DEPARTMENT OF COMMERCE

CIRCULAR

OF THE

BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 59

UNITED STATES STANDARD BAUMÉ HYDROMETER SCALES

ISSUED APRIL 5, 1916

WASHINGTON
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1916

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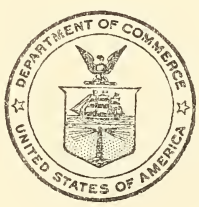

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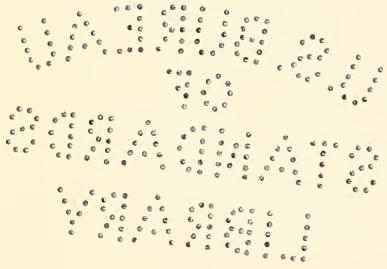

UNITED STATES STANDARD BAUMÉ HYDROMETER SCALES

The Bureau of Standards is from time to time requested to furnish information in regard to the Baumé hydrometer scales in use in the United States, and, as there appears to be a lack of general knowledge on the subject, it has been thought expedient for the Bureau to take the matter up somewhat in detail for the purpose of putting it clearly before those who are interested in it and of removing certain erroneous ideas that may exist in the minds of a few who have been misled by incorrect statements from other sources.

The relation between specific gravity and Baumé degrees represented by the formulas on page 6 of this circular was adopted by this Bureau in 1904, when it first took up the question of testing hydrometers. At that time every important manufacturer of Baumé hydrometers in the United States was using this relation as the basis of these instruments, or at least such was their claim.

The origin and early history of the Baumé scales has been admirably treated by Prof. C. F. Chandler in a paper read before the National Academy of Sciences at Philadelphia in 1881. As this paper may not be readily available to some who are interested in the matter, it may be well to include here a part of the material prepared by Prof. Chandler.

The Baumé scale was first proposed and used by Antoine Baumé, a French chemist, in 1768, and from this beginning have come the different Baumé scales that have been prepared since that time. The directions given by Baumé for reproducing his scale were first published in L'Avant in 1768, and, though simple, are not specific, and the conditions assumed are not easily reproducible. It is not strange, therefore, that differences soon appeared between the Baumé scales as set up by different observers. That this divergence did actually occur is well

shown by the large number of Baumé scales that have been used. Prof. Chandler found 23 different scales for liquids heavier than water and 11 for liquids lighter than water.

Baumé's directions for setting up his scale state that for the hydrometer scale for liquids heavier than water he used a solution of sodium chloride (common table salt) containing 15 parts of salt by weight in 85 parts of water by weight. He described the salt as being "very pure" and "very dry" and states that the experiments were carried out in a cellar in which the temperature was 10° Reaumur, equivalent to 12.5° C. or 54.5° F.

The point to which the hydrometer sank in the 15 per cent salt solution was marked 15°, and the point to which it sank in distilled water at the same temperature was marked 0°. The space between these two points was divided into 15 equal parts or degrees, and divisions of the same length were extended beyond the 15° point.

For the hydrometer for liquids lighter than water he used a 10 per cent salt solution for fixing the zero and distilled water for the 10° point. The distance between these points was divided into 10 equal parts and these divisions extended above the 10° point.

Other makers of Baumé hydrometers soon began to deviate from the procedure outlined by Baumé, the deviations being, no doubt, partly accidental and partly intentional, and in the course of time, as already pointed out, many different Baumé scales were in use.

This condition of affairs led to great confusion in the use of the Baumé scale.

From a consideration of the variations that occurred it was soon evident that some means of defining and reproducing the scale more exactly than could be done by the simple rules given by Baumé should, if possible, be found. This means was readily provided by assuming that a fixed relation should exist between the Baumé scale and the specific-gravity scale at some definite temperature, and in terms of some definite unit. When this relation is expressed in mathematical terms in the form of an equation, then the Baumé scale is fixed beyond all question or doubt. At the present time all Baumé scales in use are based on such an assumed relation, and the differences existing between them arise from differences in the assumed relation or "modulus"

on which the various scales are based, and the standard temperature at which the instruments are intended to be correct.

If a definite modulus is adopted, then the degrees Baumé corresponding to any given specific gravity, or the specific gravity corresponding to any given degree Baumé may be calculated; or if the specific gravity and corresponding degrees Baumé at any point of the scale are known, then the modulus can be determined and the complete Baumé scale calculated from this single point.

Let s = specific gravity; d = degrees Baumé; m = modulus. Then for liquids heavier than water:

$$s = \frac{m}{m - d}$$

$$d = m - \frac{m}{s}$$

$$m = \frac{ds}{s - 1}$$

For liquids lighter than water:

$$s = \frac{m}{(m - 10) + d}$$

$$d = \frac{m}{s} - (m - 10)$$

$$m = \frac{s(d - 10)}{1 - s}$$

In the calculation of Baumé tables, or any other for that matter, one error which should be avoided is that of assuming values to be exact when in reality they are only approximate. This error was not entirely avoided even by Prof. Chandler in his paper above referred to. From a single equivalent value of Baumé and specific gravity in Pemberton's table for light liquids Prof. Chandler has calculated the modulus to two decimal places and obtained the value 139.94, when if the specific gravity value used had been exact the modulus would have been found to be 140. Pemberton's table was calculated from the modulus 140 and all figures

beyond the fourth decimal place discarded without regard for their value. For example, 47° Baumé is given an equivalent specific gravity value of 0.7909, when in reality the more exact value is 0.790960.

Another point in which Prof. Chandler's paper is misleading is his having assigned the same modulus to the tables of Dalezennes and Huss, because they agree at 47°, and a noticeably lower value to Pemberton's table. In reality the tables of Dalezennes and Pemberton are in closer agreement throughout most of their range than are those of Dalazennes and Huss.

There can be little doubt that the last four tables given by Prof. Chandler, those of Dalazennes, Huss, Ziurek, and Pemberton, were all originally based on the same modulus, 140, and the slight differences later found are differences of calculation only. The moduli given by Prof. Chandler are, respectively, 140.11, 140.11, 140.03, and 139.94.

The Baumé scales in use in the United States are based on the following relation to specific gravity:

For liquids heavier than water:

$$\text{Degrees Baumé} = 145 - \frac{145}{\text{specific gravity at } 60°/60° \text{ F}} \text{ or specific}$$

$$\text{gravity } 60°/60° \text{ F} = \frac{145}{145 - \text{degrees Baumé.}}$$

For liquids lighter than water:

$$\text{Degrees Baumé} = \frac{140}{\text{specific gravity } 60°/60° \text{ F}} - 130; \text{ or, specific}$$

$$\text{gravity } 60°/60° \text{ F} = \frac{140}{130 + \text{degrees Baumé.}}$$

The specific gravities corresponding to integral degrees Baumé for both heavy and light liquids are given below:

TABLE 1

Relation Between Baumé Degrees and Specific Gravity

LIQUIDS HEAVIER THAN WATER

Baumé Degrees	Sp. Gr. 60°/60° F	Baumé Degrees	Sp. Gr. 60°/60° F	Baumé Degrees	Sp. Gr. 60°/60° F	Baumé Degrees	Sp. Gr. 60°/60° F
0	1.00000	20	1.16000	40	1.38095	60	1.70588
1	1.00694	21	1.16935	41	1.39423	61	1.72619
2	1.01399	22	1.17886	42	1.40777	62	1.74699
3	1.02113	23	1.18852	43	1.42157	63	1.76829
4	1.02837	24	1.19835	44	1.43564	64	1.79012
5	1.03571	25	1.20833	45	1.45000	65	1.81250
6	1.04317	26	1.21849	46	1.46465	66	1.83544
7	1.05072	27	1.22881	47	1.47959	67	1.85897
8	1.05839	28	1.23932	48	1.49485	68	1.88312
9	1.06618	29	1.25000	49	1.51042	69	1.90789
10	1.07407	30	1.26087	50	1.52632	70	1.93333
11	1.08209	31	1.27193	51	1.54255	71	1.95946
12	1.09023	32	1.28319	52	1.55914	72	1.98630
13	1.09848	33	1.29464	53	1.57609	73	2.01389
14	1.10687	34	1.30631	54	1.59341	74	2.04225
15	1.11538	35	1.31818	55	1.61111	75	2.07143
16	1.12403	36	1.33028	56	1.62921	76	2.10145
17	1.13281	37	1.34259	57	1.64773	77	2.13235
18	1.14173	38	1.35514	58	1.66667	78	2.16418
19	1.15079	39	1.36792	59	1.68605	79	2.19697

LIQUIDS LIGHTER THAN WATER

10	1.00000	30	0.87500	50	0.77778	70	0.70000
11	.99291	31	.86957	51	.77348	71	.69652
12	.98592	32	.86420	52	.76923	72	.69307
13	.97902	33	.85890	53	.76503	73	.68966
14	.97222	34	.85366	54	.76087	74	.68627
15	.96552	35	.84848	55	.75676	75	.68293
16	.95890	36	.84337	56	.75269	76	.67961
17	.95238	37	.83832	57	.74866	77	.67633
18	.94595	38	.83333	58	.74468	78	.67308
19	.93960	39	.82840	59	.74074	79	.66986
20	.93333	40	.82353	60	.73684	80	.66667
21	.92715	41	.81871	61	.73298	81	.66351
22	.92105	42	.81395	62	.72917	82	.66038
23	.91503	43	.80925	63	.72539	83	.65728
24	.90909	44	.80460	64	.72165	84	.65421
25	.90323	45	.80000	65	.71795	85	.65117
26	.89744	46	.79545	66	.71428	86	.64815
27	.89172	47	.79096	67	.71066	87	.64516
28	.88608	48	.78652	68	.70707	88	.64220
29	.88050	49	.78212	69	.70352	89	.63927

More complete specific gravity and Baumé tables will be found in Circulars Nos. 19 and 57 of the Bureau of Standards.

The Baumé scales, as above defined, were calculated by H. Pemberton in 1851, and have been more and more generally adopted in this country since that time. They are usually referred to in the literature as the "American standard" Baumé scales.

Below are cited publications containing the American standard Baumé scale for liquids lighter than water:

Allen's Commercial Organic Analysis, 4th ed., vol. 1, p. 15.
American Society for Testing Materials: Comm. Reports, 1915. Report of Comm. D–2, Standard Tests for Lubricants.
Das Erdöl: Hans Höfer, 1906, p. 38.
Davis, W. H.: Friction and Lubrication (1904), p. 63.
Domke u. Reimerdes: Handbuch der Araometrie (1912), p. 146.
Gebhardt: Steam Power Plant Engineering (1910), p. 672.
Gill, Augustus H.: Oil Analysis (1903), (1905), (1911), pp. 17, 18, 162.
Journal American Chemical Society, vol. 21, 1899, p. 126.
Kent's Handbook (1912), p. 172.
Lewkowitsch: Chemical Technology of Oils, Fats, and Waxes, 5th ed., vol. 1, p. 303.
Manufacturing Chemists' Association of the United States: Aqua Ammonia Tables adopted 1903 (Ferguson).
Redwood, Sir Boverton: A Treatise on Petroleum, 3d ed., vol. II, p. 202.
Smithsonian Physical Tables (1914), p. 81.
Stillman, Thos. B.: Examination of Lubricating Oils (1914).
Tagliabue, C. J.: Manual for Coal Oil Inspectors, 4th ed.
Thurston: Friction and Lost Work (1903), p. 185.
U. S. Pharmacopœia, 1900 revision.
Van Nostrand's Chemical Annual (1914), p. 383.

The above references are not intended as a complete bibliography of the subject; they are the result only of a brief study of the literature at hand. Further search would no doubt have resulted in the discovery of many additional references.

At the time the Bureau of Standards was contemplating taking up the work of standardizing hydrometers (about 1904), diligent inquiry was made of the more important American manufacturers of hydrometers as to the Baumé scales used by them. Without exception they replied that they were using the modulus 145 for liquids heavier than water, and 140 for liquids lighter than water. These scales, the "American standard," were therefore adopted by the Bureau of Standards and have been in use ever since.

There having been no objection or protest from any manufacturer or user of Baumé hydrometers at the time the scales were adopted by the Bureau, it was assumed that they were entirely satisfactory to the American trade and were in universal use. Such, in fact, appears to be the case with the scale for liquids

heavier than water, but in the case of the scale for liquids lighter than water a disturbing element has arisen which threatens to some extent the uniform practice that has heretofore existed.

The exact date of this disturbing influence can not be fixed with certainty, but it was first noticed some four or five years ago, and has been quietly at work since then to break down the uniformity of practice previously existing and to counteract as far as possible the influence of the Bureau of Standards in the interest of uniformity.

It appears that a certain manufacturer of hydrometers, especially those used in the oil trade, discovered that his Baumé hydrometers were not graduated in accordance with the American standard Baumé scale in general use based on the modulus 140. This discovery made necessary for the manufacturer one of two things: Either he must consider his instruments in error, by the amount of the difference, or he must change the basis of the scale to conform to his instruments. The manufacturer in question, C. J. Tagliabue, chose the latter course.

The developments of the problem confronting Mr. Tagliabue are well shown by the various editions of his Manual for Coal Oil Inspectors. The first few editions of this publication contained the regular American standard Baumé table, modulus 140. Then came the discovery that his instruments did not fit the table, and an attempt was made to make a table to fit the instruments. The result was an irregular table with no definite modulus. This was published in at least two editions of the manual. Then followed the table which is now published by Mr. Tagliabue in the eighth edition of his manual, based on the modulus 141.5, which more nearly fits his standard hydrometers for petroleum oil.

A small pamphlet prepared by Mr. Tagliabue has recently been widely distributed in which the impression is given that the modulus 141.5 was adopted by the United States Petroleum Association in 1864, and has been in use in the petroleum trade ever since, and that lately the modulus 140 has been proposed and that great confusion may result from its use. That such is by no means the case has been shown by the foregoing references and historical matter.

There can be little doubt that when the United States Petroleum Association adopted as standard the hydrometers made by Jarvis Arnaboldi, who was later succeeded by C. J. Tagliabue, it was believed by all concerned that the instruments were based on the

American standard Baumé scale. That this belief was shared by Mr. Tagliabue is clearly shown by correspondence, to be quoted later.

Even the supporters of Tagliabue's scale find no argument in its favor, except that there are a large number of his hydrometers used in the oil trade. To this the Bureau of Standards would reply that there are also in use in the trade many incorrect weights and measures, but that fact would hardly be advanced as a sound argument for their continuance in service.

The case against the Baumé scale, as represented by the proposed modulus 141.5, is well covered by George H. Taber, general manager of the Gulf Refining Co. and formerly chairman of Committee D–2 of the American Society for Testing Materials. in a letter to committee D–2 of the American Society for Testing Materials. That letter is published herewith.

April 14, 1915.

Committee D–2 on Standard Tests for Lubricants,
American Society for Testing Materials.

Dear Sirs: A recent booklet written by Mr. C. J. Tagliabue and copyrighted by the C. J. Tagliabue Mfg. Co., appears to have been directed against a report of Committee D–2 on Standard Tests for Lubricants, recommending to the Society for Testing Materials the use of the Baumé hydrometer based on the 140 modulus. In this book Mr. Tagliabue narrates that in the year 1864 the United States Petroleum Association adopted as the standard of the Association Baumé hydrometers made by Mr. Jarvis Arnaboldi, uncle and predecessor of Mr. Tagliabue, because the Baumé hydrometers made by him were found to agree among themselves very closely. Mr. Tagliabue goes on to state that these hydrometers were based on the modulus 141.5 and that this modulus has covered Baumé hydrometers used by the petroleum trade almost universally ever since. He says that later, however, the modulus of 140 has been urged instead, "but the adoption of petroleum hydrometers based on this modulus would again cause considerable confusion and make valueless the data accumulated during the past fifty years by the great majority who have been using hydrometers based on the association modulus. Furthermore, this 140 modulus has not been and is not to-day in universal use."

Naturally it has not been "in universal use" if the 141.5 has been "almost universally used." As to the confusion which would occur, let us see a little about the confusion that has already occurred in regard to these scales:

On January 9, 1904, I wrote Mr. Charles J. Tagliabue as follows:

> * * * Will you also tell me if your Baumé hydrometers are graduated to correspond to the equivalent tables given in your manual. What I want to know particularly is, Does 70 on the Baumé gravity hydrometers which you sell correspond strictly to 0.700 specific gravity? If not, what specific gravity does it correspond to and what is the modulus of the scale in accordance with which your instruments are made?
>
> An explicit reply to this inquiry will oblige.

He answered on January 12:

> Yes, my Baumé hydrometers are graduated to correspond with the specific gravity tables in the back of my manual and 70° Baumé is exactly 0.7000° (sic) specific gravity. These tables have been adopted by the petroleum association a great many years ago, also by the Standard Oil Co. and the other refiners

throughout the country, and I suppose you are also aware that my manual has been adopted by the trade in general for computing the gravities of oils when above or below 60° of temperature.

I replied on January 13:

> I think you are mistaken in saying your Baumé gravity table has been adopted by the Standard Oil Co. In the table which they use 45 Baumé gravity is 0.8017 specific; 50 Baumé is 0.7794 specific; and 70 Baumé is 0.7025 specific, and I should be interested to know which one of these scales the petroleum association and the produce exchange use.

He replied on January 18:

> No, I have not made a mistake regarding the specific gravity tables in the back of my manual being adopted by the Standard Oil Co., but they sometimes have made a hydrometer of specific gravity scale only, about 18 inches long, which they use for special purposes. It is called a Mason's correction, which will tally with 45 Baumé —0.8017 specific gravity, 50 Baumé —0.7794 specific gravity, 70 Baumé —0.7025 specific gravity; probably this is the hydrometer you refer to. These hydrometers are special and the cost is $5 each. This I think answers yours of the 13th.

To this I wrote him on January 23:

> I am obliged for the information contained in your letters of the 12th and 18th, on the matter of hydrometer scales. * * * I have been using your instruments in different parts of the country for the last 22 years, and am glad to learn that they are made to conform to the 140–130 formula and not to the 70=0.7025 scale, as I had been told they did.
>
> If you will further oblige me by telling me what Mason's correction is, I shall understand the whole matter. I can not conceive how there can be two standards for specific gravity instruments, unless they are based on different temperatures of water for unity of the scale. If this is the case, will you kindly tell me what temperature of water the Mason hydrometer scale is based on, and what temperature of water the ordinary specific gravity hydrometer is based on.

To which he answered on January 27:

> Replying to yours of the 23d inst., would say that all specific gravity scales are based on 60° of temperature. The Mason's correction table is gotten up strictly for the export trade by Prof. Mason, of the Troy Polytechnic Institute, some 20 years ago, and I only make these hydrometers on special orders for exporters of oil. The regular ordinary specific gravity hydrometer is always based on a temperature of 60°. I am sorry that I can not give you more information.

This ended the correspondence.

Up to this time the Tagliabue manual gave in the back part the equivalents of Baumé and specific gravities based on the 140 modulus, but sometime after a revised edition appeared in which the equivalents given were based on the 141.5 modulus, and something over a year ago Mr. Tagliabue issued cards of equivalents in which he expressly stated that they were based on the 141.5 modulus. From the statements made in Mr. Tagliabue's various letters to me and those made now in his present booklet it would seem that not only was *he* all along under a misapprehension in regard to the basis of his hydrometers, but that when the United States Petroleum Association in 1864 adopted Jarvis Arnaboldi's Baumé hydrometers because of their agreeing among themselves so closely, they were under the apprehension that they were adopting a hydrometer based on the 140 modulus. I can not fix the exact time of the change of equivalents published in the Tagliabue manuals, but I have before me while writing a fourth edition, which gives the equivalents based on the 140 modulus, and an eighth edition which gives them based on the 141.5 modulus.

By referring to the report of the New York Produce Exchange adopted April 23 and May 3, 1877, as published in their volume of rules, regulations, etc., it will be seen that they prescribed certain weights per gallon for paraffin and mineral lubricating oils for certain Baumé gravities. These equivalents show that they supposed that they were prescribing a 140 modulus hydrometer. Following I have tabulated the

Baumé degrees and the weight corresponding, given in this produce exchange report, and beside them what these equivalents will be exactly based on the 140 modulus and 141.5 modulus:

Baumé, degrees	Produce exchange report	140° modulus	141.5° modulus
24	7.57	7.573	7.581
27	7.43	7.429	7.437
30	7.29	7.290	7.300
33	7.15	7.155	7.166
36	7.03	7.026	7.038

As against Mr. Tagliabue's principal objections to the 140 modulus that it is not in universal use (if it were it would not be necessary for us to urge its adoption) and that it would make valueless the data accumulated during the past 50 years (which data have all been made practically valueless in the oil business by the large number of new crudes used having practically eliminated all reliance upon former gravity tests for indicating associated qualities), I would instance a few advantages for the 140 scale:

First. It is obvious enough that the formula $\frac{140}{130+B.^{\circ}}$=S. G. is much easier to remember and easier to work than the formula $\frac{141.5}{131.5+B.^{\circ}}$=S. G.

Second. The former formula has, besides the 10=1.000, certain equivalences with the specific gravity scale, easy to remember, as follows:

30=0.875
45= .800
70= .700
94= .625

Of these, two are exact in the first place of decimals and the other two exact in the third place; whereas the latter formula besides the 10=1.000 has only one equivalent that I can find which is exact in even four places of decimals, namely, 68.5=0.7075.

Third. The adoption of the 140 modulus by the United States Bureau of Standards, which I understand declines to standardize as a "Baumé" hydrometer any hydrometer of this type not based on the 140 modulus.

Fourth. The fact that for the last 50 years, regardless of the Baumé hydrometer actually used, the majority of people in the oil business not doing an export business have used the 140 modulus formula in changing their Baumé degrees to specific gravity and vice versa, and this formula is extensively quoted in petroleum literature.

Yours, very truly,

GEORGE H. TABER.

It is with no feeling of ill will toward Mr. Tagliabue or any of the supporters of his scale that this matter has been taken up by the Bureau of Standards. It has been done solely in the interest of truth in order that those who use the Baumé scale for petroleum oils or other liquids may have a clear understanding of the facts in the case, so that when they read a statement to the effect that lately the modulus 140 has been proposed, and that great confusion may result from its use, they may remember that the

modulus has been in use since 1851 and is the basis of the American standard Baumé scale for petroleum and other light liquids as given in all standard works, and is employed by all hydrometer manufacturers save one, who until recently believed that he also was using it.

It should also be remembered that the modulus 141.5 has no standing in the literature; in fact, can not be found in any of the standard works on petroleum except in a single instance where its existence was called to the attention of the author by this Bureau. It owes its origin only to the fact that it suited certain hydrometers made by Tagliabue better than 140 upon which they were originally based.

Having shown that the continued adherence to the modulus 140 is in the interest of uniformity and accuracy and in accordance with established practice, the Bureau of Standards is content to leave the matter in the hands of those who have occasion to make use of the Baumé scale, feeling confident that when the facts are known the American standard Baumé scale represented by the modulus 140 will be employed to the exclusion of all others.

S. W. Stratton,
Director.

Approved:

William C. Redfield,
Secretary.