JOURNAL OF CHEMICAL EDUCATION

Technology Report

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# Using Interactive Psychrometric Charts to Visualize and Explore Psychrometric Processes

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Supporting Information

**ABSTRACT:** Proper knowledge of the psychrometric properties of air is essential in the design and operation of various food storage and processing systems, such as vegetable and fruit warehouses, convection dryers, and so on. Until recently, these psychrometric properties could only be determined from measurement data by complicated calculations or by reading old, inaccurate charts. In this technology report, we discuss the availability and pedagogical uses of an interactive, Web-based psychrometric chart that has been developed to accurately compute several thermodynamic parameters and to allow students to visualize the effects of changing conditions on psychrometric properties in a conducive digital interface. This open-source software is available online free of charge and can be used effectively both in education and for solving industrial and even scientific problems.

**KEYWORDS:** *Upper-Division Undergraduate, Graduate Education/Research, Chemical Engineering, Physical Chemistry, Internet/Web-Based Learning, Phases/Phase Transitions/Diagrams*

Psychrometry is a field of science concerned with the determination of the thermodynamic properties of gas–vapor mixtures, mainly those of moist air, the mixture of dry air and water vapor. These properties are the total (barometric) pressure, dry-bulb temperature, wet-bulb temperature, dew point temperature, relative humidity, humidity ratio, specific enthalpy, and so on. Because of its great practical importance in the design and operation of air-conditioning systems, cooling towers, and dryers, psychrometry is an essential part of the curriculum of chemical engineering, food engineering, and related fields. Also, it explains many everyday phenomena, such as the formation of clouds, fog, dew, or frost or how air conditioners work. Studying psychrometry can provide students with real-world examples that help them better understand abstract thermodynamic concepts.

## BRIEF OVERVIEW OF PSYCHROMETRY FUNDAMENTALS

Water evaporates when air touches its surface. Water vapor then exerts a force on that surface. The resulting water partial pressure of the air in the closest layer adjacent to the surface is equal to the *vapor pressure* that determines the total amount of water that can be evaporated into the air at a given temperature. In other words, the propelling power will be the difference between the chemical potentials of water in the air as a whole and at the surface. The mixture of the water vapor and the air can be considered as an ideal two-component gas system by the widely accepted simplification; thus, the chemical potentials are directly proportional to the logarithm of the partial pressures. At the point of saturation, the vapor pressure is so high that no more water can evaporate. This pressure is called the *saturation pressure*, and at this point, the *absolute humidity*—the quantity of water in the air (the ratio of the water vapor mass to the dry air mass)—is at its maximum and the relative humidity is 100%. By definition, the *relative humidity* is the ratio of the actual vapor pressure to the vapor pressure of saturated air at the same temperature. The *wet-bulb temperature* is measured with a moistened thermometer and it will be the lowest temperature that can occur under adiabatic saturation of the air by evaporating water only. Its value is always lower or equal to the dry-bulb temperature because of the cooling effect of the evaporation. The difference between the two values is proportional to the difference of the vapor pressures around the two thermometer bulbs. Therefore, it can be used to calculate the relative humidity. The *dew point* is the temperature to which the air has to be cooled at constant absolute humidity (i.e., without evaporation) to reach 100% relative humidity. At constant pressure, the *enthalpy* change equals the energy transferred between a system and its environment through heating or work other than expansion work.

We can see that these properties depend on each other. According to Gibbs's phase rule, the number of degrees of freedom (the number of independent state variables) equals the number of independent components minus the number of phases plus two at the thermodynamic equilibrium of a heterogeneous system. In our case, there are two components (air and water) in one phase. Therefore, the system can be described with only three free parameters. If we choose atmospheric pressure for one, we can draw a two-dimensional chart with one independent and one or more dependent variables to illustrate their relationships.

The first psychrometric chart appeared in the early 20th century, together with other humid air diagrams. The chart depicts psychrometric parameters and graphically presents an equation of state, thus eliminating the need for convoluted numerical computations, as shown in Figure 1. With the

**Received:** August 17, 2015
**Revised:** November 25, 2015

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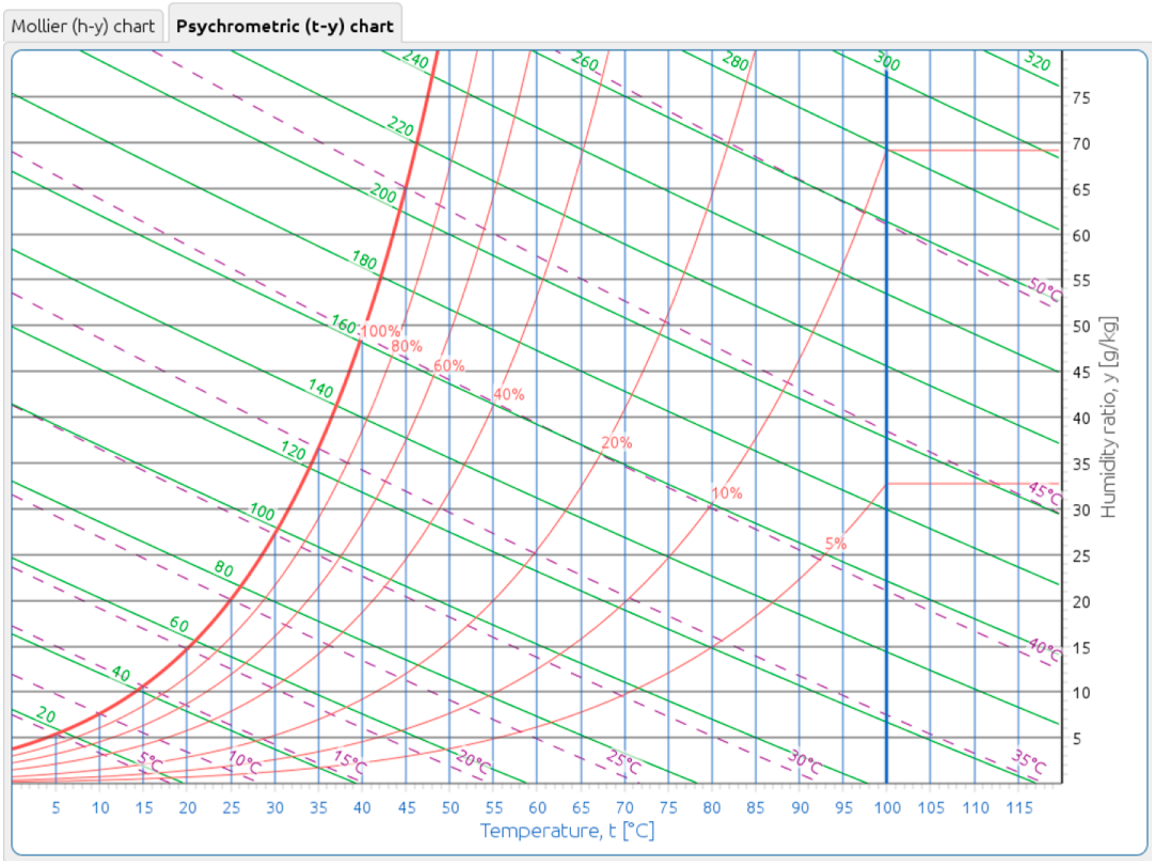


**Figure 1.** Psychrometric chart. The five determinant parameters are (1) dry-bulb temperature (blue lines), (2) wet-bulb temperature (purple dashed lines), (3) relative humidity (red curves), (4) humidity ratio (gray lines), and (5) specific enthalpy (green lines). The software[3] offers another form, the Molier ($h$–$y$) chart, as well; the lines are altered, however.

widespread use of calculators and computers, it is no longer used as a calculation tool. By 1990, approximately 75% of practitioners used the psychrometric chart, and the rest used computer software.[1] Still, the chart remains an ingenious way to visualize psychrometric processes and to build an engineer's intuition. Unfortunately, those who see it for the first time are liable to disagree with this statement.[2] With its densely packed, criss-crossing lines of at least five variables, it tends to be confusing or even intimidating for the beginning learner. After a bit of practice, however, anyone can master the reading of these charts. We created a tool with the intention of helping in this learning process.

## ■ EDUCATIONAL ASPECTS OF PSYCHROMETRY

Educational resources have gone through a significant evolution in the last few decades. For example, from the 1990s to recent years, the electronic e-materials of the Slovenian education system have transitioned from digitized d-textbooks through rich r-textbooks (with added audio and video content) to interactive i-textbooks.[4] By contrast, in Hungary only printed (or at most digitized) textbooks customarily are used. We have now tried something new by creating a psychrometrics workbook[3] in the form of an open-source, platform-independent, interactive Web site using standard HTML and JavaScript technology. The charts are made with JSXGraph, a cross-browser library for interactive geometry, function plotting, and data visualization, implemented by a group of mathematicians at the University of Bayreuth, Germany.[5]

The resulting Web site is very simple and easy to use. On the top of the page, a table has rows representing a state and columns containing the state variables. It works the same as any spreadsheet software users are already familiar with by filling in any two cells the other parameters are computed and displayed automatically, together with the related state point on the charts. The values are rounded to the correct number of significant figures, which is calculated from the precision of the input data, as implied by their number of significant figures. The Gaussian rule of the propagation of uncertainty was applied to determine the significant figures. Graphical data input is also possible: the user can place a new state point on the chart with a click of the mouse, and the corresponding state variables are automatically fill in the table. By dragging that point, the values are immediately refreshed.

A common difficulty among students is discriminating between the lines corresponding to the different variables represented conventionally as a black-and-white chart. We removed this first obstacle simply by assigning unique colors to the parameters and using them consistently across the different charts. Green lines and figures are for enthalpy, blue ones are for the dry-bulb temperature, black ones are for the absolute humidity ratio, red ones are for the relative humidity, and the purple ones are for wet-bulb temperature. On the traditional printed charts, isolines run quite close to each other to aid the graphical interpolation when reading. Because this is not necessary on the computer, we created a significantly sparser display than usual, which is easier to view and less overwhelming for the students.


DOI: 10.1021/acs.jchemed.5b00779
*J. Chem. Educ.* XXXX, XXX, XXX–XXX

To help with interactive teaching,[6] we have also developed exercises ranging from the simple task of locating an isoline to more complicated calculations involving four state points in a convection dryer. Although there are only ten basic types of exercise, the data are randomly generated (within reasonable limits), which makes the total number of challenges virtually unlimited. Whenever possible, the software uses animation to present the correct solutions for the problems. With this extra feature, our interactive, Web-based psychrometric chart can be used effectively in large-lecture science courses. The teacher or lecturer can adapt low-cost Arduino platforms with LED, LCD, or dot-matrix displays[7] that are large enough to present the figures from thermometers measuring the wet- and dry-bulb temperatures for individual or joint calculations of the other parameters of the ambient air. Students can also follow the lecturer's instructions according to the projected readings[8] on a large screen, or on their laptops, tablets, or smartphones. Students can also interact with the chart independently, investigating psychrometry concepts outside of school.

For the sake of lucidity, the Supporting Information contains a practical numerical example on a summertime air-conditioning task: preparing a prescribed condition of indoor air from a given condition of outdoor air. The solution is obtained step-by-step in detail, and it is illustrated with screenshots of the psychrometric charts online.[3]

## ■ CONCLUSIONS

The interactive psychrometric chart described here could be incorporated quite easily into chemistry or related engineering curricula. Thus, chemistry instructors and students can interact with the chart and concepts in either lectures or laboratory practices.

Besides its educational use, this psychrometric software can also be a helpful tool for practicing engineers because it was created using the most accurate formulas and algorithms. We take into account several phenomena that are usually ignored during such calculations, such as the temperature dependence of the latent heat of the water. The numerical details (special thermodynamic equations, evaluating strategies of the different unknown parameters) are out of the scope of this technology report and will be published elsewhere.

## ■ ASSOCIATED CONTENT

### Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.5b00779.

Fully developed practical numerical example: a summer-time air-conditioning task. (PDF)

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### Notes

The authors declare no competing financial interest.

## ■ ACKNOWLEDGMENTS

The research was supported partially by TÁMOP-4.1.1.C-12/1/KONV-2012-0004.

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DOI: 10.1021/acs.jchemed.5b00779
J. Chem. Educ. XXXX, XXX, XXX−XXX