NBS CIRCULAR 555

Testing of Hydrometers

UNITED STATES DEPARTMENT OF COMMERCE

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J. C. Hughes

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Testing of Hydrometers

J. C. Hughes

The design and construction of hydrometers, with particular reference to hydrometers that are to be submitted to the National Bureau of Standards for test are discussed. The various scales that are commonly used for hydrometers are defined and recommendations given for subdividing and marking them. These scales include density, specific gravity degrees Baumé, degrees API, percentage by weight, percentage by volume, percentage proof, spirit, Brix, Balling, and some others. The relations between some of the arbitrary scales (for example, API) and specific gravity are stated.

The Circular outlines the procedure of testing hydrometers that are submitted to the Bureau and discusses the forms of certificates and reports issued as a result of these tests. Instructions and other helpful information about submitting hydrometers for test are given.

1. Introduction

1.1. Purpose of Circular

The object of this Circular is twofold: (1) to present to manufacturers and users information regarding the design, construction, and calibration of hydrometers in an effort to secure uniformity in these operations; and (2) to specify the requirements for hydrometers submitted to the Bureau for certification.

1.2. Classes of Hydrometers

There are two general types of hydrometers, namely, hydrometers proper and hydrometers combined with a thermometer, called thermohydrometers.

With reference to the indication or scale, hydrometers may be classified as follows:

(a) Density hydrometers, indicating density of a specified liquid, at a specified temperature, in specified units; for example, in grams per milliliter.

(b) Specific gravity hydrometers, indicating the specific gravity of a liquid, at a specified temperature, in terms of the density of water at a specified temperature as unity.

(c) Percentage hydrometers, indicating, at a specified temperature, the percentage of a substance dissolved in water; for example, the percentage of salts in a sample of sea water, or the percentage of sugar in an aqueous solution.

(d) Arbitrary scale hydrometers, indicating concentration or strength of a specified liquid, or its density, referred to an arbitrarily defined scale at a specified temperature (Baumé hydrometers and API hydrometers).

2. Recommendations on Construction

2.1. Materials and Form

Hydrometers should be made of smooth, transparent glass, free of bubbles, striae, or other imperfections. The glass should be of a kind that will adequately resist the action of chemical reagents in which it is normally used and also have suitable thermal qualities to permit its use over the range of temperatures to which it may be subjected. It should be thoroughly annealed before final adjustment and sealing.

The total length of any hydrometer should not exceed 45 cm, and, for convenience in use, a length of 35 cm or less is desirable.

All sections perpendicular to the axis should be circular, such that the outer surface is symmetrical about the vertical axis. There should be no uneven or unnecessary thickening of the walls and no abrupt changes nor constrictions that would hinder thorough cleaning.

The stem should be uniform in cross section with no perceptible irregularities. The top of the stem should be neatly rounded without unnecessary thickening. It should extend above the top graduation line at least 1.5 cm and should continue cylindrical below the bottom graduation line for at least 3 mm.

Material used for ballast should be confined to the bottom of the instrument, and no loose material of any sort should be inside a hydrometer. The disposition of the weight should be such that the hydrometer will always float with its axis vertical. Bulbs containing shot may be flattened, but in all cases the shot must be confined in the bottom either by a glass partition or a cement that does not soften at temperatures to which it may normally be subjected.

Only the best quality of material should be used for scales and designating labels. Paper usually known as first-class ledger paper is suitable for this purpose. The scales and labels should be securely fastened in place by some material that does not soften at the highest temperature to which the instrument will be exposed in use, and which does not deteriorate with time. When reference marks are used on stem and scale to provide a means of detecting slippage of the scale, they must coincide exactly. If a line other than the top numbered line is used as a reference, it must be clearly identified as such. The scale should be straight and without twist.

The graduation lines must be perpendicular to the axis of the hydrometer, that is, horizontal when the instrument is floating. They should extend at least one-fourth around the circumference of the stem, the minimum length being 2 mm, and join or intersect a line parallel to the axis indicating the front of the scale.

The lengths of division and subdivision lines should be so chosen as to facilitate readings. Sufficient lines should be numbered to clearly indicate the reading at any point. The numbers at the ends of the scale intervals should be complete, but those intermediate may be abbreviated.

The graduation lines and inscriptions should be clear and distinct in permanent ink, such as india ink.

The distance between any two adjacent subdivision lines of the scale should never be less than 0.8 mm nor more than 3.0 mm, and a distance of 1.5 to 2.0 mm is recommended.

If flat scales are used, the length and spacing of the graduation lines should conform to recommendations given above.

To facilitate readings near the end of the hydrometer scale, the graduations should be continued a few divisions beyond the ends of the principal interval.

The scale of a hydrometer for density indications should be divided into 0.001, 0.0005, 0.0002, or 0.0001 subdivisions. Similar values of the scale intervals may be used in specific gravity hydrometers. For percentage or degree indications, the hydrometer scale should be divided into whole, half, fifth, or tenth percents or degrees (never into fourths).

No hydrometer should have more than one scale, and there should be no secondary or auxiliary graduations.

In response to the demand from some users, a few hydrometers have been made with two scales, of the same units and range, and spaced about 180 deg apart in the stem. Although the use of such duplex scales does not conform to the recommendation of a single scale, such hydrometers will be calibrated, provided:

(a) That on one scale, and preferably both, the graduation lines extend one-fourth of the way around the circumference of the stem; and

(b) That where the numbered scale lines on one scale meet or overlap those of the second scale, there is no vertical displacement.

Furthermore, even when these provisions are fulfilled, hydrometers with duplex scales will receive reports only, since it is impracticable to check, adequately, the uniformity of the subdivisions of the two scales.

With thermohydrometers, the thermometer scale may be contained in either the body or stem of the hydrometer. In either case, the capillary stem of the thermometer should be parallel to the hydrometer axis. Other desirable features of the thermometer element are: the stem should contain an expansion chamber that will permit heating to 120° C; the space above the mercury should be either evacuated or filled with an inert gas; the thermometer scale should be divided into whole or half degrees; the thermometer scale should include the ice point (0° C); when within the stem of the hydrometer, the thermometer scale should be distinguished from the hydrometer scale by the use of a differently colored ink.

There should be no apparent irregularities in either the hydrometer scale or the thermometer scale.

The hydrometer should be thoroughly dry on the inside when sealed.

2.2. Inscriptions

The hydrometer scale or a suitable special label should bear an inscription that indicates unequivocally the purpose of the instrument. This inscription should denote: (a) the liquid for which the instrument is intended, if necessary; (b) the temperature at which it is to be used; and (c) the character of the indication, including definition of any arbitrary scale employed.

The designation of standard temperature and reference temperature may be abbreviated, as, for example, specific gravity 15°/15° C, meaning that the hydrometer indicates at 15° C the specific gravity of the liquid referred to water at 15° C as unity.

Hydrometers submitted to the Bureau for testing must show upon the scale or label, the maker's name or trade mark and an individual identifying number. This is important because it will be the only means by which the instrument may be associated with its certificate or report. Therefore, manufacturers must be particularly careful not to duplicate their identification numbers, although these numbers may be associated with the year.

3. Definition and Graduation of Various Scales

The tables used in the standardization of hydrometers by the Bureau are contained in NBS Circular 19 (6th edition), Standard density and volumetric tables, and are referred to below by the numbers used in that Circular.

3.1. Alcoholometers

Alcoholometers may be graduated to indicate the percentage of ethyl alcohol, either by weight or by volume, in mixtures of ethyl alcohol and water, or they may be graduated to indicate percentages of "proof spirit" as defined by the Bureau of Internal Revenue, United States Treasury Department.[1]

3.2. Saccharometers

Saccharometers should be graduated to indicate percentage of sugar by weight[2] or degrees Baumé at 20° C.

The basis for graduation of saccharometers, standard at 20° C, should be density at 20° C, as given in table 12 of NBS Circular 19.

Balling saccharometers should be graduated to indicate the percentage of sugar by weight at 60° F, and Brix saccharometers the percentage of sugar by weight at the temperature indicated.

Degrees Baumé for sugar is defined by the formula[3]

$$\text{degrees Baumé at } 20°\text{C} = 145 - \frac{145}{\text{sp gr } 20°/20°\text{ C}}.$$

3.3. Hydrometers for Sulfuric Acid

The basis for the graduation of hydrometers indicating percentage of sulfuric acid by weight in mixtures of acid with water should be density at 20° C as given in table 13 of Circular 19.

3.4. Baumé Hydrometers

The basis for hydrometers indicating degrees Baumé of liquids lighter than water should be the relation to specific gravity at 60°/60° F=15.56°/15.56° C given by the formula

$$\text{degrees Baumé} = \frac{140}{\text{sp gr } 60°/60°\text{ F}} - 130,$$

as given in tables 22 and 23 of Circular 19.

For hydrometers indicating degrees Baumé of liquids heavier than water, the basis should be the relation to specific gravity at 60°/60° F=15.56°/15.56° C given by the formula

$$\text{degrees Baumé} = 145 - \frac{145}{\text{sp gr } 60°/60°\text{F}},$$

as given in tables 20 and 21 of Circular 19.

The liquids for standardization of Baumé hydrometers should be, in general, mineral oils for liquids lighter than water, mixtures of sulfuric acid and water for heavier liquids, the Thoulet solution for liquids heavier than sulfuric acid.

3.5. Hydrometers for Petroleum Oil

The hydrometers in general use in the petroleum oil industry in the United States are based on the modulus 141.5, which is the basis for the API scale (American Petroleum Institute Scale).

The formula for converting specific gravity to API is as follows:

$$\text{degrees API} = \frac{141.5}{\text{sp gr } 60°/60°\text{ F}} - 131.5,$$

as given in tables 24 and 25 of Circular 19.[4]

3.6. Density Hydrometers

Hydrometers indicating density should be graduated to indicate, at the temperature marked on the scale, the density of liquids in grams per milliliter.

3.7. Specific Gravity Hydrometers

The scales of hydrometers for indicating specific gravity should be graduated to indicate the ratio of the density of the liquid at a specified temperature (usually 60° F or 20° C) to the density of water at a specified temperature (4° C, 60° F, or 20° C) as unity. Normally these scales will apply to a particular liquid and specific gravity range. The following are some of the common liquids and solutions and the approximate range of their specific gravities.

Liquids	Range
Mineral oil	0.62 to 1.00
Ammonia	.85 to 1.00
Common salt	1.00 to 1.23
Hydrocholoric acid	1.00 to 1.25
Caustic soda	1.00 to 1.55
Nitric acid	1.00 to 1.55
Sulfuric acid	1.00 to 1.85
Thoulet solution (K_2HgI_4)	1.84 to 3.00

4. Manipulation of Hydrometers

Hydrometers are seldom used for the greatest accuracy, as the usual conditions under which they are used preclude such special manipulation and exact observation as are necessary to obtain high precision. It is, nevertheless, desirable that they be accurately graduated to avoid, as far as possible, the use of instrumental corrections. To obtain this result, it is helpful to employ certain precautions and methods in standardizing these instruments.

The methods of manipulation described below are, in general, the ones employed at the Bureau in testing hydrometers, and it may be helpful for a maker or user to follow them to such extent as his needs for accuracy require.

[1] "Proof spirit" is that alcoholic liquor that contains one-half of its volume of pure ethyl alcohol of a specific gravity of 0.7939 at 60° F, referred to water at 60° F as unity. "Gauging Manual," p. 7, 1938, U. S. Treasury Dept., Bureau of Internal Revenue. (The percentage of proof spirit is in every case twice the percentage of ethyl alcohol by volume at 60° F.)

[2] Both of the terms, "Brix" and "Balling," are interpreted as meaning the percentage by weight of pure sucrose. The relation between percentage of sugar and density used by the Bureau is that determined by F. Plato, (Wiss. Abh. Kaiserlichen Normal-Eichungs-Kommission 2, 153, 1900.)

[3] See NBS Tech. Pap. T115, New Baumé scale for sugar solutions; and NBS Circular 440, Polarimetry, saccharimetry, and the sugars.

[4] More complete petroleum oil tables may be found in the ASTM-IP Petroleum Measurement Tables, published by the American Society for Testing Materials, 1916 Race Street, Philadelphia 3, Pa.

4.1. Observation

The hydrometer should be clean, dry, and at the temperature of the liquid before immersing to make a reading.

The liquid in which the observation is made should be contained in a clear, smooth glass vessel of suitable size and shape.

The liquid should be thoroughly mixed by means of a stirrer reaching to the bottom of the vessel. In the hydrometer comparator, (fig. 1), this is accomplished by the propeller, E, in figure 2.

The hydrometer should be slowly immersed in the liquid slightly beyond the point where it floats naturally and then allowed to float freely.

The scale reading should not be made until the liquid and hydrometer are free from bubbles and at rest.

In reading the hydrometer scale the eye is placed slightly below the plane of the surface of the test liquid; it is raised slowly until the surface, seen as an ellipse, becomes a straight line. The point where this line intersects the hydrometer scale should be taken as the reading of the hydrometer.

4.2. Influence of Temperature

In order that a hydrometer may indicate correctly the density or strength of a specified liquid it is essential that the liquid be uniform throughout and at the temperature specified on the instrument. In comparing two hydrometers having the same standard temperature and made of the same type of glass, however, the temperature of the liquid need not be considered, since the correction required due to variation from the standard temperature is the same for both instruments.

To insure uniformity in the liquid, thorough mixing is required shortly before making the observation. This may be accomplished by a per-

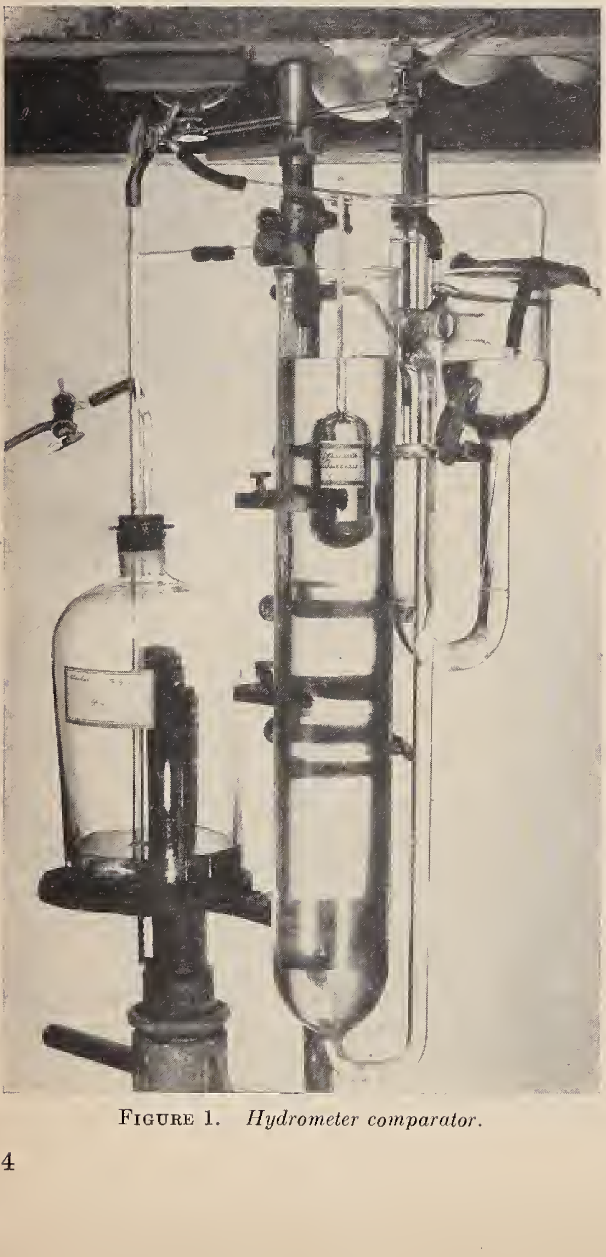

FIGURE 1. *Hydrometer comparator.*

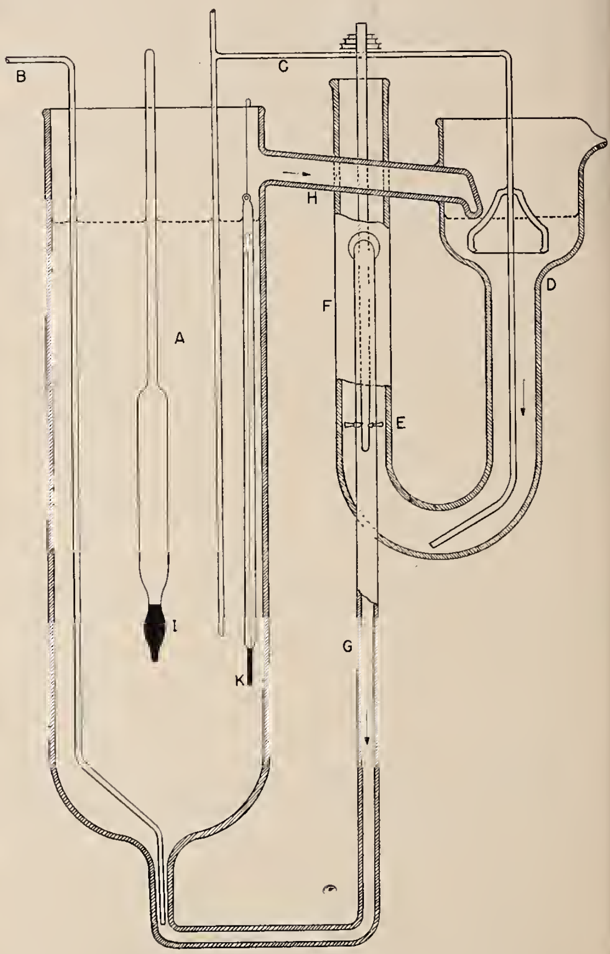

FIGURE 2. *Section of hydrometer comparator.*

A, Cylinder containing the test liquid; B, glass tube for filling and emptying A; C, siphon for removing the liquid from D into A; E, propeller that stirs the liquid and raises it in the tube, F, making it flow through G into A and through the cross tube, H, into D; I, hydrometer; K, thermometer.

forated disk or spiral at the end of a rod long enough to reach the bottom of the vessel. Motion of this stirrer from top to bottom serves to disperse layers of the liquid of different density. Or, if using a hydrometer comparator, the stirring can be accomplished by means of the propeller, E, in figure 2.

The temperatures of the liquid and of the surrounding atmosphere should be nearly equal during the observation; otherwise the temperature of the liquid will be changing, causing not only differences in density but also doubt as to the actual temperature. If an observation is made at some other temperature than that for which the hydrometer is designed, the reading will be in error. The magnitude of the error will depend upon the thermal expansion of the hydrometer and, in some cases, of the liquid used.

If the latter properties are known, tables of corrections for temperature may be prepared for use with hydrometers at various temperatures. Such tables should be used with caution, and only for approximate results when the temperature differs much from the standard temperature or from the temperature of the surrounding air. (See table 28, NBS Circular C19.)

Publications in which temperature correction tables may be found are listed below.

Liquid	Publication
Ethyl alcohol	NBS Circular 19. Gauging Manual, 1938, U. S. Treasury Department, Bureau of Internal Revenue.
Petroleum oils	NBS Circular 19. ASTM–IP Petroleum Measurement Tables.
Sulfuric acid solutions	NBS Circular 19.
Sugar solutions	NBS Circulars 19 and 440.
Vegetable tanning extracts	NBS Circular 449.
Turpentine	NBS Technical Paper 9.

4.3. Influence of Surface Tension

When a hydrometer is floated in a liquid, a small quantity of the liquid rises about the stem to form a meniscus. This liquid adhering to the stem, above the general level of the liquid in which the instrument is floating, has the same effect as adding to the mass of the hydrometer, thus increasing the depth of immersion.

Because a hydrometer will indicate differently in two liquids having the same density but different surface tensions, and since surface tension is a specific property of liquids, it is necessary to specify the liquid for which a hydrometer is intended.

Although hydrometers of equivalent dimensions may be compared, without error, in a liquid differing in surface tension from the specified liquid, the results of comparisons of dissimilar instruments in such a liquid must be corrected for the effect of the surface tension.

In many liquids spontaneous changes in surface tension occur due to the formation of surface films of impurities, which may come from the apparatus, the liquid, or the air.

Errors from this cause may be avoided by the use of liquids not subject to such changes; however, if the liquid used is different in surface tension from the specified liquid, a correction is required when dissimilar instruments are compared, as mentioned above. A second method of avoiding these errors is to purify the surface of the test liquid before making an observation, by causing an overflow of the liquid. This method is employed at the Bureau for testing hydrometers in sulfuric acid, sodium chloride, and alcohol solutions, and is accomplished by causing the liquid to overflow from the part of the apparatus in which the hydrometer is immersed by a small rapidly rotating propeller, which serves also to stir the liquid.

The necessity for such special manipulation is confined to the reading of hydrometers in liquids that are subject to surface contamination. Such, in general, are aqueous solutions or mixtures of acids, alkalies, salts, sugar, and weak alcoholic mixtures. Oils, alcoholic mixtures of strength above 40 percent by volume, and other liquids of relatively low surface tension are not, in general, liable to surface contamination sufficient to cause appreciable changes in hydrometer readings.

4.4. Cleanliness

The accuracy of hydrometer observations depends, in many cases, upon the cleanliness of the instruments and of the liquids in which the observations are made.

In order that readings shall be uniform and reproducible, the surface of the hydrometers, and especially of the stem, must be clean, so that the liquid will rise uniformly and merge into an imperceptible film on the stem.

The readiness with which this condition is fulfilled depends somewhat upon the character of the liquid. Certain liquids, such as mineral oils and strong alcoholic mixtures, adhere to the stem very readily. On the other hand, with weak aqueous solutions of sugar, salts, acids, and alcohol, scrupulous cleaning of the stem is required in order to secure the normal condition.

Before being tested, hydrometers are thoroughly cleaned by dipping in a mixture of one part concentrated sulfuric acid and two parts fuming sulfuric acid, rinsed with water, and dried by wiping with a clean, lint-free cloth.

If they are to used in aqueous solutions that do not adhere readily to the glass, the stems are wiped with alcohol and dried immediately before each reading.

5. Tolerances

5.1. General

The maximum error of the hydrometer scale should not exceed the following:

Smallest subdivision of hydrometer scale	Tolerance
Fifth, tenth, or twentieth percents or degrees or any density subdivision.	One smallest division.
Whole or half percents of proof spirit.	One smallest division.
Whole or half percents or degrees (other than above).	One-half smallest division.

The maximum error of thermometer scales in thermohydrometers should not exceed the following:

Smallest division of thermometer scale	Tolerance
2.0° F	1.0° F
1.0° C	0.5° C
0.5° C	0.3° C

5.2. Special

When the smallest subdivision of the hydrometer scale is less than 0.0002 specific gravity or its equivalent in other units, the following tolerances shall apply:

Scale	Tolerance (scale divisions)
Specific gravity in 0.0001	2. 0
Percentage of alcohol by volume in 0.1:	
0.0 to 9.9	1. 5
10.0 to 34.9	2. 0
35.0 to 44.9	1. 5
45.0 to 100.0	1. 0
Percentage of proof spirit in 0.2:	
0.0 to 19.8	1. 5
20.0 to 69.8	2. 0
70.0 to 89.8	1. 5
90.0 to 200.0	1. 0

Scale—Continued	Tolerance (scale divisions)—Continued
Percentage of proof spirit in 0.1:	
0.0 to 19.9	3. 0
20.0 to 69.9	4. 0
70.0 to 89.9	3. 0
90.0 to 149.9	2. 0
150.0 to 189.9	1. 5
190.0 to 200.0	1. 0
Degrees API in 0.05:	
10.00 to 79.95	1. 0
80.00 to 100.00	1. 5
Baumé for heavy liquids in 0.02:	
0.00 to 19.98	1. 5
20.00 to 70.00	1. 0
Baumé for heavy liquids in 0.01:	
0.00 to 9.99	3. 0
10.00 to 19.99	2. 5
20.00 to 39.99	2. 0
40.00 to 59.99	1. 5
60.00 to 70.00	1. 0
Quevenne scale for milk in 0.1	2. 0
N. Y. State Board of Health lactometer in 0.5	1. 5
N. Y. State Board of Health lactometer in 0.2	3. 0

Other scales not specifically mentioned here will be governed by the same principle; i. e., when the general requirements above would result in a tolerance of less than the equivalent of 0.0002 specific gravity, the limit of error shall be 0.0002 specific gravity expressed to the nearest one-half scale division.

5.3. Accuracy of Corrections Reported

Corrections will be expressed to one-tenth of a scale division, as has been the practice heretofore. The accuracy of these corrections will vary with the instrument design and no general statement of the accuracy can be made. However, even in those cases where the inaccuracies exceed one-tenth of a scale division it is preferable to give the corrections as found, since the value actually observed is the best estimate that can be obtained from a given test, and any rounding introduces an additional error. In general, the precision of the measurement process is such that only in rare instances (and depending on the quality of the instrument tested) will the reported correction differ from the true correction by more than a third of the listed tolerance.

6. Tests Performed by the Bureau

6.1. Instruments Admitted for Test

At present the Bureau is prepared to test the following kinds of hydrometers and thermohydrometers: Alcoholometers, saccharometers, salinometers, lactometers,[5] API hydrometers, Baumé hydrometers, hydrometers indicating either density or specific gravity of liquids lighter than water or heavier than water, hydrometers indicating percentage of sulfuric acid.

Instruments other than the above should not be submitted for test without previous arrangement.

6.2. Description of Tests

a. General Inspection

All hydrometers submitted for test will be given a preliminary examination to insure conformity with the recommendations on construction contained in section 2.

b. Points Tested

The hydrometer will be tested at three points on the scale: one point in the upper 25 percent of the scale length, one point near the middle of the scale, and one point in the lower 25 percent of the scale length.

Tests will be made at more than three points if requested. An additional fee is charged for each point over three tested.

c. Precision Stamp and Certificate

If the preliminary inspection of any hydrometer or thermohydrometer indicates a satisfactory conformity with the recommendations on construction, and at all points tested the results are within the limits given in the section on tolerances, the official precision stamp, consisting of the letters NBS and the year, as shown below, is etched on the instrument.

In order that this stamp may be applied to a thermohydrometer, the thermometer element also must meet the requirements set forth above.

The calibration of thermohydrometers containing "temperature correction" tables does not include a check of the accuracy of these tables, as they can, in general, be correct for only a very limited portion of the hydrometer scale.

[5] The corrections to lactometer readings as reported by the Bureau apply to readings taken at the top of the milk meniscus.

If request is made when the hydrometer is submitted, a certificate of corrections will be furnished for any instrument qualified to receive the precision stamp. An additional fee is charged for this service. Hydrometers for which certificates are issued will be marked as shown below.

d. Report of Corrections

When the results of the test show that at one or more of the points tested the corrections exceed the tolerance for precision grade but are not more than three times the precision tolerance, a report giving the corrections will be furnished if requested. When a hydrometer does not conform to the specifications as to construction, but is found suited to the testing facilities of the Bureau and adapted to the intended purpose, a report may be furnished giving the corrections and a statement explaining in what respect the hydrometer does not meet the requirements for a certificate. The fee for reports is the same as for certificates. Hydrometers on which reports are issued will receive the "reported" stamp, such as shown below, to show that they have been tested by the Bureau and, while not meeting the precision requirements, are of serviceable quality.

Certificates or reports may be issued for thermohydrometers based on test of the hydrometer element alone. The absence of any entry in the space provided for data on the test of the thermometer element will be evidence that the thermometer element was not tested.

If the correction at one or more test points exceeds three times the precision tolerance, or if for some other reason the hydrometer is found to be unsuited for the grade of use intended, neither certificate nor report is issued. Also, there is no NBS stamp applied to the instrument. The results of the test and reason for the action taken may be given in a letter.

e. Weight in Air

In addition to making the tests outlined above, the weight in milligrams of the hydrometer against brass weights in air at 760 mm of mercury pressure and 20° C, will be determined and reported if the sender so requests. (There is an additional charge for this.)

7. Directions for Submitting Apparatus for Test

7.1. Application for Test

The request for test should be made in writing and should include a complete list of the apparatus and a statement of the nature of the test desired as explained in section 6.2.

It is important that the request specify if a certificate is desired, also whether a report of corrections would be acceptable in the event that any instrument is found not qualified for a certificate.

For thermohydrometers, the request should further indicate whether or not a test of the thermometer element is desired (see section 6.2, c and d).

The sender should always examine apparatus carefully before submitting it for test to determine whether or not it complies with the recommendations and is qualified for the test desired.

7.2. Identification Marks

Instruments and the packages in which they are shipped should both be plainly marked to facilitate identification, preferably with the name of the manufacturer or shipper, and a special reference number should be given, which should be referred to in the correspondence concerning the test. After the Bureau has acknowledged the request for the test and assigned to it a test number, this test number should be given on any correspondence about the test.

7.3. Shipping Directions

Instruments should be securely packed in cases or packages, which may be used in returning them to the owner. In all cases, transportation charges are payable by the party desiring the test and must be prepaid. Return shipment is made by express, collect unless other arrangements are made in advance. Apparatus must be accompanied by an itemized shipping invoice.

7.4. Breakage

About 3.0 percent of the hydrometers shipped to the Bureau for test are received broken. In most cases this is due to inadequate protective packing, although rough handling in shipment is undoubtedly a contributing factor. About 0.5 percent of the hydrometers received are broken during the testing operations in the laboratory. There is insufficient information at hand on which to estimate the breakage in return shipments. While the Bureau endeavors to keep the laboratory and return shipment breakage to a minimum, such breakage must be viewed as a part of the cost of submitting hydrometers for test.

7.5. Address

Articles should be addressed, "National Bureau of Standards, Washington 25, D. C." Articles delivered in person or by messenger may be left at the Shipping Room of the Bureau, or at the laboratory if the submitter wishes to discuss the tests in which he is interested. In either case, there should be a written request for the tests desired.

7.6. Remittances

Payment of test fee should be made promptly upon receipt of bill. Copies of current Test Fee Schedules may be obtained from the Bureau upon request.

8. Appendix. Relations Between Principal Scale Interval and the Dimensions of Hydrometers

Referring to figure 3, let

- V=total volume (cm^3) of hydrometer from top scale mark to bottom of bulb
- v=volume (cm^3) of stem per unit length
- m=total mass (g) of hydrometer
- D=diameter (cm) of the bulb
- d=diameter (cm) of the stem
- H=length (cm) of bulb
- L=length (cm) of principal interval of scale in the stem (that is, distance between the two extreme marked graduation lines)
- h=distance (cm) between top of bulb and bottom of scale
- s_1 and s_2=distances (cm) from the top (zero) scale line to any two readings.

If the hydrometer is placed in a liquid of density ρ_0, it will sink to the zero (top) scale mark, hence

$$m=V\rho_0. \qquad (1)$$

If placed in a second liquid having a density ρ_1, ($\rho_1>\rho_0$) and sinks only to position s_1, then

$$m=(V-s_1v)\rho_1 \qquad (2)$$

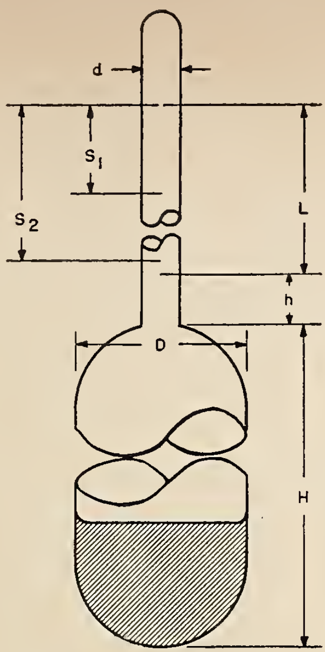

FIGURE 3. *Principal dimensions of a hydrometer.*

If a third liquid is used having a density ρ_2 ($\rho_2 > \rho_1$) the reading position will be s_2, and

$$m = (V - s_2 v)\rho_2. \tag{3}$$

From eq (1) and (2),

$$V\rho_0 = (V - s_1 v)\rho_1$$

and

$$s_1 = \frac{V}{v}\left(\frac{\rho_1 - \rho_0}{\rho_1}\right); \tag{4}$$

likewise, from eq (1) and (3),

$$s_2 = \frac{V}{v}\left(\frac{\rho_2 - \rho_0}{\rho_2}\right), \tag{5}$$

and by eq (4) and (5),

$$s_1 - s_2 = \frac{V}{v}\left[\left(\frac{\rho_1 - \rho_0}{\rho_1}\right) - \left(\frac{\rho_2 - \rho_0}{\rho_2}\right)\right]. \tag{6}$$

Now assume that the densities ρ_1 and ρ_2 are going to be so chosen that the positions determined by s_1 and s_2 will coincide with the highest and lowest principal graduation lines of the scale. This means that $\rho_1 = \rho_0$, $s_1 = 0$ and $s_2 = L$, and, therefore eq (6) reduces to

$$s_1 - s_2 = 0 - s_2 = -L = \frac{V}{v}\left[\left(\frac{\rho_1 - \rho_1}{\rho_1}\right) - \left(\frac{\rho_2 - \rho_1}{\rho_2}\right)\right],$$

or

$$L = \frac{V}{v}\left(\frac{\rho_2 - \rho_1}{\rho_2}\right). \tag{7}$$

If the ends of the bulb are assumed to be spherical segments approximately $D/3$ cm in height, the volume, V, of the hydrometer is

$$V = \frac{\pi}{4}D^2(H - 0.3D) + \frac{\pi}{4}d^2h + \frac{\pi}{4}d^2L. \tag{8}$$

The 0.3 factor in $(H - 0.3D)$ is a rounded value but is sufficiently exact for most purposes. Also, since by definition, the length factor of v is unity,

$$v = \frac{\pi}{4}d^2. \tag{9}$$

Therefore,

$$\frac{V}{v} = \frac{D^2}{d^2}(H - 0.3D) + h + L \tag{10}$$

and with eq (7)

$$L\left(\frac{\rho_2}{\rho_2 - \rho_1}\right) = \frac{D^2}{d^2}(H - 0.3D) + h + L. \tag{11}$$

In many cases it may be more convenient to use specific gravity, g, in place of density. This will not change the numerical value of the density term; hence, in place of eq (11) we may write

$$L\left(\frac{g_2}{g_2 - g_1}\right) = \frac{D^2}{d^2}(H - 0.3D) + h + L. \tag{12}$$

Returning to eq (6), if ρ_2 is the density corresponding to the lowest scale mark, then $s_2 = L$ and eq (6) may be written

$$L - s_1 = \frac{V}{v}\rho_0\left(\frac{\rho_2 - \rho_1}{\rho_1\rho_2}\right). \tag{13}$$

Having determined the dimensions of the bulb and stem, we have established the values of V and v, so that V/v is a constant. Also, for any given range, ρ_0 is a constant. Therefore, the density term $(\rho_2 - \rho_1)/\rho_1\rho_2$, governs the distance between the graduation lines on the scale. Furthermore, as ρ_1 is increased by equal increments from ρ_0 to ρ_2, the value of the density term changes by decreasing increments. This means that for equal changes in density the distance between graduation marks on the scale will be smaller near the bottom of the scale than at the top of the scale.

In order to use either eq (11) or (12) to determine the proportions of a hydrometer, it will be necessary to assign values to enough of the variables, or to use additional relations between some of them, so as to make it possible to solve for one variable. One additional relation that may be used is

$$\text{total length} = H + h + L. \tag{14}$$

Thus, we may assign values to total length, D, d, and h. Then for any range of specific gravities that it is desired to have the hydrometer cover, we may solve for H and L.

Example:

$$\text{Total length} = 21.0 \text{ cm}$$
$$D = 3.0 \text{ cm}$$
$$d = 0.6 \text{ cm}$$
$$h = 1.0 \text{ cm}$$
$$g_1 = 0.95178$$
$$g_2 = 1.0000$$

Then by eq (14)

$$H = 20 - L$$

and by eq (12)

$$19.738L = 25(19.10 - L) + 1$$

or

$$L = 10.70 \text{ cm}$$

and

$$H = 9.30 \text{ cm}.$$

WASHINGTON, April 28, 1954.

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