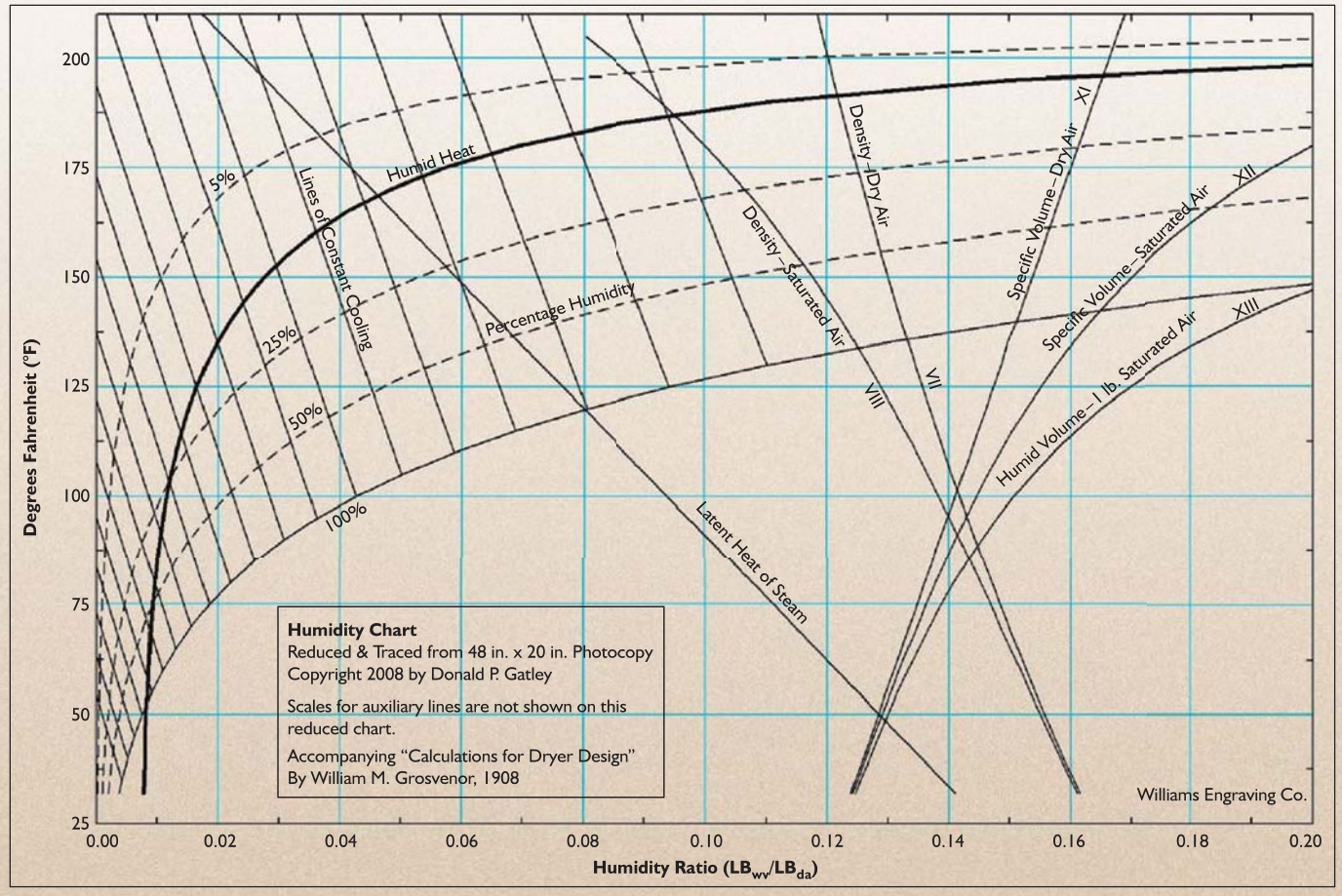

Figure 1: Supplement to **Transactions of American Institute of Chemical Engineers, Volume 1,** ***published in 1908.***

GROSVENOR HUMIDITY CHART

By Donald P. Gatley, P.E., Fellow/Life Member ASHRAE

ASHRAE Journal and designers of air conditioning, drying, dehumidification, food science and humidification processes, and meteorologists celebrated the 100th anniversary of Willis H. Carrier's hygrometric chart in 2004.[1] Four years later, we celebrate the centennial of the humidity chart produced by William Mason Grosvenor Jr., Ph.D., a chemical engineer of New York City. Both charts are now known as psychrometric charts in most of the world and as Mollier h-x charts in parts of Europe.

A quick comparison of the lives of the two chart creators is shown in the sidebar "Lives of William Mason Grosvenor and Willis Haviland Carrier." Grosvenor and Carrier were recent college graduates and newly employed in an industry that would benefit significantly from the psychrometric chart. They were committed to helping other engineers in their fields by developing and sharing more accurate and less tedious design methods.

Grosvenor Humidity Chart

Grosvenor's chart (*Figure 1*) accompanied his 19-page manuscript in volume one (1908) of the *Transactions of the American Institute of Chemical Engineers*.[2] The chart and humidity table required more than 3,000 tedious calculations. To the untrained eye, the Grosvenor Humidity Chart bears little resemblance to the Carrier chart primarily because the abscissa and ordinate coordinates are

About the Author

Donald P. Gatley, P.E., is a retired consulting engineer and moisture consultant. He is the author of *Understanding Psychrometrics, 2nd edition* published by ASHRAE.

exchanged, and the Grosvenor chart extends the temperature from 105°F to 250°F and the humidity ratio from 0.026 to 0.200 lb_{wv} /lb_{da}. *Table 2* compares the two charts.

Because of the exchanged plotting coordinates, a realistic visual comparison requires rotating one of the charts 90° and then viewing it from the reverse or flipping it horizontally. Tim Padfield, a retired museum conservator, graphically explains the comparison at www.padfield.org/tim/cfys/mollier/moll3.php.

The Grosvenor chart is ideally suited for the higher temperatures and moisture contents of drying. The Carrier chart is ideally suited for the field of air conditioning.

Grosvenor Chart "Firsts"

Grosvenor is sometimes cited as the creator of the first psychrometric chart. This requires a definition of what a chart must be for it to earn the "first" distinction. The 2004 ASHRAE Journal article cites an 1865 instrument patent with a chart having many of the properties displayed on the Carrier and Grosvenor charts. For our purpose, Grosvenor and Carrier are both psychrometric pioneers who contributed significantly to the current ASHRAE psychrometric chart. Grosvenor chart firsts include:

- First chart to plot moisture content as the ratio of the mass of water vapor to the mass of dry air in the sample of moist air. This simplified calculations. A majority of later psychrometric charts followed the lead of Grosvenor.
- First chart in a peer-reviewed publication. Carrier's chart printed in a Buffalo Forge catalog preceded Grosvenor's by two years. Carrier's landmark peer-reviewed paper, "Rational Psychrometrics," was published three years later in 1911 by ASME.
- First chart to place temperature on the vertical scale and moisture content (humidity ratio) on the horizontal scale. The Grosvenor chart resembles the later 1923 Mollier chart.[3] It is possible that Mollier patterned his chart after that of Grosvenor. Mollier's significant contribution from that chart was the use of a skewed enthalpy coordinate replacing the vertical temperature coordinate. ASHRAE adopted the skewed enthalpy coordinate in 1961.
- Many psychrometric charts introduced after 1908 included auxiliary isolines as an aid to the design engineer. The Grosvenor chart included the following isolines:
  - Specific heat of humid (saturated) air;
  - Density of saturated moist air;
  - Density of dry air;
  - Specific volume of saturated moist air;
  - Specific volume of dry air; and
  - Latent heat of vaporization of steam.
- The Grosvenor chart also included "straight lines of cooling by evaporation." On current charts the labels for these lines would be either thermodynamic wet-bulb temperature or enthalpy. Analysis of Grosvenor's equations suggests that these are actually lines of constant enthalpy. Grosvenor used these lines in constructing the sequence of processes in a drying cycle. The lines were not identified as enthalpy or wet-bulb lines but merely served as an alignment tool to connect the leaving statepoint of the dryer-reheat process to the leaving-air statepoint of the evaporative drying process. It is not known if Grosvenor intended these lines to be wet-bulb lines or enthalpy lines. The difference is small since enthalpy and wet-bulb lines are nearly parallel.

Lives of William Mason Grosvenor And Willis Haviland Carrier

William Mason Grosvenor: 1873–1944

Secondary Education
Greenwich Academy, Connecticut
College
Brooklyn Polytechnic Institute
Johns Hopkins University
Pennsylvania University, Ph.D.—Thesis: Electrolytic Reductions
Field of Study
Chemical Engineering
Career Years
1898-1940
Employment That Lead to the Chart
Dryer Engineering Co. (1907–08)
Field of Work
Drying of chemicals & pharmaceuticals
Career Locations
New York City and New Jersey

Willis Haviland Carrier: 1876–1950

Secondary Education
Angola New York schools
College
Cornell University
Field of Study
Mechanical and Electrical Engineering
Career Years
1901–1950
Employment That Lead to the Chart
Buffalo Forge (1901–1915)
Field of Work
Air Conditioning
Career Locations
Buffalo, N.Y., Syracuse, N.Y. and Newark, N.J.

Grosvenor's Career

Grosvenor spent about three years of his career in the drying industry as shown in the sidebar "Career of William Mason Grosvenor Jr." He made a major contribution with his chart and then moved on to other fields of chemical engineering. He applied for a drying system patent in 1910 (No. 1,119,011 issued in 1914), which proposed a recirculation drying arrangement offering simplification and increase in economy. Most of his career

was as a self-employed chemical engineer at W.M. Grosvenor Laboratories.

Grosvenor was an active leader in his industry and his remarks appear in the archives of New York papers when searching the Internet. He was a member of American Association for the Advancement of Science, American Chemical Society, Association of Consulting Chemists, Chemist's Club of New York, Professional Engineers Association, Societe Chimique de France, Society of Chemical Industry (SCI), and Chair of the American International Group 1915–16. SCI maintains good member records and Ms. Baston of the London Headquarters reports: "he was issued at least eleven patents between 1900 and 1944 covering drying, coatings, combustible gases, the manufacture of glue, and apparatus for determining the properties of fluids."

A New York Times article on April 22, 1916 writes of Grosvenor's remarks at an SCI meeting at the Chemist's club. The U.S. textile industry was heavily dependent on dyestuffs from Germany, and Grosvenor stated that Germany had recently agreed to send 16,000 tons (14 500 Mg) of dyestuffs to the U.S. This was during World War I. The textile industry could not obtain dyestuffs because all of the raw materials necessary to make dyestuffs in the U.S. were being used in the manufacture of high explosives, which were being exported to the warring countries in Europe.

Grosvenor's Drying System

The common method of drying chemicals and pharmaceuticals in 1908 used steam-heated air, which was passed over drying racks. Most systems used 100% outside air. In winter, the fuel requirements to produce the steam were high. Some drying operations tried recirculated air but soon realized that the moisture content of the recirculated air would rise to the point that no drying occurred.

Grosvenor promoted the concept of using a dehumidification cycle to drastically reduce energy consumption and better control the quality of the dried product. *Figure 2* is a drawing from Grosvenor patent 1,119,011, Drying System, dated March 8, 1910 and issued Dec. 1, 1914. The diagram shows a refrigerant com-

	Grosvenor Humidity Chart	Carrier Hygrometric Chart
Overall Chart Size	48 in. x 20 in.	11 in. x 8.5 in. (Also a Larger Blueprint)
Chart Ordinate	0–250°F	0–13 $grains_{wv}/ft^3$ (0–0.026 lb_{wv}/lb_{da})
Chart Abscissa	0–0.20 lb_{wv}/lb_{da}	20–105°F

Table 1: Overview of two early psychrometric charts.

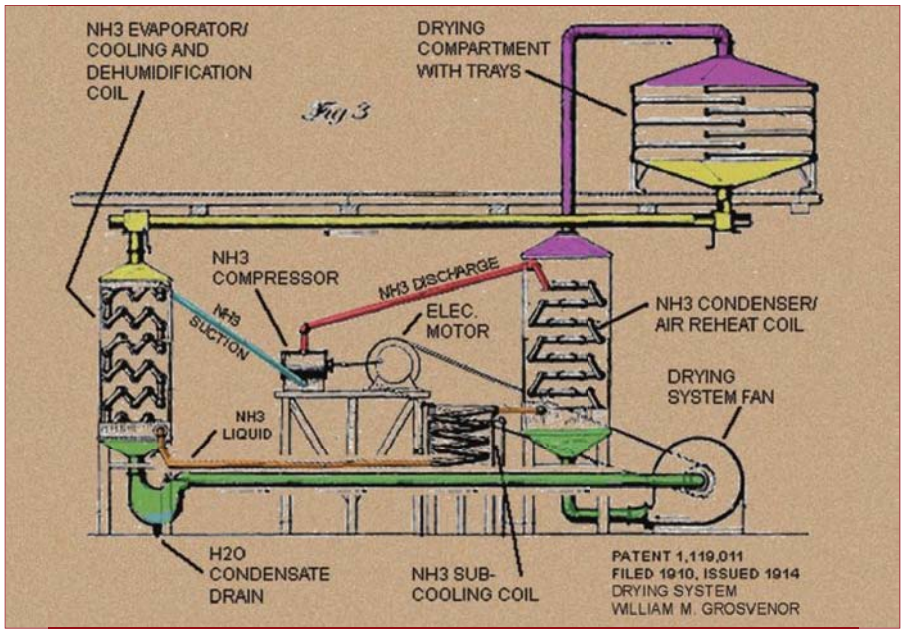

Figure 2: Grosvenor patent 1,119,011, Drying System, dated March 8, 1910, and issued Dec. 1, 1914. Color key: air conduits are shown in pink, yellow and green. Water condensate is shown in blue at lower left. Ammonia is show in blue (suction), red (discharge) and orange (liquid).

pressor, pipe coils for the condenser and evaporator, the drying chamber in the upper right, the fan and the conduits for conveying the moist air from the drying chamber to the dehumidification chamber to the reheating chamber and back to the drying chamber.

More Chart Anniversaries

Are there future psychrometric chart centennial anniversaries? This ASHRAE Journal article and the 2004 article covered the major contributions to the development of the psychrometric chart as we know it today. One significant contribution is yet to be celebrated: *Changing from the rectangular plotting coordinate of temperature to the oblique plotting coordinate of enthalpy*. The credit for this accomplishment is usually given to Richard Mollier in 1923.[3] Leonid K. Ramzin (1887–1948), a teacher and researcher at the Moscow Maximum Technical School (now the N.E. Bauman Moscow State Technical University) may have created an enthalpy–humidity diagram in 1918 for personal use in lectures and design of drying apparatus for peat. Two 1927 papers by M.J. Lurie[4,5] discuss the underlying calculations for a Ramzin circa 1925 diagram and list as a reference the Mollier 1923 paper. Readers from Russia and Eastern Europe are encouraged to look in their libraries and other sources to locate and forward a photocopy of an actual 1918 Ramzin diagram and any accompanying paper in Russian with English translation.

Readers may also help the author concerning the origination or early use of the

descriptor "temperature of adiabatic saturation." Carrier used this term in his 1911 paper but never claimed to have been the first to use it. A reviewer of Carrier's paper, Prof. G.A. Goodenough (University of Illinois) commented that this descriptor would not be recognized by many, even those fairly familiar with thermodynamic principles. Perhaps, Carrier acquired the term from another field, or he was the originator after all.

ASHRAE Journal welcomes reader suggestions for articles on other psychrometric charts or early history. These could include the Otto H. Mueller 1905 State Diagram of Moist Air with enthalpy–temperature coordinates, as well as the Skew-T Log P diagram and similar charts used by meteorologists in the 20th century.

Career of William Mason Grosvenor Jr.

Date	Employment
1896	Chemist, Mathieson Alkali Works Inc., Virginia (probably an interim job while pursuing his Ph.D.)
1898–99	Metallurgist, Millview Mining Co.
1899	Engineer, Ampere Electrochemical Co.
1900–02	Assistant Research Superintendent, General Chemical Co., Bayonne, N.J.
1903–04	Assistant Manager, General Chemical Co., Bayonne, N.J.
1905	Superintendent, Contact Process Company
1906	Engineer, George F. Westcott Co.
1907	Engineer, Dryer Engineering Co.
1908–40	W.M. Grosvenor Laboratories

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