OIV-MA-BS-06 Density of alcohols and alcoholic beverages method for determining electronic densimetry (principle based on measuring the period of oscillation)

Type IV method

1. Introduction

This method for determining the density of neutral alcohols and alcoholic beverages is based on the change in oscillation frequency in relation to the change in mass based on calibration with two fluids of known density.

Electronic densimeters with digital displays are commercially available to perform this determination.

2. Object and scope of application

The purpose of this document is to describe a method for determining the density of alcohols and alcoholic beverages at atmospheric pressure.

The application of the method is restricted to products with a vapour pressure of less than 800 hectoPascal (600 mmHg) and a viscosity of less than approximately 15,000 m $m^2$2/s (I mm^2/s = 1 cSt) at the test temperature.

With reference to the currently applicable regulations, the test temperature is set to: 20°C.

3. Density

The density of a liquid at a given temperature is equal to its mass divided by its volume:

$$\rho = \frac{m}{V}$$

It is expressed in kilograms per cubic meter (kg/m^3) at a temperature of 20 degrees Celsius (°C) for alcohols and alcoholic beverages.

Note: electronic densimeters display results expressed in grams per cubic centimetre which may be converted into kilograms per cubic meter.

4. Principle

4.1. A liquid sample of a few millilitres is introduced into a vibrating measuring tube.

Measuring the period of oscillation of the tube containing the sample determines the density of the sample at the test temperature, using a previously calibrated apparatus.

4.2. Principle of vibrating measuring tube.

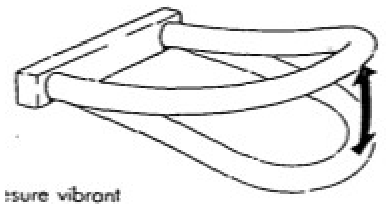

Figure 1: Vibrating measuring tube

Electronic densimeters operate according to the vibrating measuring tube principle (fig. 1): the fluid is introduced into a U-shaped tube and subjected to electromagnetic excitation (fig. 2 and fig. 3).

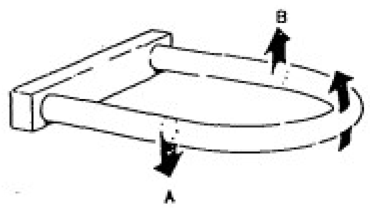

Figure 2: Reactive forces exerted by the fluid

The induced period of oscillation is thus proportional to the total mass subject to vibration and can be used to determine the density of the sample based on the following equation:

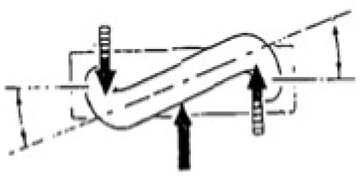

Figure 3: Resulting torsion

$$T = 2\pi\sqrt{(M + pV)/C}$$

- where T = induced period of vibration
- M = mass of the empty tube
- V = volume of the oscillated sample
- C = spring constant
- p = density of the sample

4.3. Detailed principle.

The density of the liquids is determined by the electronic measurement of the oscillations of a vibrating U-shaped tube.

To carry out this measurement, the sample is introduced into an oscillating system, whose specific frequency is thus modified by the mass of the substance introduced.

The system comprises an undamped U-shaped vibration tube, subject to electronic excitation. The two straight sections of the U-shaped tube act like a spring mechanism. The oscillatory movements occur perpendicular to the U. The filling capacity, V, is delimited by the two fastening points. If the oscillator contains the volume established as V, the latter vibrates within and with the tube. It is accepted that the mass is proportional to the density. Since filling the tube beyond the fastening point does not affect the measurement, it is possible to perform a continuous flow measurement.

By maintaining a constant temperature over the entire system, the density will be calculated based on the period assuming a hollow container having mass M suspended by a spring, with a spring constant c. The hollow container will be filled with a volume of liquid of density p. The natural frequency of this vibratory system is:

$$F=1/2\sqrt{\frac{Vc}{M}} + pV$$

$$T = 2\sqrt{(VM + \frac{pV}{c})} * p = T2 * (c/4)^2 * (V - M)/M$$

.

- $A = (c/4)^2 \ \ V$
- et B=M/V

- which gives p = A T2 - B
- (p = rho).

Constants A and B are the oscillator's spring constants, i.e. the mass of the empty tube and the tube's filling capacity. A and B are therefore system constants specific to each oscillator. They can be deduced from the measurement of two periods when the oscillator is filled with substances of known densities.

5. Apparatus

5.1. Digital display densimeter.

This appliance comprises the following elements:

- a glass measuring cell containing the measuring tube, a constant temperature chamber to be connected to an external circulating thermostatic bath, and a thermowell. The chamber can also be thermostated using an integrated device with a semiconductor element which uses the PELTIER effect,
- a system for oscillating the measuring tube and for measuring the period of oscillation,
- a clock,
- a calculator and digital display.

5.2. Temperature control.

The densimeter's performance standards can only be met if the measuring cell is connected to a thermostatic bath, ensuring a temperature stability better than ± 0.02 °C, or if the densimeter has an integrated thermal control device which can achieve the same temperature stability.

5.3. Sample injection syringes.

At least 2 ml polypropylene or glass syringes with tips that fit to the cell inlet. An adapter with PTFE cones is required in order to avoid the deterioration of the tip of the measuring cell.

The electronic densimeter can also be equipped with the appropriate autosampler for the apparatus.

5.4. Temperature measurement.

Temperature measurement is carried out on the cell with a temperature probe whose sensing device (a platinum resistance probe compliant with class A of standard NF C

42.330), which is mounted with 4 wires, is introduced into the thermowell provided for this purpose in the cell. The probe is combined with an electronic temperature transmitter whose readout has a resolution of 0.01 °C. The probe and transmitter must first have been be calibrated in an approved calibration centre in order to ensure temperature measurement with an uncertainty less than or equal to ± 0.05°C.

The probe and transmitter must be periodically checked.

6. Products

1. Reference fluids.

During tests, the fluids must maintain their density characteristics; therefore, they must not be made of mixtures of products with different vapour pressures; their molecular composition and purity must be known. Their viscosity must be lower than 2 mm^2/s.

Reference fluids must be chosen so that the densities encompass those of the products to be measured. The difference in density between the 2 reference fluids at the same temperature must be higher than 0.01 g/m^3.

The reference fluid densities determined at a temperature of 20 °C with an uncertainty of less than ± 0.05 °C must be known with an uncertainty of less than ± 0.05 kg/m^3.

When measuring the density of alcohols and alcoholic beverages, the following must be used, under the conditions previously described:

- hydro-alcoholic solutions whose density is exclusively determined using the pycnometric method (reference method).
- recently prepared, degassed double distilled water, or water of equivalent analytical purity,
- dry air.

6.2. Cleaning products.

- chromic acid,
- organic solvents: ethanol 96 vol%, pure acetone.

3. Drying.

- Pure acetone, dry air

7. Period measurements in ambient air

Prior to the commissioning and calibration of the densimeter, it is essential to ensure the reproducibility of the measurement in the ambient air so that this measurement can be used to quickly check the cleanliness of the cell and consistency of the densimeter before every density measurement.

It should be possible to perform measurements of periods in the ambient air with a reproducibility of ± 10^{-5} in relative values over the period for the same barometric pressure and the same temperature.

With some densimeters, the resonant period in the ambient air varies depending on the position of the temperature probe in the thermowell. For these densimeters, either the measuring cell must be replaced, or the temperature probe must be permanently attached, or its position in the thermowell must be accurately determined in order to achieve the reproducibility conditions described above.

NOTE: The use of polluted or excessively humid air may negatively influence the measurements. When these characteristics are combined in the test room, it is advisable to make the drying air flow through a purifier/dryer.

8. Apparatus calibration

1. General.

The apparatus must be calibrated upon initial commissioning. It must be recalibrated if a deviation in the air measurement is observed (see section 9.20) and, in any case, every three months.

8.2. During initial calibration, it is necessary to calculate the values of constants A and B, determined by measuring the periods of oscillation (T1 and T2) respectively obtained using two reference fluids.

8.2.1. Place the display selector on the period measurement (T) position. Rinse the cell with acetone. Dry it with dry air generated by the pump that is integrated to the densimeter. When the reading is almost stable, stop the air supply, wait for thermal equilibrium and record the period of oscillation (Ta) obtained with an ambient air temperature of 20 °C. This process helps to check the cleanliness of the cell and stability of the apparatus at every calibration or determination of sample density.

8.2.2. Calibration measurement using the first reference fluid. Use a syringe to fill the cell through its bottom port with the standard liquid until it comes flush with the top port. Leave the syringe in place. While performing this, check the filling quality by visually checking for any air bubbles, even tiny ones. When thermal equilibrium has been reached, record the reading for the period of oscillation (T1). If the thermal control is compliant with the required accuracy, the value of T1 must not vary by more than ± 20 nanoseconds (2 resolution points).

8.2.3. Calibration measurement using the second reference fluid. Empty the cell with the syringe by drawing from the bottom port. Rinse the cell with acetone. Dry it with dry air generated by the pump that is integrated to the densimeter. To do so, connect the air outlet to the top port of the cell, start the pump and allow it to operate until the reading for T2 is almost constant; stop the pump, and when thermal equilibrium is reached, record the reading for the period of oscillation (T2) which corresponds to the air. If the reading for T2 matches the value obtained during previous tests carried out with a properly cleaned cell and at the same temperature, the cell can be considered clean and dry.

Carry out calibration using the second standard by repeating the steps in paragraph 8.22 and record the reading for the period of oscillation (T2) corresponding to the second reference fluid.

8.2.4. Based on the T1 and T2 values measured and the known values for the densities of both reference fluids, calculate constants A and B using the following equations:

- $A = T1^2 - T2^2 / p1 - p2$
- $B = T2^2 - A \quad p2$

where

- T1 is the observed period of oscillation with the cell containing the first reference fluid (in ms).
- T2 is the observed period of oscillation with the cell containing the second reference fluid (in ms).
- p1 is the density of the first reference fluid at the test temperature (in g/cm^3),
- p2 is the density of the second reference fluid at the test temperature (in g/cm^3).

Depending on the procedure for the densimeter being used:

8.2.5. Enter constants A and B using the digital display at the top of the apparatus. In order to make sure they have been correctly memorised, display the values by placing the selector on the "A" and "B" positions.

8.2.6. Place the selector on the measurement position. The densimeter should immediately display the densities of the samples introduced into the measuring cell.

NOTE: Some electronic densimeter models automatically calculate the calibration constants.

8.3. Checking the calibration.

In order to validate the operation, measure a reference solution whose density value is within the calibration range used.

Reference substances, verified by a metrology agency, are commercially available.

The calibration is validated if the result of the measurement of the reference substance density complies with the accuracy class of the electronic densimeter being used.

9. Procedure

1. Preparation of test apparatus.

- Place the densimeter on a perfectly stable support, isolated from any vibrations.
- Connect the densimeter to the circulating constant temperature bath using flexible rubber pipes or insulating tubes. Fill the water bath according to the manufacturer's instructions and add a product to prevent the formation of algae.

Set the bath temperature to reach and maintain the requisite test temperature on the densimeter.

- Accurately setting and controlling the temperature in the measuring cell are very important parameters, as a 0.1 °C error can result in a variation in density in the order of 0.1 kg/m^3.
- The following rules must be observed:
- the measuring cell must be maintained at a constant temperature for 6 hours before the test.
- the maximum temperature variation measured by the temperature probe of the measuring cell must not exceed ± 0.02 °C.

- the pipe flow, length and insulation between the thermostatic bath and the cell are to be adjusted to ensure the stability of the cell temperature.

9.2. Checking period measurements in the ambient air.

- Clean, rinse and dry the cell.
- Carry out a measurement in the ambient air. Check that the period measured does not deviate by more than i0- in relative values from the period determined under the conditions described in section 7. If deviation occurs, clean the cell again with a lukewarm chromatic acid solution (warning: this product can cause serious burns), which is the most effective cleaning agent. If the deviation persists after several cleaning operations, repeat the calibration process.

9.3. Density measurement.

- Filter the sample first, if necessary.
- Illuminate the cell.

If only a small quantity of sample is available, use the syringe to introduce the quantity needed so that the liquid to be measured reaches the top port of the clean and dry cell. While filling the cell, make sure all air bubbles are completely removed; the sample must be homogeneous and must not contain any solid particulates.

- Leave the syringe in place on the bottom port of the cell.

NOTE: Introducing dark coloured samples into the cell does not help to establish the absence of air bubbles or solid particulates with certainty.

Switch off the lamp immediately after introducing the sample, as the heat it produces influences the measurement temperature.

9.4. Calculation and expression of results.

9.4.1. Densimeter with an integrated calculator.

After a few minutes, the density value stabilises, indicating that the equilibrium temperature of the measurement has been reached. If the measurement temperature does not differ by more than ± 0.01 °C from a temperature of 20 °C, record the reading.

If needed, convert the obtained result into kg/m^3.

9.4.2. Densimeter without a calculator.

Allow the reading for the period of oscillation (T) to stabilise within one unit from the fourth decimal place. If the measurement temperature does not differ by more than

± 0.01 °C from a temperature of 20 °C, record the reading.
Calculate the density of the sample in kg/m3 using the following formula:

$$p = \frac{1000}{A} * (T2 - B)$$

where

- T is the period of oscillation for the sample measured (in ms).
- A and B are the constants defined during the calibration prescribed in paragraph 8.

9.4.3. Viscosity correction.

If the liquid whose density is being measured has a viscosity higher than 2 mm^2/s, correction is required to take the viscosity into account, using the formula provided by the manufacturer of the densimeter.

10. Test report

The test report must indicate:

- the method used,
- the result and mode of expression of results,
- the specific details and any unforeseen events recorded during the measurement,
- operations not included in the method.

APPENDIX A

TABLE 1

AIR DENSITY

Air density, expressed in g/cm^3, varies with the pressure P expressed in mbar and the temperature expressed in °C.
A t °C and p Ton-, calculate the density using the following formula:

$$density\ t,p = \frac{0,0012930}{1 + 0;00367t} * \frac{P}{760}$$

Values are given for contents of 0.03 vol% of CO_2 in the air; values change by ± 1/19000 with each variation of ± 0.0001 of the CO_2 volume.

Composition of dry air at ground level:

	N_2	O_2	A	CO_2	Ne	He	Kr	X	H_2
Volume in %	78.09	20.95	0.93	0,03	0.0018	0.0005	0.041	0.068	0.045
Mass in %	75.52	23.15	1.28	0.05	0.0013	0.047	0.043	0.044	0.084

Units are g/ml
Pressure (H) in centimetres of mercury

les unités sont des g/ml
Presion (H) en centimètres de mercure

proport. parts

T °C	72.0	73.0	74.0	75.0	76.0	77.0	parties proport.
10	0.001182	0.001198	0.001215	0.001231	0.001247	0.001264	17
11	178	193	210	227	243	259	cm
12	173	190	206	222	239	255	0,1 2
13	169	186	202	218	234	251	0,2 3
14	165	181	198	214	230	246	0,3 5
							0,4 7
15	0.001161	0.001177	0.001193	0.001210	0.001226	0.001242	0,5 8
16	157	173	189	205	221	238	0,6 10
17	153	169	185	201	217	233	0,7 12
18	149	165	181	197	213	229	0,8 14
19	145	161	177	193	209	225	0,9 15
							16
20	0.001141	0.001157	0.001173	0.001189	0.001205	0.001221	cm
21	137	153	169	185	201	216	0,1 2
22	134	149	165	181	197	212	0,2 3
23	130	145	161	177	193	208	0,3 5
24	126	142	157	173	189	204	0,4 6
							0,5 8
25	0.001122	0.001138	0.001153	0.001169	0.001185	0.001200	0,6 10
26	118	134	149	165	181	196	0,7 11
27	115	130	146	161	177	192	0,8 13
28	111	126	142	157	173	188	0,9 14
29	107	123	138	153	169	184	15
30	10.001104	0.001119	0.001134	0.001150	0.001165	0.001180	0,1 1
							0,9 13

Proportional parts 17:

Dry air density at 20° and 760 mm of mercury: 1.204 mg/ml

DENSITY OF PURE DEAERATED WATER

0 °C : 0.99987	3,98 °C : 1.0000	5 °C : 0.99999	10 °C : 0.9973
15 °C : 0.99913	18 °C : 0.99862	20 °C : 0.99823	25 °C : 0.99707
30 °C : 0.99567	35 °C : 0.99406	38 °C : 0.99299	40 °C : 0.99224
45 °C : 0.99025	50 °C : 0.98807	55 °C : 0.98573	60 °C : 0.98324
65 °C : 0.98059	70 °C : 0.97781	75 °C : 0.97489	80 °C : 0.97183
85 °C : 0.96865	90 °C : 0.96534	95 °C : 0.96192	100 °C : 0.95838

Water density according to the temperature: ρ (g/cm³) (1)

t (°C)	0,0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9
0	0,999 839	0,999 846	0,999 852	0,999 959	0,999 865	0,999 871	0,999 877	0,999 882	0,999 888	0,999 893
1	0,999 898	0,999 903	0,999 908	0,999 913	0,999 917	0,999 921	0,999 925	0,999 929	0,999 933	0,999 936
2	0,999 940	0,999 943	0,999 946	0,999 949	0,999 952	0,999 954	0,999 956	0,999 959	0,999 961	0,999 962
3	0,999 964	0,999 966	0,999 967	0,999 968	0,999 969	0,999 970	0,999 971	0,999 971	0,999 972	0,999 972
4	0,999 972	0,999 972	0,999 972	0,999 971	0,999 971	0,999 970	0,999 969	0,999 968	0,999 967	0,999 965
5	0,999 964	0,999 962	0,999 960	0,999 958	0,999 956	0,999 954	0,999 951	0,999 943	0,999 946	0,999 943
6	0,999 940	0,999 937	0,999 934	0,999 930	0,999 926	0,999 923	0,999 919	0,999 915	0,999 910	0,999 906
7	0,999 901	0,999 897	0,999 892	0,999 887	0,999 882	0,999 877	0,999 871	0,999 866	0,999 860	0,999 854
8	0,999 848	0,999 842	0,999 836	0,999 829	0,999 823	0,999 816	0,999 809	0,999 802	0,999 795	0,999 788
9	0,999 781	0,999 773	0,999 765	0,999 758	0,999 750	0,999 742	0,999 734	0,999 725	0,999 717	0,999 708
10	0,999 699	0,999 691	0,999 682	0,999 672	0,999 663	0,999 654	0,999 644	0,999 635	0,999 625	0,999 615
11	0,999 605	0,999 595	0,999 584	0,999 574	0,999 563	0,999 553	0,999 542	0,999 531	0,999 520	0,999 509
12	0,999 497	0,999 486	0,999 474	0,999 462	0,999 451	0,999 439	0,999 426	0,999 414	0,999 402	0,999 389
13	0,999 377	0,999 364	0,999 351	0,999 338	0,999 325	0,999 312	0,999 299	0,999 285	0,999 272	0,999 258
14	0,999 244	0,999 230	0,999 216	0,999 202	0,999 188	0,999 173	0,999 159	0,999 144	0,999 129	0,999 114
15	0,999 099	0,999 084	0,999 069	0,999 054	0,999 038	0,999 022	0,999 007	0,998 991	0,998 975	0,998 958
16	0,998 943	0,998 926	0,998 910	0,998 894	0,998 877	0,998 860	0,998 843	0,998 826	0,998 809	0,998 792
17	0,998 775	0,998 757	0,998 740	0,998 722	0,998 704	0,998 686	0,998 668	0,998 650	0,998 632	0,998 614
18	0,998 595	0,998 577	0,998 558	0,998 539	0,998 520	0,998 502	0,998 482	0,998 463	0,998 444	0,998 425
19	0,998 405	0,998 385	0,998 366	0,998 346	0,998 326	0,998 306	0,998 286	0,998 265	0,998 245	0,998 224
20	0,998 204	0,998 183	0,998 162	0,998 141	0,998 120	0,998 099	0,998 078	0,998 057	0,998 035	0,998 014
21	0,997 992	0,997 971	0,997 949	0,997 927	0,997 905	0,997 883	0,997 860	0,997 838	0,997 816	0,997 793
22	0,997 770	0,997 747	0,997 725	0,997 702	0,997 679	0,997 656	0,997 632	0,997 609	0,997 585	0,997 562
23	0,997 538	0,997 515	0,997 491	0,997 467	0,997 443	0,997 419	0,997 394	0,997 370	0,997 345	0,997 321
24	0,997 296	0,997 272	0,997 247	0,997 222	0,997 197	0,997 172	0,997 146	0,997 121	0,997 096	0,997 070
25	0,997 045	0,997 019	0,996 993	0,996 967	0,996 941	0,996 915	0,996 889	0,996 863	0,996 836	0,996 810
26	0,996 783	0,996 757	0,996 730	0,996 703	0,996 676	0,996 649	0,996 622	0,996 595	0,996 568	0,996 540
27	0,996 513	0,996 485	0,996 458	0,996 430	0,996 402	0,996 374	0,996 346	0,996 318	0,996 290	0,996 262
28	0,996 233	0,996 205	0,996 176	0,996 148	0,996 119	0,996 090	0,996 061	0,996 032	0,996 003	0,995 974
29	0,995 945	0,995 915	0,995 886	0,995 856	0,995 827	0,995 797	0,995 767	0,995 737	0,995 707	0,995 677
30	0,995 647	0,995 617	0,995 586	0,995 556	0,995 526	0,995 495	0,995 464	0,995 433	0,995 403	0,995 372
31	0,995 341	0,995 310	0,995 278	0,995 247	0,995 216	0,995 184	0,995 153	0,995 121	0,995 090	0,995 058
32	0,995 026	0,994 997	0,994 962	0,994 930	0,994 898	0,994 865	0,994 833	0,994 801	0,994 768	0,994 735
33	0,994 703	0,994 670	0,994 637	0,994 604	0,994 571	0,994 538	0,994 505	0,994 472	0,994 438	0,994 405
34	0,994 371	0,994 338	0,994 304	0,994 270	0,994 236	0,994 202	0,994 168	0,994 134	0,994 100	0,994 066
35	0,994 032	0,993 997	0,993 963	0,993 928	0,993 893	0,993 859	0,993 824	0,993 789	0,993 754	0,993 719
36	0,993 684	0,993 648	0,993 613	0,993 578	0,993 543	0,993 507	0,993 471	0,993 436	0,993 400	0,993 364
37	0,993 328	0,993 292	0,993 256	0,993 220	0,993 184	0,993 148	0,993 111	0,993 075	0,993 039	0,993 002
38	0,992 965	0,992 928	0,992 891	0,992 855	0,992 818	0,992 780	0,992 743	0,992 706	0,992 669	0,992 631
39	0,992 594	0,992 557	0,992 519	0,992 481	0,992 444	0,992 406	0,992 368	0,992 330	0,992 292	0,992 254
40	0,992 215	0,992 177	0,992 139	0,992 100	0,992 062	0,992 023	0,991 985	0,991 946	0,991 907	0,991 868
41	0,991 830	0,991 791	0,991 751	0,991 712	0,991 673	0,991 634	0,991 594	0,991 555	0,991 515	0,991 476
42	0,991 436	0,991 396	0,991 357	0,991 317	0,991 277	0,991 237	0,991 197	0,991 157	0,991 116	0,991 076
43	0,991 036	0,990 995	0,990 955	0,990 914	0,990 873	0,990 833	0,990 792	0,990 751	0,990 710	0,990 669
44	0,990 628	0,990 587	0,990 546	0,990 504	0,990 463	0,990 421	0,990 380	0,990 338	0,990 297	0,990 255
45	0,990 213	0,990 171	0,990 129	0,990 087	0,990 045	0,990 003	0,989 961	0,989 919	0,989 876	0,989 834
46	0,989 792	0,989 749	0,989 706	0,989 664	0,989 621	0,989 578	0,989 535	0,989 492	0,989 449	0,989 406
47	0,989 363	0,989 320	0,989 276	0,989 233	0,989 190	0,989 146	0,989 103	0,989 059	0,989 015	0,988 971
48	0,988 928	0,988 884	0,988 840	0,988 796	0,988 752	0,988 707	0,988 663	0,988 619	0,988 574	0,988 530
49	0,988 485	0,988 441	0,988 396	0,988 352	0,988 307	0,988 262	0,988 217	0,988 172	0,988 127	0,988 082
50	0,988 037	0,987 992	0,987 946	0,987 901	0,987 844	0,987 810	0,987 764	0,987 719	0,987 673	0,987 627
51	0,987 581	0,987 536	0,987 490	0,987 444	0,987 398	0,987 351	0,987 305	0,987 259	0,987 213	0,967 166

Water density according to the temperature: ρ (g/cm³) (1) (end)

t (°C)	0,0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9
52	0,987 120	0,987 073	0,987 027	0,986 980	0,986 933	0,986 886	0,986 840	0,986 793	0,986 746	0,986 699
53	0,986 652	0,986 604	0,986 557	0,986 510	0,986 463	0,986 415	0,986 368	0,986 320	0,986 272	0,986 225
54	0,986 177	0,986 129	0,986 081	0,986 033	0,985 985	0,985 937	0,985 889	0,985 841	0,985 793	0,985 745
55	0,985 696	0,985 648	0,985 599	0,985 551	0,985 502	0,985 454	0,985 405	0,985 356	0,985 307	0,985 258
56	0,985 219	0,985 160	0,985 111	0,985 062	0,985 013	0,984 963	0,984 914	0,984 865	0,984 815	0,984 766
57	0,984 716	0,984 666	0,984 617	0,984 567	0,984 517	0,984 467	0,984 417	0,984 367	0,984 317	0,984 267
58	0,984 217	0,984 167	0,984 116	0,984 066	0,984 016	0,983 965	0,983 914	0,983 864	0,983 813	0,983 762
59	0,983 712	0,983 661	0,983 610	0,983 559	0,983 508	0,983 457	0,983 406	0,983 354	0,983 303	0,983 252
60	0,983 200	0,983 149	0,983 097	0,983 046	0,982 994	0,982 943	0,982 891	0,982 839	0,982 787	0,982 735
61	0,982 683	0,982 631	0,982 579	0,982 527	0,982 475	0,982 422	0,982 370	0,982 318	0,982 265	0,982 213
62	0,982 160	0,982 108	0,982 055	0,982 002	0,981 949	0,981 897	0,981 844	0,981 791	0,981 738	0,981 685
63	0,981 631	0,981 578	0,981 525	0,981 472	0,981 418	0,981 365	0,981 311	0,981 258	0,981 204	0,981 151
64	0,981 097	0,981 043	0,980 989	0,980 935	0,980 881	0,980 827	0,980 773	0,980 719	0,980 665	0,980 611
65	0,980 557	0,980 502	0,980 443	0,980 393	0,980 339	0,980 284	0,980 230	0,980 175	0,980 120	0,980 065
66	0,980 011	0,979 956	0,979 901	0,979 846	0,979 791	0,979 736	0,979 680	0,979 625	0,979 570	0,979 515
67	0,979 459	0,979 403	0,979 348	0,979 293	0,979 237	0,979 181	0,979 126	0,979 070	0,979 014	0,978 958
68	0,978 902	0,978 846	0,978 790	0,978 734	0,978 678	0,978 621	0,978 565	0,978 509	0,978 452	0,978 396
69	0,978 339	0,978 283	0,978 226	0,978 170	0,978 113	0,978 056	0,977 999	0,977 942	0,977 885	0,977 828
70	0,977 771	0,977 714	0,977 657	0,977 600	0,977 543	0,977 485	0,977 428	0,977 370	0,977 313	0,977 255
71	0,977 198	0,977 140	0,977 082	0,977 025	0,976 967	0,976 909	0,976 851	0,976 793	0,976 735	0,976 677
72	0,976 619	0,976 56[illegible]	0,976 503	0,976 444	0,976 386	0,976 327	0,976 269	0,976 211	0,976 152	0,976 093
73	0,976 035	0,975 976	0,975 917	0,975 858	0,975 800	0,975 741	0,975 682	0,975 623	0,975 564	0,975 504
74	0,975 445	0,975 386	0,975 327	0,975 267	0,975 208	0,975 148	0,975 089	0,975 029	0,974 970	0,974 910
75	0,974 850	0,974 791	0,974 731	0,974 671	0,974 611	0,974 551	0,974 491	0,974 431	0,974 371	0,974 311
76	0,974 250	0,974 190	0,974 130	0,974 069	0,974 009	0,973 948	0,973 888	0,973 827	0,973 767	0,973 706
77	0,973 645	0,973 584	0,973 524	0,973 463	0,973 402	0,973 341	0,973 280	0,973 218	0,973 157	0,973 096
78	0,973 025	0,972 974	0,972 912	0,972 851	0,972 789	0,972 728	0,972 666	0,972 605	0,972 543	0,972 481
79	0,972 419	0,972 356	0,972 296	0,972 234	0,972 172	0,972 110	0,972 048	0,971 986	0,971 923	0,971 861
80	0,971 799	0,971 737	0,971 674	0,971 612	0,971 549	0,971 487	0,971 424	0,971 361	0,971 299	0,971 236
81	0,971 173	0,971 110	0,971 049	0,970 985	0,970 922	0,970 859	0,970 796	0,970 732	0,970 669	0,970 606
82	0,970 543	0,970 479	0,970 416	0,970 353	0,970 289	0,970 226	0,970 162	0,970 098	0,970 035	0,969 971
83	0,969 907	0,969 843	0,969 772	0,969 715	0,969 652	0,969 587	0,969 523	0,969 459	0,969 395	0,969 331
84	0,969 267	0,969 202	0,969 138	0,969 073	0,969 009	0,968 944	0,968 880	0,968 815	0,968 751	0,968 686
85	0,968 621	0,968 556	0,968 491	0,968 427	0,968 362	0,968 297	0,968 232	0,968 166	0,968 101	0,968 036
86	0,967 971	0,967 906	0,967 840	0,967 775	0,967 709	0,967 641	0,967 578	0,967 513	0,967 447	0,967 381
87	0,967 316	0,967 250	0,967 184	0,967 118	0,967 052	0,966 986	0,966 920	0,966 854	0,966 788	0,966 722
88	0,966 656	0,966 589	0,966 523	0,966 457	0,966 390	0,966 324	0,966 257	0,966 191	0,966 124	0,966 057
89	0,965 991	0,965 924	0,965 857	0,965 790	0,965 723	0,965 656	0,965 589	0,965 522	0,965 455	0,965 388
90	0,965 321	0,965 254	0,965 187	0,965 119	0,965 052	0,964 984	0,964 917	0,964 849	0,964 782	0,964 714
91	0,964 647	0,964 579	0,964 511	0,964 443	0,964 376	0,964 308	0,964 240	0,964 172	0,964 104	0,964 036
92	0,963 967	0,963 899	0,963 831	0,963 763	0,963 694	0,963 626	0,963 558	0,963 489	0,963 421	0,963 352
93	0,963 284	0,963 215	0,963 146	0,963 077	0,963 009	0,962 940	0,962 871	0,962 802	0,962 733	0,962 664
94	0,962 595	0,962 526	0,962 457	0,962 387	0,962 318	0,962 249	0,962 180	0,962 110	0,962 041	0,961 971
95	0,961 902	0,961 832	0,961 762	0,961 693	0,961 623	0,961 553	0,961 483	0,961 414	0,961 344	0,961 274
96	0,961 204	0,961 134	0,961 064	0,960 993	0,960 923	0,960 853	0,960 783	0,960 712	0,960 642	0,960 572
97	0,960 501	0,960 431	0,960 360	0,960 289	0,960 219	0,960 148	0,960 077	0,960 006	0,959 936	0,959 865
98	0,959 794	0,959 723	0,959 652	0,959 581	0,959 510	0,959 438	0,959 367	0,959 296	0,959 225	0,959 153
99	0,959 082	0,959 010	0,958 939	0,958 867	0,958 796	0,958 724	0,958 653	0,958 581	0,958 509	0,958 431
100	0,958 365									

(1) Tenths of degrees are shown in the column headers, e.g. at 4.5 °C, ρ = 0.999 970