Newly Established Hydrometer Calibration Set Up at UM

Ümit Y. AKÇADAĞ, S. Eren SAN

TÜBİTAK, Ulusal Metroloji Enstitüsü (UME)

Gebze – Kocaeli, Turkey

Abstract

Hydrometer calibration could be performed by 'Cuckow Method' in which just a single liquid is sufficient for the calibration of the whole scale. Hydrometers are weighed first in air and then in a reference liquid in this method. The density of the reference liquid is well known and it is possible to determine the associated density value of the graduation mark by making use of weighing values and the density value of liquid in related formulas. The entire scale of Hydrometer can be calibrated in this way by immersing the hydrometer to the interested scale marks. In this paper, hydrometer calibration set up of UME is introduced and obtained measurement results from this set up are given for a sample hydrometer.

1. Introduction

Hydrometers play an important role in the accurate and reliable density measurements of liquids. This equipment is designed in such a way that the density value of the liquid corresponds to the scale mark at which hydrometer floats freely. They must be calibrated and traceable so that their applications become satisfactory. A general view of this glass equipment is shown in Figure 1.
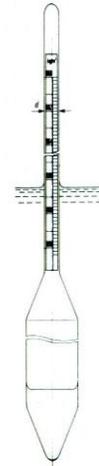

Figure 1. Hydrometer

In the process of calibration; several liquids were used as reference until Cuckow, who introduced a method allowing the usage of a

single reference liquid for the calibration of different scale marks. This method saves time and decreases the expense of the calibration procedure by reducing the reference demand to just one liquid whose density is well known [1].

2. Method and Theory

The method is based on weighing of the hydrometer when it has been floating at the scale mark, which is supposed to be calibrated. Density of the liquid must be previously measured.

Hydrometer experiences an upthrust equal to its weight when it is immersed up to the scale mark and order of upthrust is proportional to the amount of immersion. If we weigh the body immersed to interested extent in two media of known density it would be possible to determine the density corresponding to interested extent which is supposed to be a scale mark. Application of this procedure requires special apparatus and special designs for sensitive immersion.

Theory of the method is based on the fact that, if we weigh a solid body at a point in between two media whose densities are known we may find the density of the medium in which the upthrust on the immersed portion would be equal to the weight of the body. One can exploit this principle in such a way that hydrometers are firstly weighed in air and then in a reference liquid of known density, which is used as reference. The weighing value is measured while the hydrometers were immersed up to different levels and the corresponding density values of different immersion levels could be determined by linear extrapolation [1,2,3].

Theoretical analyses starts from the weighing equations. If a hydrometer freely floats in a liquid we can write,

$$m + \frac{\pi.D.\gamma_1}{g} = V\rho_L + v\rho_1 \qquad (1)$$

In the case of weighing in air below equation holds,

$$W_2 = m - V\rho_2 - v\rho_2 \qquad (2)$$

Having completed the process of weighing in air, it is started to carry out measurements while the hydrometer is partly immersed into the liquid of density ρ.

$$m + \frac{\pi.D.\gamma_2}{g} = W + V\rho + v\rho_3 \qquad (3)$$

Used notation, throughout the paper, is presented altogether for simplicity,

m = Mass of the hydrometer,

D = Stem diameter at meniscus level,

γ_1 = Surface tension of the liquid during the free floating,

γ_2 = Surface tension of the liquid during the immersed floating (here in tridecane),

g = Gravitational acceleration,

V = Volume of the hydrometer under the liquid at 20°C,

v = Volume of the hydrometer above the liquid at 20°C,

ρ = Density of tridecane during the measurement,

ρ_T = Tridecane density obtained by using Sinker at a certain temperature,

ρ_L = Liquid density corresponding to scale mark of hydrometer,

ρ_1 = Air density during the free floating,

ρ_2 = Air density during the weighing in air,

ρ_3 = Air density during the weighing in liquid of density ρ,

W_2= Weighing value of hydrometer while it is weighed in air,

W = Weighing value while the hydrometer is partly immersed up to a certain level,

t = Temperature value during the measurement,

t_R = Reference temperature,

α_v = Thermal volume expansion coefficient of hydrometer,

ρ_N = Nominal density value of hydrometer,

m_s = Mass of the sinker,

V_S = Volume of the sinker,

m_N = Reference masses equivalent to mass of sinker,

V_N = Volume of reference masses,

ρ_g = Density of weights of the balance (usually: ρ_g =8000 kg/m^3),

Δw = Difference in the weighing value,

In order to be able to assume the equality of air density value we carry out measurements in air and in liquid one after the other in short periods and letting $\rho_1 = \rho_2 = \rho_3 = \rho_a$ the equations (1), (2) and (3) are transformed to the following forms,

$$m = V\rho_L + v\rho_a - \frac{\pi.D.\gamma_1}{g} \qquad (4)$$

$$m = W_2 + V\rho_a + v\rho_a \qquad (5)$$

$$m = W + V\rho + v\rho_a - \frac{\pi.D.\gamma_2}{g} \qquad (6)$$

Equation (5) is substracted from equation (4),

$$V\rho_L - \frac{\pi.D.\gamma_1}{g} - W_2 - V\rho_a = 0 \qquad (7)$$

Equation (6) is substracted from equation (5),

$$W_2 + V\rho_a - W - V\rho + \frac{\pi.D.\gamma_2}{g} = 0 \qquad (8)$$

V is eliminated from equation (7) as,

$$V = \frac{1}{(\rho_L - \rho_a)} \{W_2 + \frac{\pi.D.\gamma_1}{g}\} \qquad (9)$$

Having inserted V into (8) and performing algebraic manipulations it yields,

$$W_2 + \frac{(\rho_a - \rho)(W_2 + \frac{\pi.D.\gamma_1}{g})}{(\rho_L - \rho_a)} - W + \frac{\pi.D.\gamma_2}{g} = 0$$

$$(10)$$

If we eliminate ρ_L which denotes the density value of scale mark of the hydrometer,

$$\rho_L = \frac{(\rho - \rho_a)\{W_2 + \frac{\pi.D.\gamma_1}{g}\}}{W_2 - W + \frac{\pi.D.\gamma_2}{g}} + \rho_a \qquad (11)$$

Having concerned with coefficient of cubical expansion (α_v) of the material of hydrometer, equation (11) turns out to the following form so that it could be used at reference temperature [1].

$$\rho_L(t_R) = \frac{(\rho - \rho_a)\{W_2 + \frac{\pi.D.\gamma_1}{g}\}}{W_2 - W + \frac{\pi.D.\gamma_2}{g}}[1 + \alpha_V(t - t_R)] + \rho_a$$

$$(12)$$

3. Measurement

Firstly measurements are carried out in air medium with a balance having 0.1 mg readability (Mettler, AT 400). Calibrated weights are used in substitution method and air density is calculated by using ambient conditions so that air buoyancy correction would be concerned in weighing value. Right after weighing hydrometers in air, it is important to measure stem diameters at the interested scale marks of hydrometer, and reference surface tensions of the liquid, where

the hydrometer is supposed to be used, are determined from related tables. Surface tension of the calibration liquid (tridecane) is already known.

Second stage is to perform hydrostatic 'Cuckow' weighing. In this process; the balance (Mettler, AT 400) is located at the top of the system and it has the ability to perform measurements inside the liquid via an apparatus, which connects the balance into the liquid. Thermostatically controlled bath (TAMSON, TV 7000) is used for temperature stabilization. Actually, temperature is the major effect for the density of liquid in which the weighing takes place. Ambient conditions are monitored during the weighing in liquid.

The design of the system, allowing the immersion of hydrometer at different immersion extent, is critical during the measurements.

Density of tridecane is determined by using sinker whose density and mass are known [4]. Substitution method is applied with below formula for liquid density determination.

$$\rho_T = \frac{m_s - m_N + V_N\rho_a - \Delta w(1 - \frac{\rho_a}{\rho_g})}{V_S} \qquad (13)$$

Density of tridecane could be obtained by using equation (14) at 20°C

$$\rho_{20^{\circ}C} = \rho_T + 0{,}715.(t - 20) \qquad (14)$$

Temperature of tridecane is determined with platinum sensing element having 0.001^{o}C resolution during the measurements.

The evaluation of meniscus effect is important in the weighing value. For this evaluation; surface tension of tridecane is taken as $\gamma_2=25,9$ mN/m and stem diameter of each scale is measured by compass before the measurements.

Hydrostatic weighing system, used in our measurements for hydrometer calibrations, is shown in   Figure 2.

Figure 2. Hydrometer calibration system

4. Results and Conclusion

A sample hydrometer in the range of 860 – 880 kg/m^3 having 0,2 kg/m^3 readability is calibrated in terms of Cuckow method. This hydrometer has been being used for density determination of mineral oils whose surface tension is considered in the evaluation of measurement results.

Calibration process is carried out in the newly established set up of UME and ambient conditions of labarotory are controlled during the measurement. Temperature dependency of liquid is critically concerned and Liquid temperature is specifically measured at all measurement steps by a glass thermometer. Density information of tridecane is given in the following table.

Table 1. Density of Tridecane

Liquid	Density (20°C)
$C_{13}H_{28}$	756,378 kg/m^3

Usage of a density standard known as sinker satisfies the density determination of tridecane during the measurements.

Results of measurements, theoretically obtained from equation (12), are given in Table 2.

Table 2. Measurement results

ρ_N [kg/m^3]	ρ [kg/m^3]	D [mm]	γ_1 [mN/m]	W_2 [g]	ρ_a [kg/m^3]	t_R [^{o}C]	γ_2 [mN/m]	t [^{o}C]	W [g]	ρ_L [kg/m^3]	Correction [kg/m^3]
860	756,344	6,640	28,00	147,1386	1,158	20	25,9	20,047	17,7592	859,988	-0,012
862	756,344	6,645	28,10	147,1386	1,158	20	25,9	20,047	18,0637	862,014	0,014
864	756,344	6,650	28,20	147,1386	1,158	20	25,9	20,047	18,3738	864,088	0,088
866	756,344	6,635	28,30	147,1386	1,158	20	25,9	20,047	18,6612	866,018	0,018
868	756,344	6,635	28,40	147,1386	1,158	20	25,9	20,047	18,9598	868,033	0,033
870	756,344	6,635	28,50	147,1386	1,158	20	25,9	20,047	19,2495	869,998	-0,002
872	756,343	6,640	28,60	147,1386	1,158	20	25,9	20,049	19,5501	872,043	0,043
874	756,343	6,635	28,70	147,1386	1,158	20	25,9	20,049	19,8381	874,014	0,014
876	756,340	6,625	28,80	147,1386	1,158	20	25,9	20,053	20,1267	875,995	-0,005
878	756,340	6,630	28,90	147,1386	1,158	20	25,9	20,053	20,4163	877,994	-0,006
880	756,339	6,630	29,00	147,1386	1,158	20	25,9	20,055	20,7014	879,970	-0,030

Calculated uncertainty is 1/5 th of density value for each scale mark. It is shown that measurement uncertainty is at a reasonable level for the reliable dissemination applications of liquid density scale for industry.

5. References

[1]. Cuckow F. W., *A new method of high accuracy for the calibration of reference standard hydrometers*, Journal of the Society of Chemical Industry, 1949, 68, pp.44-49

[2]. Lorefice S., Heinonen M. and Madec T., *Bilateral comparisons of hydrometer calibrations between the IMGC-LNE and the IMGC-MIKES*, Metrologia, 2000, 37, 141-147

[3]. Spiweck F., & Bettin H., *Solid and Liquid Density Determination*, Technisches Messen 59, 1992

[4]. Lorefice S., IMGC facility for reference liquids in density measurements, IMEKO-XV World Congress.

Contact Person for paper:

Ümit AKÇADAĞ

Address: TUBITAK-Ulusal Metroloji Enstitüsü

P.O.Box:21   41470 Gebze-Kocaeli-TURKEY

Fax:+90 262 646 59 14, Tel: +90 262 646 63 60

e-mail : akcadag@ume.tubitak.gov.tr