becomes saturated. As the air continues to cool, the moisture vapour within the air will lose energy as well, some of which will condense back into moisture droplets and release its latent heat of vaporization (Brooker et al., 1992). The term adiabatic simply means without energy loss or gain. Dehumidification occurs when the air comes into contact with a substance that absorb moisture directly from the air. In this process, the latent heat of vaporization is released back into the air, raising its temperature and reducing the humidity ratio. The humidification is the opposite process. In both humidification and dehumidification the net overall enthalpy remains the same (Navarro and Noyes, 2001).

When two air samples of different states are mixed, the resulting air lies in between the straight line connecting the two initial conditions. That is, the resulting condition will vary in proportion to the relative masses of the two air streams (Brooker et al., 1992).

This work aims to relate the accuracy of the analytical methods used to estimate the psychrometric properties and processes to the versatility of the psychrometric charts. For this, a software, called GRAPSI_DRAW, was developed to perform the calculations and to show the results in a graphical way.

2. METHODOLOGY

The software GRAPSI_DRAW was written in Delphi 6.0 and was divided in three modules. In the first one the psychrometric chart scales can be changed and the properties at any point in the chart can be viewed moving the mouse over it. In the second module the properties of an specific state point can be calculated by means of the supply of two known properties. In this module the user has the option of viewing lines indicating how each psychrometric property is graphically obtained. In the third module, the basic psychrometric processes can be graphically simulated. These processes can be simulated sequentially, resulting in a more complex event, or they can be simulated individually, indicating independent events. In all modules, the resulting sets are also showed in a written report. As much the chart as the report can be saved for later analysis. Fig. 1 shows the basic algorithm of GRAPSI_DRAW.

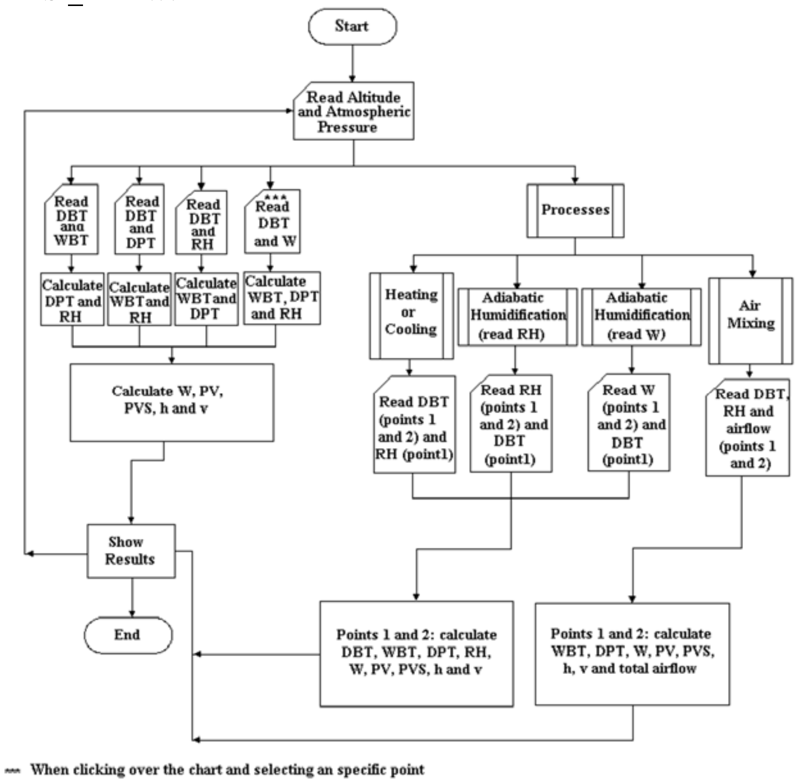

Fig.1: Basic algorithm of GRAPSI_DRAW.

The equations used by the software are based on the information available in the American Society of Heating Refrigerating and Air-Conditioning Engineers Handbook of Fundamentals (Ashrae, 1972). Some equations were modified to produce results in SI units and others were replaced with were more suitable because of better accuracy or ease of application under conditions such as wide range values (Zolnier, 1994; Navarro and Noyes, 2001; Wilhelm, 1976; Johannsen, 1981).

The saturation pressure must be accurate since it is used in calculating other properties. GRAPSI_DRAW uses equation 1 to determine this property due they be valid on a wide range of temperatures. Equation 1 is valid for temperatures from 0ºC to 374ºC (Johannsen, 1981).

$$\begin{aligned} PVS = (22087.83 \exp\left(\frac{0.01}{T}(100.98 - T)\sum_{i=1}^{8} F_i\,(0.65 - 0{,}01\,(T - 273.16))^{i-1}\right) \\ + 0.00141 \exp(0.0386(T - 273.16)))/1000 \end{aligned} \qquad (1)$$

Where: PVS is the saturation pressure (kPa), T is the temperature (K) and the values of F vary as:

$F_1 = -741.9242$ $F_3 = -11.552860$ $F_5 = 0.1094098$ $F_7 = 0.2520658$

$F_2 = -29.210$ $F_4 = -0.8685635$ $F_6 = 0.4399930$ $F_8 = 0.05218684$

By using the perfect gas relationships, equations 2 and 3 are used for calculating partial pressure and specific volume, respectively (Navarro and Noyes, 2001; Wilhelm, 1976; Brooker et al., 1982).

$$PV = \frac{P_{atm}\ W}{0.622 + W} \qquad (2)$$

$$v = \frac{0.28705\ T}{P_{atm}}(1 + 1.6078\ W) \qquad (3)$$

Where: W is the humidity ratio (g g^{-1}), PV is the partial pressure (kPa), v is the specific volume (m^3 kg^{-1}) and Patm is the atmospheric pressure (kPa).

Equation 4, used to estimate the humidity ratio, is based on an energy balance for an adiabatic saturation process. This considers that the enthalpy of the incoming air plus the enthalpy of the water added must equal the enthalpy of the saturated air at its thermodynamic wet bulb temperature (Wilhelm, 1976).

$$W = \frac{(2501 - 2.41\ WBT)\ W_S - 1.006\ (DBT - WBT)}{2501 + 1.775\ DBT - 4.186\ TWB} \qquad (4)$$

Where: WBT is the wet bulb temperature (ºC), DBT is the dry bulb temperature (ºC) and Ws is the humidity ratio at saturation (g g^{-1}).

To calculate the humidity ratio when the wet bulb temperature isn't known and at saturation equation 3 can be used.

Relative humidity, expressed in %, is defined as 100 times the ratio of the partial pressure divided by the saturated pressure at the same temperature (Johannsen, 1981).

Equation 5 is used to estimate the enthalpy. This equation considers that the enthalpy of the moist air is equal to the sum of the enthalpies of its components. So, the enthalpy of dry air was approximated closely as the product of specific heat and temperature, taking the value of specific heat equal to 1.006 J g^{-1} K^{-1} (Wilhelm, 1976).

$$h = 1.006\ T + W\,[2501 + 1.775\ T] \qquad (5)$$

Where: h is the enthalpy (kJ kg^{-1}).

Since the temperature of saturated vapor is dependent only on the absolute pressure, the dew point temperature is calculated by using equation 6 (Zolnier, 1994).

$$DPT = \frac{186.4905 - 237.3\ \log_{10}(10\ PV)}{\log_{10}(10\ PV) - 8.2859} \qquad (6)$$

Where: DPT is the dew point temperature (ºC).

The wet bulb temperature is derived using an iterative procedure. The software considers that this property lies somewhere between the dry bulb temperature and the dew point temperature. So, keeping enthalpy constant, the wet bulb temperature, starting from the dry bulb one, is decremented by a small delta and its correspondent relative humidity is calculated, until a value between 99.99 and 100% is found. The initial delta is 0.1 ºC but, if a relative humidity greater than 100% is verified, delta is divided by two and the temperature is incremented by it.

When simulating air mixing input data are dry bulb temperatures, relative humidities and airflow of two samples of air. Starting from this, the psychrometric properties of the two initial points are calculated and the final condition is obtained from mass and energy balances. Equations 7, 8 and 9 are used to estimate the dry bulb temperature, the humidity ratio and the airflow of the mixture, respectively. Other properties are calculate by making use of basic equations presented previously in this paper (Lopes et al., 2000).

$$DBT_M = \frac{u_1\ DBT_1 + u_2\ DBT2}{u_1 + u2} \tag{7}$$

$$W_M = \frac{u_1\ W_1 + u_2\ W2}{u_1 + u2} \tag{8}$$

$$h_M = \frac{u_1\ h_1 + u_2\ h2}{u_1 + u2} \tag{9}$$

Where: u is the airflow ($m^3\ h^{-1}$), index M denotes the mixture properties, index 1 denotes the first sample properties and index 2 denotes the second sample properties.

The required input data to simulate heating and cooling processes are the dry bulb temperatures of the two sate points and the relative humidity of the first one. With these input data, all psychrometric properties of the first point can be estimated by using the known equations. Since during these processes the humidity ratio and partial pressure are unchanged, the properties of the second point also can be calculated by using the same equations. Condensation is verified when the dry bulb temperature of point 2 is smaller than the dew point temperature of point 1. In this case, relative humidity of point 2 is assumed as 100% and the other properties, including the humidity ratio and the partial pressure, are calculated considering this new situation (Zolnier, 1994).

The adiabatic humidification can be simulated by knowing the relative humidities or the humidity ratios of two state points, besides the dry bulb temperature of the first one. As two properties of point 1 are known, the other psychrometrics properties of it can be easily calculated. Thus, keeping the enthalpy and, consequently, the wet bulb temperature constant, the properties of the second point can be also calculated by using the known equations. If humidity of second point is smaller than that of the first one, the dehumidification process is simulated.

3. RESULTS AND DISCUSSION

GRAPSI_DRAW was tested over a wide range of conditions and the results obtained from each module were compared to tabulated values. All results agreed well with the theory. The most notable differences were with dew point temperature and enthalpy which presented maximum errors of 1.5% and 1.0% at higher temperatures.

Figures 2 to 4 present examples of use of GRAPSI_DRAW for the three available modules.

As illustrated in Figure 2, using the module "Chart", the graph settings can be selected and psychrometric properties of different points can be estimated. The chart can be viewed by selecting the "Plot graphic" option. When passing the mouse over any area of the chart, main psychrometric properties are showed in the upper part of screen. All properties can be viewed in a report through a single click on some state point. Options "Save", "About" and "Exit" can be used to save the results, view information about the software and close the software, respectively.

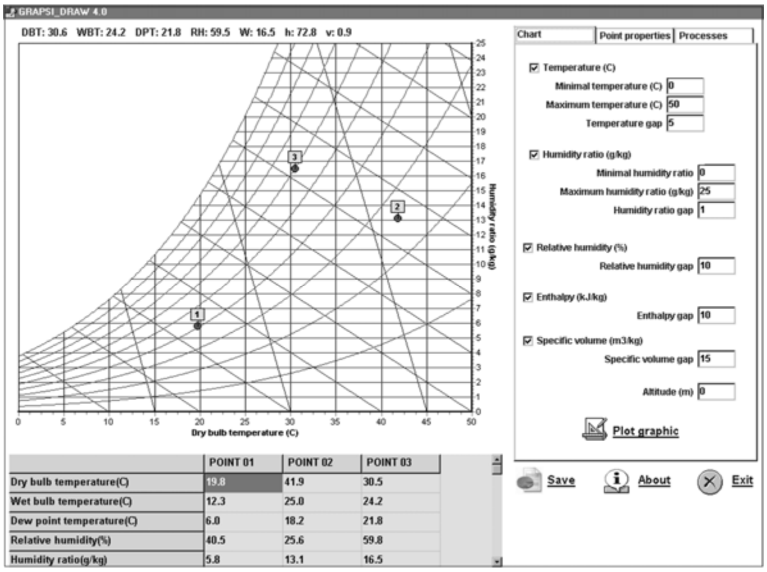

Fig.2: Module "Chart" of GRAPSI_CHART.

Figure 3 presents the software interface when the module “Point properties” is selected. User should inform the dry bulb temperature of the point and some one of the three other properties: wet bulb temperature, dew point temperature or relative humidity. The properties of the input point can be calculated by clicking on the “Plot graphic” option. An interesting feature of this module, which is useful for didactic purposes, is the possibility of viewing lines that illustrate how to read the chart. Also in this module graph and report can be saved.

Viewing Figure 4 it’s possible verify that various psychrometric processes can be simulated sequentially by using the module “Processes” of GRAPSI_DRAW, including cooling with condensation. After selecting the process and inform required input data, the user should only click on the “Plot graphic” option to view the results. When selecting “Clear” the chart and the report are deleted, allowing new simulations in combination or individually. As well as other modules, graphical and written results can be saved.

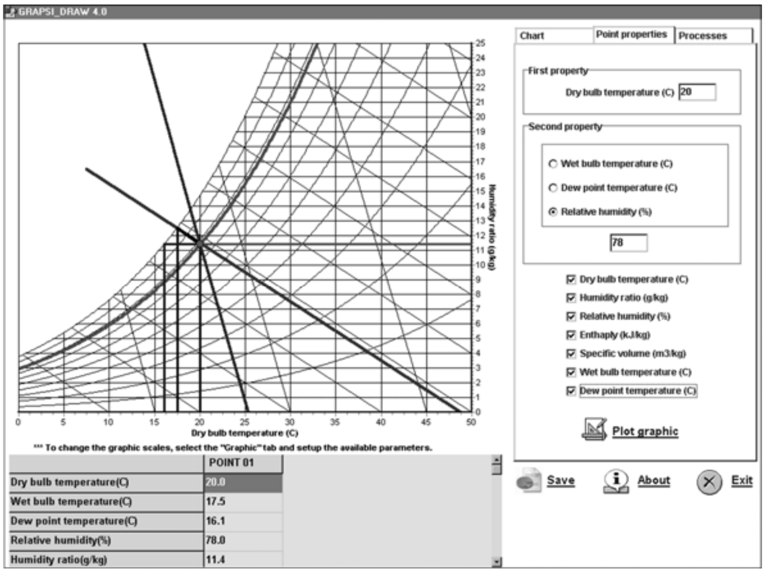

Fig 3: Module “Point Properties” of GRAPSI_CHART.

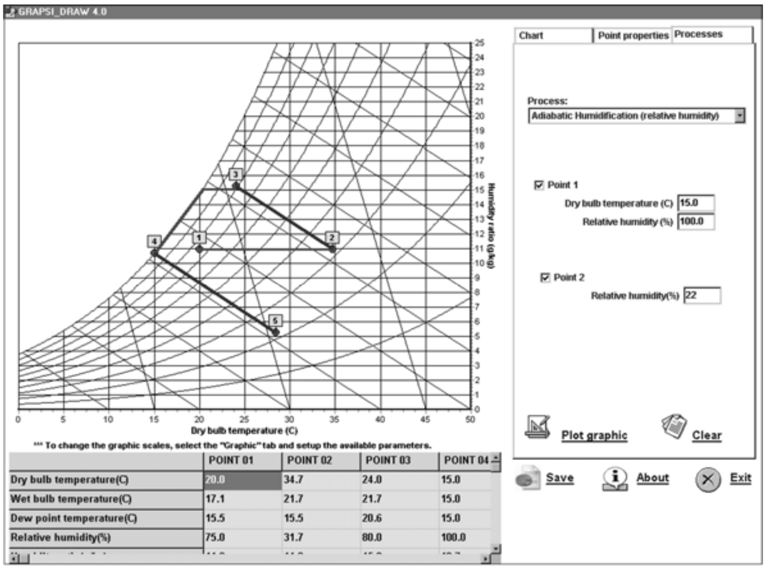

Fig 4: Module “Processes” of GRAPSI_CHART.

4. CONCLUSION

GRAPSI_DRAW is an efficient tool for all professionals that work with psychrometry. This software is capable of efficiently calculate the psychrometric properties of air and simulate psychrometric processes. Its friendly interface is suitable as for didactic purposes as for speeding up analysis involving psychrometry.

ACKNOWLEDGEMENTS

Funding for this research was provided by FAPEMIG (Fundação de Amparo à Pesquisa de Minas Gerais) from Brazil.

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