OIML R 22

Traceability and computerization of alcoholometric tables

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Abstract

The alcoholometric tables are still used around the world by wine and spirits professionals, and were originally published by the OIML in 1973 under the reference OIML R 22, which included a mathematical model and a specification. The Recommendation was followed by a European Directive in 1976. However, both the original OIML document and other official documents, models and specifications are reproduced with inaccuracies, or even errors.

The computerization of these tables has therefore become a necessity for wines and spirits professionals.

To develop a program that meets OIML R 22 and its specifications for reliable and legitimate computerized tables, research was conducted on the traceability of the proposed model and its validation to ensure that the model was effectively leading to the first tables published by the OIML.

The work described in this article confirms the mathematical model and the specifications for generating the alcoholometric tables. A dedicated computer program was developed, allowing reliable and compliant computerized tables to be generated. This program allows both the mathematical model and some constants used in the original specification to be varied in order to check the impact on the accuracy of the calculated data. It also underlines the inaccuracies related to the use of interpolation methods unduly recommended in some tables, or to an incorrect glass expansion coefficient for the alcoholmeter.

The results of this work and particularly the dedicated program can be used as a basis for reviewing the resulting regulations and official documents.

Key Words: Alcoholometric tables, Computerization, Wines, Spirits, OIML R 22

Traçabilité et informatisation des tables d'alcoométrie

Les tables d'alcoométrie, encore très utilisées par les professionnels de vins et spiritueux du monde entier, sont issues d'une Recommandation de l'OIML datant de 1973 qui a publié un modèle mathématique et un cahier des charges, dont découlent ces tables. La Recommandation a été suivie d'une Directive européenne en 1976. Cependant, aussi bien dans le document original de l'OIML que dans les autres documents officiels, le modèle et le cahier des charges sont reproduits avec des imprécisions, voire des erreurs.

L'informatisation de ces tables est donc devenue une nécessité pour les professionnels des vins et spiritueux.

Afin de développer un programme respectant la R 22 et son cahier des charges pour disposer de tables informatisées fiables et légitimes, il a été entrepris une recherche sur la traçabilité du modèle proposé et sa validation pour s'assurer que le modèle conduisait bien aux premières tables publiées par l'OIML.

Les travaux décrits dans cet article ont permis de confirmer le modèle mathématique et le cahier des charges permettant de générer les tables d'alcoométrie. Il a été développé un programme informatique spécifique permettant de générer des tables informatisées fiables et conformes à la réglementation. Ce programme permet de faire varier aussi bien le modèle mathématique que certaines constantes utilisées dans le cahier des charges original, afin d'en vérifier l'impact sur les données des tables. Il fait aussi apparaître les imprécisions liées à l'utilisation de méthodes d'interpolation indûment recommandées dans certains guides, ou à la prise en compte incorrecte du coefficient de dilatation du verre de l'alcoomètre.

Les résultats de ces travaux et en particulier le programme développé peuvent servir de base à des fins de révision de la réglementation et des documents officiels qui en découlent.

Mots clés : Tables d'alcoométrie, Informatisation, Vins, Spiritueux, OIML R 22

1 Introduction

1.1 The use of alcoholometric tables

For over a hundred years professionals in the field of spirits and other alcoholic drinks around the world have needed tables to perform the necessary conversion calculations for certain production activities or production quality controls: conversion of density, alcohol and volume depending on the temperature, measurement of the volume of barrels, measurement of the liquid volume in barrels, etc.

These tables are also used for all commercial transactions and alcohol statements. Therefore, they are essential not only for wine and spirits professionals but also for regulators (e.g. Customs) or agencies that authenticate the volume of pure alcohol content before shipping containers of alcohol sold in bulk.

Table 1 Summary of parameters used in OIML R 22

Parameters	Symbols	Units	Scopes	Intervals
Alcoholic strength by mass	p	% mass	0 to 100	1% mass
Alcoholic strength by volume	q	% vol.	0 to 100	1 % vol.
Temperature	t	°C	−20 to 40	1 °C
Density	ρ	kg/m^3	789.24 to 998.2	0.1 kg/m^3
Volume in pure alcohol	VAP	dm^3	-	

Table 2 Summary of the synthesis functions of the alcoholometric tables of OIML R 22

1	Table I	$\rho = \rho\,(p,t)$
2	Table II	$\rho = \rho\,(q,t)$
3	Table IIIa	$\rho_{20\,°C} = \rho_{20\,°C}\,(p)$
4	Table IIIb	$q_{20\,°C} = q_{20\,°C}\,(p)$
5	Table IVa	$\rho_{20\,°C} = \rho_{20\,°C}\,(q_{20\,°C})$
6	Table IVb	$p = p\,(q_{20\,°C})$
7	Table Va	$p = p\,(\rho_{20\,°C})$
8	Table Vb	$q_{20\,°C} = q_{20\,°C}\,(\rho_{20\,°C})$
9	Table VI	$p = p\,(\rho,t)$
10	Table VII	$q = p\,(\rho,t)$
11	Table VIIIa	$p = p\,(p,t)$
12	Table VIIIb	$q_{20\,°C} = q_{20\,°C}\,(q,t)$
13	Table IXa	$p = p\,(\rho,t)$
14	Table IXb	$q_{20\,°C} = p\,(\rho,t)$
15	Table Xa [1]	$p = p\,(\rho,t)$
16	Table Xb [1]	$q_{20\,°C} = q_{20\,°C}\,(\rho,t)$
17	Table XIa [2]	$VAP_{20\,°C} = VAP_{20\,°C}\,(p,\,t)$
18	Table XIb [2]	$VAP_{20\,°C} = VAP_{20\,°C}\,(q,\,t)$
19	Table XIIa [3]	$VAP_{20\,°C} = VAP_{20\,°C}\,(p,\,t)$
20	Table XIIb [3]	$VAP_{20\,°C} = VAP_{20\,°C}\,(q,\,t)$

equation which contains 60 constants. From this model, it is possible to calculate 20 tables of various conversions, described in Annex I of the Recommendation, as well as the methodology for reconstructing these tables. The parameters found in these tables are summarized in Table 1. A summary of the functions of these tables is given in Table 2.

(1) Tables for which the density measurements (ρ) were made with a borosilicate glass apparatus, wherein the cubic expansion coefficient of the glass is 10×10^{-6} °C^{-1}

(2) These two tables give, in cubic decimetres, the volume (V) at 20 °C of pure ethanol contained in 100 dm^3 of a mixture of known alcoholic strength by mass or volume at the Celsius temperature t, assuming that the volume of 100 dm^3 was measured by a steel container calibrated at 20 °C. The cubical coefficient of expansion of steel is 36×10^{-6} °C^{-1}.

(3) These two tables give, in cubic decimetres, the volume (V) at 20 °C of pure ethanol contained in 100 kg of a mixture of known alcoholic strength by mass or by volume at the Celsius temperature (t) (it is assumed that the weighting took place in air whose density was 1.2 kg/m^3, by means of weights characterized by the conventional value of the result of their weighting in air - see OIML R 33).

OIML R 22 is associated with the publication of Tables I, II, IIIa, IIIb, IVa, IVb, Va and Vb only.

1.2 Origin of alcoholometric tables

Among all the existing tables for use in the field of beverages, the alcoholometry tables allow the conversion of the measurement of the density, alcohol and volume, depending on the temperature.

All the alcoholometric tables result from OIML R 22 [1]. This Recommendation originates from work described and summarized by Wagenbreth in two OIML Bulletins in 1973 [2], [3]. It selected a mathematical model, which is called here "Wagenbreth's model", to generate these tables. This model is based on an

1.3 Mathematical model published by the OIML

The original OIML publication, in French, reproduced the equation leaving some ambiguities in the formula. This work was the object of a European Directive of 1976 (76/766/EEC) [4], in which the equation was deferred, but left some ambiguity about the formula. In addition, a constant is different from that published in OIML R 22.

Directive 2011/17/EU [5], although repealing Directive 76/766/EEC, does not include the equation and constants, but surprisingly, maintains the reference to the equation in the 1976 Directive repealed.

Moreover, neither of the two Directives considers a formula for the density conversion, involving the conventional value of the cubic expansion coefficient of soda-lime glass specific to alcohol hydrometers and recommended by the OIML. This formula is needed to calculate some of the alcoholometric tables including Table VIIIb: conversion of volumetric alcoholic strength at 20 °C.

The equation and constants reproduced in various official documents (sometimes with differences from the original formula) almost never refer to the correction calculation related to the coefficient of cubic expansion of the glass. This is the case of Regulation (EEC) No. 2676/90 [6] which covers the Community analysis methods for the wine sector or the collection of wines analysis methods published by the International Office of Vine and Wine (OIV) [7].

1.4 Reliability and legitimacy of the available alcoholometric tables

Among the existing tables, we can mention:

1) The Practical Guide of alcoholometry published by Adm. P. Oudin [8] in French, in paper format, is used throughout France and in many other countries. It identifies a number of conversion tables, including Table VIIIb, specific to the conversion of alcohol measurement depending on the temperature, and which also contains the factor for volume correction as a function of volume fraction (q) and temperature. It also contains Table IVa, giving the correspondence between the density (ρ) and the alcoholic strength by volume (q) expressed in % volume at 20 °C. A new edition, the 6th was published in 2015.

In this guide, in Table VIIIb the conversions of alcohol measurement (q) depending on temperature are reported with intervals of respectively 0.1 % vol. and 0.5 °C, and the volume correction factors depending on (q) and temperature are reported with intervals of respectively 1 % vol. and 1 °C.

2) Luxembourg has published a document in five languages including French, English and German, containing Table VIIIb [9] with the same interval. Volume correction factors are not reproduced in this table.

3) The Swiss Federal Administration also issued an alcohol conversion table depending on temperature. It is simplified compared to the previous ones, offering only conversions of (q) with an interval of 0.5 % vol. and temperature of 1 °C. Volume correction factors [10] are not reproduced either.

In most cases, the tables contain reprographic errors, partially corrected in new editions.

In the latest revision of the French alcoholometry Guide (6th edition 2015), obvious errors still exist, including the following two examples:

- page 67, 8 % vol. and 3 °C, the value of 9.6 % vol. is given, clearly erroneous; given the proximity values, the value should be 9.5 % vol., as shown in other official tables.
- page 253, the scale of (q) should not read from 60 to 60.9 % vol., but from 70 to 70.9 % vol.

Many more errors can be found in the earlier editions which are still in use.

Computerized charts have been developed for personal use, but by copying data from the "paper" tables, and therefore with the risk of errors.

The French Bureau of Metrology of the Ministry of Economy, Industry and Digital DGE - SQUALPI confirms that the tables of alcoholometry guide edited by Oudin library were never verified. The publisher only received a publishing license. The tables published in this guide cannot be considered as "Official". Only the mathematical model with the equation and constants, reproduced in Directive 76/166 EEC [4] can be considered as official.

The risk of errors related to incorrect data published in tables, misinterpretation of these tables or misreading can have a significant financial impact on commercial transactions, control of production, or on the statements of pure alcohol stocks.

Moreover, according to the accuracy of the tables, it is sometimes necessary to perform interpolation to improve the accuracy. These calculations may be required by regulations, production specifications or imposed by the final customer. In this case, the risk of errors related to wrong interpolation is even greater.

2 Objectives of the work - methodology and results

2.1 Objectives

The main objective is to develop a specific program to generate the alcoholometric tables as computerized databases, while respecting OIML R 22.

To establish the specifications of the program, given the elements set out in 1.3, it was necessary to confirm the equation and associated constants, then check out some assumptions which were not specified in the original document (such as rounding rules).

This article presents the results of the initial research and the methodology for developing such a program. It also presents some additional work that was done

after development of the computer program, such as the impact assessment of certain assumptions used in the Recommendation, the test of a newer mathematical model, as well as recommendations for proper use of the tables.

2.2 Methodology

In the original edition of R 22, the OIML published the first tables (up to Table Vb) and gave the applicable steps to find all the tables.

Some constants of the equation are given with 23 decimals and 16 significant digits. In the 70's, the programming languages (such as FORTRAN IV) took into account all the significant digits. However, current languages and common calculation sheets only use 15 significant digits, which can create rounding errors.

The OIML has not provided the rules for rounding: all values are presented with a single decimal in the tables published with OIML R 22. Given the absence of an international rounding rule, this creates additional uncertainty.

The generation of these tables has required the development of a sophisticated computer program that takes into account and stores 23 decimals and 16 significant digits.

The resources selected for this program are: C++ /11 that uses a standardized specific library for calculations of "large numbers" BOOST [11], C++ library and interface to the C library "MPFR", and GNU (Lesser LPG) based on the ANSI/IEEE-754 (standard for double-precision floating-point arithmetic). "BOOST" is distributed as a free software license "Boost Software License" [12].

The program was designed so that a number of factors could be varied, in order to study their influence on the final result: the number of significant digits, the rounding method, the mathematical model, the step of the parameters and the coefficient of the cubic expansion of the glass.

2.3 Results

2.3.1 Validation of the model proposed in OIML R 22

This program generated tables up to VIIIb (the conversion table of the alcoholic strength by volume measured at a given temperature, to report it at 20 °C).

Comparing the overall results of the first five tables with those published by the OIML has allowed the original equation to be corrected, to confirm the values

of the constants involved and to clarify the methodology to follow up.

Good writing of the equation and associated constants, which led to the publication of tables published in OIML R 22, is given in Figure 1 (see opposite).

It could be inferred that the rounding rule used by the OIML and especially for Table VIIIb, is to round the decimal from the 2nd decimal place, as does a default spreadsheet, when no other rule is imposed.

Thanks to the computerized recording of 98000 data of Table VIIIb from the Practical Guide of alcoholometry [8], the comparison of these values with those of Table VIIIb generated by the program showed that 192 values presented a deviation of +/– 0.1 % vol.

In fact, these differences are absolute values between 0.049 and 0.051 % vol. In the table published by Luxembourg, the differences are almost all the same. However, compared to the Swiss official table, only four differences remain among the 19 values which can be compared. An extract from the comparative is given in Table 3.

These results confirm the origin of the errors, presumably typographical and their propagation by duplication, in several documents including the Practical Guide of alcoholometry.

2.3.2 Comparison of the OIML mathematical model with that of H. Bettin & Al.

The mathematical model proposed in OIML R 22 uses an international standard temperature IPTS-68, which was replaced in 1990 by the ITS-90 standard. It justified the work undertaken by Bettin H. & Spieweck F. [13] in 1990 to propose another equation and the associated constants. Based on this work, the maximum difference found for the values of table Ia, which is obtained directly from the equation, would be only 12×10^{-6} kg/m^3.

In 2006 at a conference in Brazil on metrology, Rezende Zucchini R. & de Souza Themudo [14] presented a comparison of these two models. Since this publication includes transcription errors of the constants in the equation, it is best to refer to the original document of Bettin H. & Al.

The program developed in our work has tested this model and compared the results, especially for Tables Ia and VIIIb.

For Table Ia, the differences are greater than those announced by Bettin & Al. Many values exceed 12×10^{-6} kg/m^3. The maximum calculated difference is 0.0035 kg/m^3 and is in a low temperature range (< -15 °C).

Figure 2 shows the ranges of values for the differences.

$$\rho = A_1 + \sum_{k=2}^{12} A_k \times p^{k-1} + \sum_{k=1}^{6} B_k \times (t - 20°C)^k + \sum_{i=1}^{n} \sum_{k=1}^{m_i} C_{i,k} \times p^k \times (t - 20°C)^i$$

Figure 1 Good writing of the equation and associated constants. Values of n and m: $n = 5$, $m_1 = 11$, $m_2 = 10$, $m_3 = 9$, $m_4 = 4$, $m_5 = 2$

k	A_k	B_k
1	$9.982\ 012\ 300 \times 10^2$	$-2.061\ 851\ 3 \times 10^{-1}$
2	$-1.929\ 769\ 495 \times 10^2$	$-5.268\ 254\ 2 \times 10^{-3}$
3	$3.891\ 238\ 958 \times 10^2$	$3.613\ 001\ 3 \times 10^{-5}$
4	$-1.668\ 103\ 923 \times 10^3$	$-3.895\ 770\ 2 \times 10^{-7}$
5	$1.352\ 215\ 441 \times 10^4$	$7.169\ 354\ 0 \times 10^{-9}$
6	$-8.829\ 278\ 388 \times 10^4$	$-9.973\ 923\ 1 \times 10^{-11}$
7	$3.062\ 874\ 042 \times 10^5$	
8	$-6.138\ 381\ 234 \times 10^5$	
9	$7.470\ 172\ 998 \times 10^5$	
10	$-5.478\ 461\ 354 \times 10^5$	
11	$2.234\ 460\ 334 \times 10^5$	
12	$-3.903\ 285\ 426 \times 10^4$	

k	$C_{1.K}$	$C_{2.K}$	$C_{3.K}$
1	$1.693\ 443\ 461\ 530\ 087 \times 10^{-1}$	$-1.193\ 013\ 005\ 057\ 010 \times 10^{-2}$	$-6.802\ 995\ 733\ 503\ 803 \times 10^{-4}$
2	$-1.046\ 914\ 743\ 455\ 169 \times 10^1$	$2.517\ 399\ 633\ 803\ 461 \times 10^{-1}$	$1.876\ 837\ 790\ 289\ 664 \times 10^{-2}$
3	$7.196\ 353\ 469\ 546\ 523 \times 10^1$	$-2.170\ 575\ 700\ 536\ 993$	$-2.002\ 561\ 813\ 734\ 156 \times 10^{-1}$
4	$-7.047\ 478\ 054\ 272\ 792 \times 10^2$	$1.353\ 034\ 988\ 843\ 029 \times 10^1$	$1.022\ 992\ 966\ 719\ 220$
5	$3.924\ 090\ 430\ 035\ 045 \times 10^3$	$-5.029\ 988\ 758\ 547\ 014 \times 10^1$	$-2.895\ 696\ 483\ 903\ 638$
6	$-1.210\ 164\ 659\ 068\ 747 \times 10^4$	$1.096\ 355\ 666\ 577\ 570 \times 10^2$	$4.810\ 060\ 584\ 300\ 675$
7	$2.248\ 646\ 550\ 400\ 788 \times 10^4$	$-1.422\ 753\ 946\ 421\ 155 \times 10^2$	$-4.672\ 147\ 440\ 794\ 683$
8	$-2.605\ 562\ 982\ 188\ 164 \times 10^4$	$1.080\ 435\ 942\ 856\ 230 \times 10^2$	$2.458\ 043\ 105\ 903\ 461$
9	$1.852\ 373\ 922\ 069\ 467 \times 10^4$	$-4.414\ 153\ 236\ 817\ 392 \times 10^1$	$-5.411\ 227\ 621\ 436\ 812 \times 10^{-1}$
10	$-7.420\ 201\ 433\ 430\ 137 \times 10^3$	$7.442\ 971\ 530\ 188\ 783$	
11	$1.285\ 617\ 841\ 998\ 974 \times 10^3$		

k	$C_{4.K}$	$C_{5.K}$
1	$4.075\ 376\ 675\ 622\ 027 \times 10^{-6}$	$-2.788\ 074\ 354\ 782\ 409 \times 10^{-8}$
2	$-8.763\ 058\ 573\ 471\ 110 \times 10^{-6}$	$1.345\ 612\ 883\ 493\ 354 \times 10^{-8}$
3	$6.515\ 031\ 360\ 099\ 368 \times 10^{-6}$	
4	$-1.515\ 784\ 836\ 987\ 210 \times 10^{-6}$	

Table 3 Comparison of the Table VIIIb values generated by the program with a few tables published (Values in bold and grey are those that differ from those obtained with the developed program)

| t °C	q in % vol.	Our results	Practical Guide of Alcoholometry	Luxembourg official table	Swiss official table
−10	17.5	26.0	**26.1**	**26.1**	26.0
−8	23	34.5	**34.4**	**34.4**	**34.4**
−7	26	37.4	**37.5**	**37.5**	37.4
−7	36	46.9	**47**	**47**	46.9
−6	15.5	20.6	**20.7**	**20.7**	20.6
−1	27	35.7	**35.8**	**35.8**	35.7
0	68	74.3	**74.4**	**74.4**	74.3
0	71	77.2	**77.3**	77.2	77.2
3	8	9.5	**9.6**	**9.6**	9.5
3	14.5	17.8	**17.9**	**17.9**	17.8
6	57	61.8	**61.9**	**61.9**	61.8
7	25	30.0	**30.1**	**30.1**	30.0
8	5.5	6.6	**6.7**	**6.7**	6.6
11	21.5	24.5	**24.6**	**24.6**	24.5
12	1.5	2.2	**2.3**	**2.3**	2.2
12	37	40.2	**40.3**	**40.3**	40.2
18	3.5	3.7	**3.8**	**3.8**	**3.8**
27	83.5	81.4	**81.5**	**81.5**	**81.5**
35	67	61.8	**61.9**	**61.9**	**61.9**
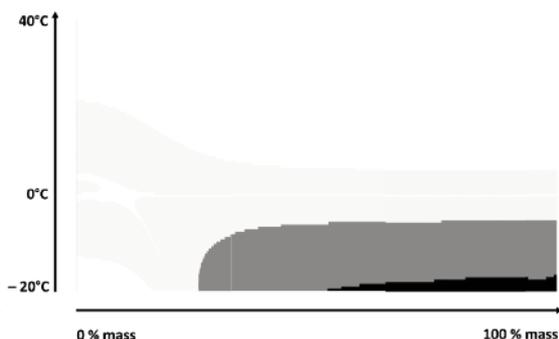
Figure 2 Highlighting the differences between the values
obtained for Table Ia with the mathematical models
of Wagenbreth and Bettin

- White zone: differences are less than 0.000012 kg/m³
- Lighter grey zone: differences are between 0.000012
  and 0.001 kg/m³
- Darker grey zone: differences are between 0.001
  and 0.003 kg/m³
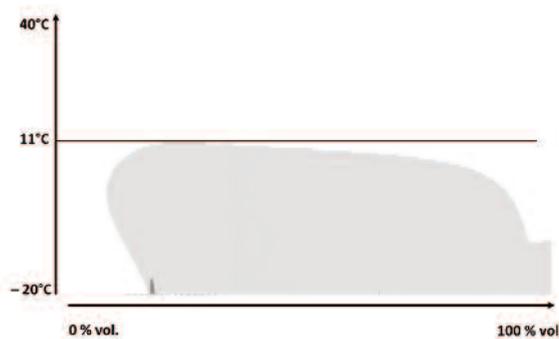- Black zone: differences are larger than 0.003 kg/m³

Figure 3 Highlighting the differences between the values
obtained for Table VIIIb, with the mathematical models
of Wagenbreth and Bettin

- White zone: differences are less than 0.001 % vol.
- Lighter grey zone: differences are between 0.001
  and 0.01 % vol.
- Darker grey zone: differences are between 0.01
  and 0.025 % vol.

However, the accuracy achieved at 10^{-2} kg/m³ can be considered as sufficient for the practical use of this Table.

As regards Table VIIIb, the calculations of the difference of volume fractions from the two corrected mathematical models (Wagenbreth and Bettin), lead to a maximum difference of 2.5×10^{-2} % vol. It should be noted that the most significant differences (> 0.01 % vol.) are all for measuring temperatures below 11 °C. Figure 3 shows the ranges of values for the differences.

In view of the desired accuracy of 0.01 % vol., the model proposed by Bettin & Al. can be considered as identical to the one proposed in OIML R 22.

2.3.3 Visual representation of Table VIIIb values

Table VIIIb provides alcohol conversion data depending on temperature. Overwhelmingly we observe a regular interval of 0.1 % vol. between two data. Nevertheless, these intervals are sometimes 0 % vol. or 0.2 % vol. and more rarely 0.3 % vol. Specific software has coloured the data according to the interval value. Interval values that are different from 0.1 % vol. are coloured. Surprisingly, clover shapes appeared, represented in Figure 4.

2.3.4 Impact of the value of the cubic expansion coefficient of glass

The cubic expansion coefficient of glass chosen in OIML R 22 is a conventional value of 25×10^{-6}. It is used in an additional equation to correct volumetric mass values

obtained from Tables IIIa or IVa to generate respectively Tables VIIIa and VIIIb.

As stipulated in NF B 35-512 [15], depending on the hydrometer's type of glass used for measuring, its volumetric expansion coefficient may differ. In this case, it is necessary to recalculate the value indicated by the aerometer R' using the following equation: R = R' [1 + $(0.000025 - \gamma)$ $(\theta - t)$, for which θ is the measured temperature in °C and γ is the cubic expansion coefficient at a given temperature t (generally 20 °C).

When looking to determine the volumetric alcoholic strength and in the case of a density measurement with an aerometer R' at temperature θ, after calculation of R, Table VII allows the conversion in volumetric alcoholic strength at temperature θ, and then Table VIIIb allows the volumetric alcoholic strength at 20 °C to be obtained.

Typically, the measurement of the volumetric alcoholic strength is made with an alcoholmeter. In this case, we must first find the density equivalent R' using Table II and then calculate R, applying the above equation, and continue to obtain the previous conversions by volume at 20 °C.

Apart from the conventional value of the coefficient chosen in OIML R 22 to establish the tables, different coefficients have been found in the literature, among others 23×10^{-6} and 27×10^{-6}. The program developed in this work allows the cubic expansion coefficient of the glass used to be varied. We therefore investigated the impact of replacing the conventional value of these two values in Table VIIIb.

Indeed, for a relatively small difference of 2×10^{-6}, the observed differences are very important and can reach 1.5 % vol.
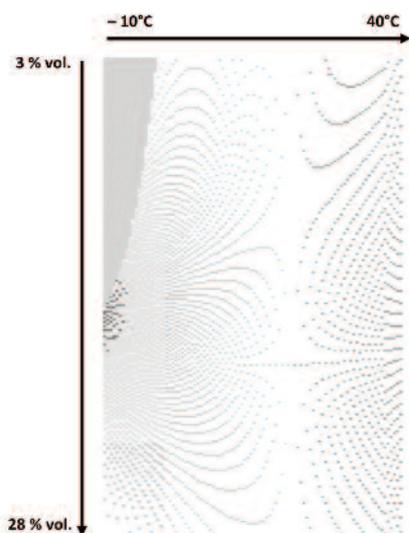
Figure 4 Extract from the imaging differences in steps between two correction values of the alcoholic strength in volume from Table VIIIb
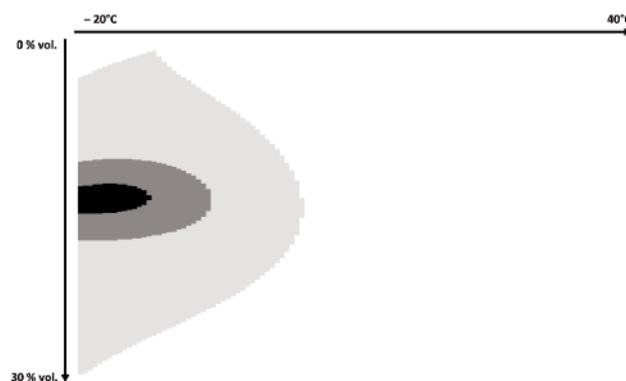

Figure 5 Highlighting the differences between the values obtained for Table VIIIb with a coefficient of cubic expansion at 23×10^{-6} instead of the conventional value of 25×10^{-6}

- White zone: differences are less than 0.1 % vol.
- Shaded area from light to dark: differences range from 0.1 to 1.5 % vol.

For example, Figure 5 highlights the temperature zones and alcoholic strength for which the differences are the most important when comparing the values in Table VIIIb calculated with a cubic expansion coefficient of 23×10^{-6} instead of 25×10^{-6} (conventional value used in OIML R 22).

In the case where the cubic expansion coefficient of the glass used to make the hydrometer is not 25×10^{-6} at 20 °C, Table VIIIb provides an incorrect response in a wide temperature range.

2.3.5 Calculation of the volume correction factor

When measuring the volume of a hydro-alcoholic solution at a given temperature, it is necessary to apply a correction to know the volume at 20 °C.

These correction factors are partly reported in Table VIIIb of the Practical Guide of alcoholometry, only for integer values of alcoholic strength by volume and temperature.

The Guide provides a method of interpolation (page 25 of the 6th edition) to calculate the volume of corrections for intermediate values.

Indeed, the method proposed in the Guide works with the example, but this is not the case with all values, as will be demonstrated here.

Table II of OIML R 22 allows the density (ρ) of a hydro-alcoholic solution to be determined, after measurement of the alcoholic strength by volume (q) and temperature (t). The volume correction factor can therefore be calculated by the ratio of (ρ) at measured temperature (t) and (ρ) at 20 °C.

Some examples of calculations of the volume correction factor by comparison with the values of the Guide, with and without interpolation, are reported in Table 4.

These examples show that it is more accurate to calculate this factor for all values of (q) and temperature, as a computer program can, incorporating Table II of alcoholometry. Otherwise, it is preferable to indicate the value of the volume correction factor for all values of (q) and temperature, and not encourage the user to apply a method of interpolation.

3 Conclusions

This work shows the need to change the tools used by professionals for the characterization of the alcohol content of wines and spirits. The computerization of alcoholometric tables through programs can ensure greater reliability and traceability, compared to conversions and calculations done manually.

Indeed, in this research, numerous copying errors were highlighted in tables regarded as official by many users, including official bodies. It was shown that certain guidelines for the extrapolation of the correction factor of the volume which depends on the alcoholic strength and temperature are incorrect.

It was also shown that OIML R 22, European regulations resulting from it and other official documents describe the mathematical model imprecisely and in an incomplete and sometimes erroneous manner [4] [5] [6].

Table 4 Comparison of the calculated factor volume correction using Table II of alcoholometry and the method proposed in the
Practice Guide of alcoholometry

Example no.	q % vol.	t/°C	$\rho/(g \cdot l^{-1})$ at t	$\rho/(g \cdot l^{-1})$ at 20 °C	Correction factor by calculation	Correction factor deducted from the Guide
1 – example p25 of the Guide	98	32.5	788.09 = average of 788.52 at 32 °C and 787.65 at 33 °C	798.9	986.5	986.5
2	55	15	923.84	919.86	**1004.3**	**1004**
3	55	16.5	922.69 = average of 923.07 at 16 °C and 922.3 at 17 °C	919.96	**1003**	**1002.5**
4	70	12.5	891.74 = average of 892.14 at 12 °C and 891.33 at 13 °C	885.56	**1007**	**1006.5**

The work undertaken has helped redefine the formal mathematical model: equations and values of the constants used by the OIML and rounding rules.

This work can serve as the basis for a revision of OIML R 22 and an update of the resulting documents.

The design of the program developed for this work allowed a number of factors to be varied and to study the impact on the values of the tables.

Factor changes studied during this work led to the following:

1) The model proposed by Bettin H. [13], simpler and more recent than the one proposed in OIML R 22, given the generally necessary accuracy, can be considered as achieving the same results. For Table Ia, the density differences are below 10^{-2} kg/m^3. For Table VIIIIb, the differences are less than 0.01 % vol., with the exception of a very small temperature and volume fraction range between 16.2 and 17 % vol. and –20 °C at –17.5 °C, for which the accuracy is between 0.01 and 0.025 % vol.

2) Tests of the change in the cubic expansion coefficient of soda-lime glass showed that it is important to check that the cubic expansion factor of hydrometers and alcoholmeters used for the measurement is really 0.000025. Otherwise, the use of Table VIIIb may become inadequate.

Comparison of the tables generated by the computer program, developed specifically for this work, with the first tables published by the OIV and Table VIIIb published in paper guides, demonstrated that the program was reliable and that the tables obtained with it comply with the regulation, as they result from the specifications of OIML R 22.

The program developed in this work can be used, should the mathematical model be re-examined or come into question, as suggested in the report of the CIML in 2003 [16].

These tables can therefore be used as computerized databases in software for wine and spirits professionals (producers, traders, brokers, laboratories, computerized management providers of production, customs, etc.).

They are currently used in LABOX®, a software program dedicated to alcohol and volume conversions depending on temperature, which also performs other useful calculations for spirits professionals such as the calculations for increasing or reducing the alcohol content of spirits, taking into account the volume contraction of the calculation or the census of pure alcohols in stock.

It is also possible with the program, which served as the basis for this work, to increase the accuracy of the values obtained with the use of the tables with a reduced interval. For example in Table VIIIb, we can change the 0.1 % vol. into 0.01 or 0.05 % vol. and replace the temperature interval of 0.5 °C by 0.1 °C.

However, the tables generated will be larger. An interval of 0.1 °C will lead to the number of values of the table to be multiplied by 5 (500 000 values, versus about 100 000 currently in the Practical Guide of alcoholometry). If the interval of (q) changes to 0.05 % vol., the multiplication factor will be 5 and 10 with an interval of 0.01 % vol. This amount of data would make the use of paper tables extremely tedious. Access to this level of accuracy is easy with the use of the computer program. This practical difference is an ultimate justification of the need to computerize the alcoholometric tables for wine and spirits professionals.

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