Applied Thermal Engineering 50 (2013) 511–515

Contents lists available at SciVerse ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Simple predictive tool to estimate relative humidity using wet bulb depression and dry bulb temperature

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HIGHLIGHTS

- ► Rapid estimation of relative humidity percent using wet-bulb depression and temperature.
- ► Development of an accurate and simple mathematical predictive tool using Vandermonde matrix.
- ► Monitoring relative humidity parameter using a simple technique without expensive experimental trials.

ARTICLE INFO

Article history:
Received 28 March 2012
Accepted 29 July 2012
Available online 14 August 2012

Keywords:
Relative humidity
Wet bulb depression
Predictive tool
Water vapor

ABSTRACT

In this work, a simple predictive tool is presented to estimate relative humidity as a function of wet bulb depression and dry bulb temperature. The predictive tool is simple, straightforward, and can be readily implemented in any standard spreadsheet program leading to accurate, smooth, and non-oscillatory datapoints. The prime application of the method is as a quick-and-easy evaluation tool in conceptual development and scoping studies where the estimation of the relative humidity, as a function of wet bulb depression and temperature, is being considered. Results from the proposed correlation are successfully compared to available data in the literature for a wide range of wet bulb depression and dry bulb temperatures. This gives us the confidence to offer our findings for engineering applications where a rough and ready programmable estimate is sought.

1. Introduction

The amount of moisture air can hold is dependent on its temperature and pressure [1]. The warmer the air the more water vapor it can contain. Dry bulb temperature, usually referred to as (air) temperature, is the air property that is most commonly measured [2–4].

When people refer to the air temperature, they are normally referring to the dry bulb temperature. It is called "dry bulb" because the air temperature is indicated by a thermometer not affected by the air moisture [1,2].

Wet bulb temperature, on the other hand, is the temperature indicated by a moistened thermometer bulb exposed to the air flow. Wet bulb thermometer can be measured using a thermometer with the bulb wrapped in wet muslin. A wet bulb thermometer measures the extent of cooling as moisture is removed from a surface (evaporative cooling). The wet bulb temperature is always lower than the dry bulb temperature except when there is 100% relative humidity, making the wet bulb temperature a more accurate measurement of temperature [3–5]. The temperature difference in degrees between dry-bulb temperature (temperature hereafter) and wet-bulb temperature is called the wet-bulb depression [2,3]. This wet-bulb depression then allows the relative humidity to be calculated; as will be explained in the forthcoming discussion. Relative humidity is the amount of water vapor present in the air relative to the full saturation case, i.e. when air cannot hold any more water (moisture). More accurately, the relative humidity is the ratio of the actual amount of moisture in the air to that of the saturated air at the same temperature.

Given the fat that in a large number of engineering applications, including wet cooling towers and air conditioning, knowing the relationship between relative humidity and wet bulb depression for a given temperature is of paramount importance, next section briefly touches on a theoretical analysis of the problem before we move on to introduce the new predictive tool developed in this study.

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http://dx.doi.org/10.1016/j.applthermaleng.2012.07.033

Table 1
Tuned coefficients for equations (13)–(16).

Coefficient	Value
A_1	1.596472429981
B_1	$2.526542976345 \times 10^{3}$
C_1	$-7.081061499914 \times 10^{5}$
D_1	$6.633490667299 \times 10^{7}$
A_2	2.006008608747
B_2	$-1.682514867194 \times 10^{3}$
C_2	$4.663714465255 \times 10^{5}$
D_2	$-4.42695433801 \times 10^{7}$
A_3	$-2.555047611301 \times 10^{-1}$
B_3	$2.148937854907 \times 10^{2}$
C_3	$-6.02086366306 \times 10^{4}$
D_3	$5.618611709148 \times 10^{6}$
A_4	$6.05401959589 \times 10^{-3}$
B_4	-5.044770954636
C_4	$1.400091203898 \times 10^{3}$
D_4	$-1.295789496968 \times 10^{5}$

1.1. Theoretical background

The relative humidity of an air–water mixture is defined as the ratio of the partial pressure of water vapor in the mixture to the saturated vapor pressure of water at the same temperature [5], i.e.

$$\gamma = \frac{P_{\mathrm{w}}}{P_{\mathrm{ws}T_{\mathrm{a}}}} \tag{1}$$

The wet-bulb temperature can be estimated from the following well-known psychrometric relation

$$P_{\mathrm{w}} = P_{\mathrm{s}T_{\mathrm{wb}}} - B'(T_{\mathrm{a}} - T_{\mathrm{wb}}) \tag{2}$$

Furthermore, the approximation can be used to correlate the pressure difference with the wet-bulb and dew point temperature

Table 2
Comparison of calculated values with typical data.

Temperature, °C	Wet-bulb depression, °C	Reported data [6]	Calculated values	Absolute deviation percent
−10	1	92	92.7	0.76
0	2	86	86.4	0.46
10	3	82	81.5	0.61
20	4	78	77.6	0.51
30	5	75	74.5	0.66
40	6	72	72.1	0.13
−10	7	57	56.3	1.22
0	8	55	54.6	0.72
10	9	54	53.4	1.11
20	10	53	52.4	1.13
30	11	52	51.7	0.58
40	12	51	51.1	0.20
−10	13	34	33.7	0.88
0	14	34	33.9	0.29
10	15	34	34.3	0.88
20	16	35	34.8	0.57
30	17	35	35.3	0.85
40	18	36	35.7	0.83
−10	19	20	19.6	2
0	20	21	20.5	2.38
10	21	22	21.5	2.27
20	22	23	22.6	1.74
30	23	24	23.6	1.66
40	24	25	24.6	1.6
−10	25	11	11	0
0	26	12	11.9	0.83
10	27	13	13	0
20	28	14	14.2	1.42
30	29	15	15.4	2.66
40	30	17	16.8	1.17
Average absolute deviation, percent				1%

$$P_{\mathrm{s}T_{\mathrm{wb}}} - P_{\mathrm{w}} = \Delta\left(T_{\mathrm{wb}} - T_{\mathrm{dp}}\right) \tag{3}$$

Eliminating pressure differences from Eqs. (2) and (3), we have

$$B'(T_{\mathrm{a}} - T_{\mathrm{wb}}) = \Delta\left(T_{\mathrm{wb}} - T_{\mathrm{dp}}\right) \tag{4}$$

or

$$T_{\mathrm{wb}} = \frac{B'T_{\mathrm{a}} + \Delta T_{\mathrm{dp}}}{B' + \Delta} \tag{5}$$

where B' is the thermodynamic value of the psychrometric constant given (for air) as

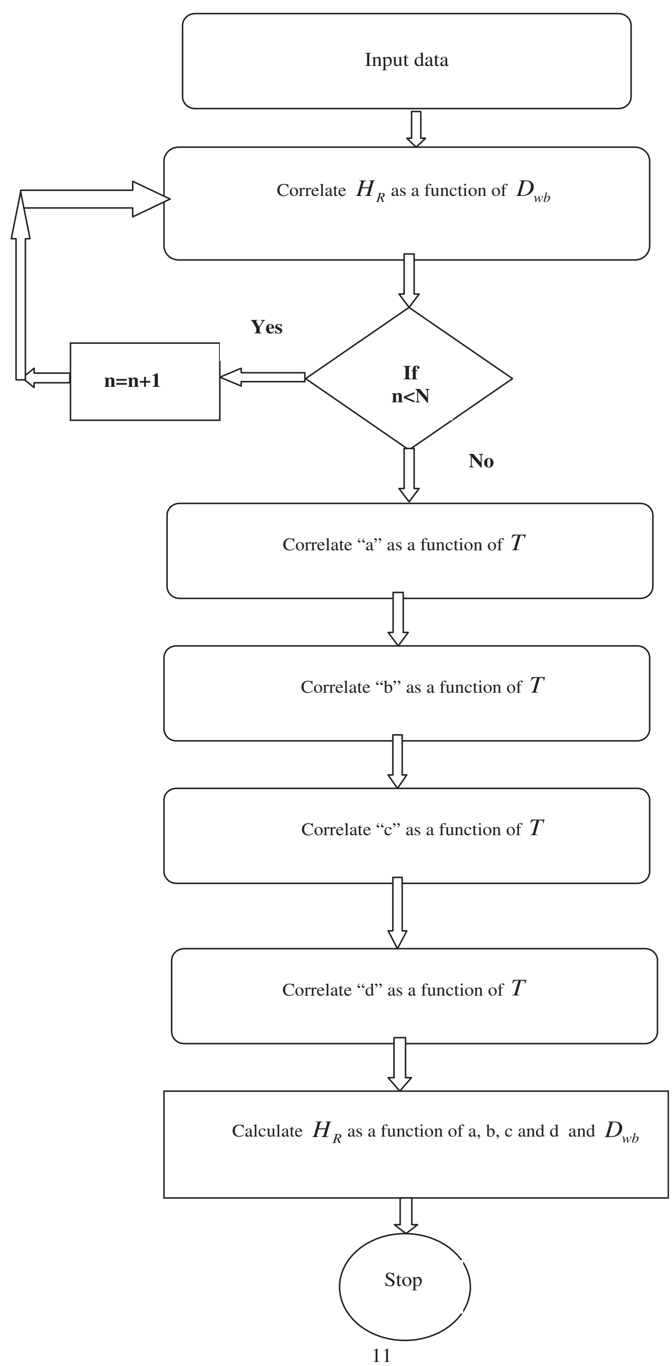

Fig. 1. General workflow of algorithm used for tuning the coefficients in Eqs. (13)–(16).