



FINAL – REPORT
COMPARISON OF THE CALIBRATIONS OF HYDROMETERS FOR LIQUID
DENSITY DETERMINATION AMONG SIM LABORATORIES
SIM.M.D-S6

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1. Introduction

Hydrometers are instruments widely used for different levels of precision to measure density, specific gravity, alcoholic strength, sugar concentration, etc. of liquids.

In the frame of SIM, it was planned a Supplementary Comparison on the calibration of hydrometers of high accuracy among SIM countries. The aim of this SIM comparison is to check the stated uncertainty levels and degrees of equivalence of NMI laboratories for hydrometer calibrations in the density range between 600 kg m^{-3} and $1\,300 \text{ kg m}^{-3}$ at 20°C and to check liquid density measuring instruments used for this purpose.

The comparison is intended to be a regional supplementary comparison according to the Mutual Recognition Arrangements, and be support to entries for the CMC tables in this sub-field for participant laboratories.

CENAM - Mexico acted as the pilot laboratory in this SIM comparison and NMI – Colombia acted as the co-pilot laboratory.

After starting the comparison, there were received the requests of NIMT – Thailand and SASO – Saudi Arabia, members of APMP and GULFMET correspondingly, to take part in this comparison, requests that were accepted by original participant laboratories.

2. Participant laboratories

The participant laboratories are listed in table 1. NMIs from all SIM sub-regions participated in this comparison.

Table 1. Participants of hydrometer comparison

National Metrology Institute	Acronym	Technical Contact
Centro Nacional de Metrología km. 4,5 Carretera a los Cués, Mpio. El Marqués Querétaro, México	CENAM	Luis Omar Becerra lbecerra@cenam.mx Arturo Dauded adaued@cenam.mx Victor Alfonso Servin vservin@cenam.mx Tel: +52 442 211 05 73
Instituto Nacional de Metrología Av. Carrera 50 No.26 – 55 Int. 2, Bogotá, Colombia	INM	Luis Carlos Castro lcastro@inm.gov.co Gina Paola Bustos gpbustos@inm.gov.co Tel: +57 1 2542222 Ext. 1618
CESMEC Ltda. Av. Marathon 2595, 781-0552 Macul, Santiago de Chile, Chile	CESMEC	Fernando García fernando.garcia@cesmec.cl Tel: +56 2 2350 2100
Instituto Nacional de Tecnología Industrial. Av. Gral. Paz 5445, B1650KNA, San Martín, Prov. de Buenos Aires, Argentina	INTI	Rubén Quille rquille@inti.gob.ar Tel: +54 11 4724 6200/300/400 Interno 64370800 444 4004
Instituto Boliviano de Metrología Av. Camacho No. 1488 La Paz, Bolivia	IBMETRO	Romer Larico rlarico@ibmetro.gob.bo Tel: + 591 2 237 20 46 + 591 2 214 79 45 Int. 320-192
Servicio Ecuatoriano de Normalización Autopista "General Rumiñahui, Sector Conocoto, puente peatonal No. 5", Quito-Ecuador	INEN	Victor Guevara vguevara@normalizacion.gob.ec Tel: 393 1010 al 1019 ext. 2076
Laboratorio Costarricense de Metrología 500 m N, 50 m O del Supermercado Muñoz & Nanne, Ciudad de la Investigación, Universidad de Costa Rica, San Pedro de Montes de Oca, Costa Rica	LACOMET	Francisco Sequeira fsequeira@lacomet.go.cr Tel: 506 283 65 80 ext 111-112, 506 253 20 48 ext 111-112

Laboratorio Tecnológico del Uruguay Av. Italia 6201 Montevideo – URUGUAY	LATU	Sheila Preste spreste@latu.org.uy Gabriel Almeyda galmeida@latu.org.uy Tel: 005 982 601 27 30 /24 Fax: 59 8 26 01 85 54
National Institute of Metrology (Thailand) 3/4-5 Moo 3, Klong 5, Klong Luang Pathumthani 12120, THAILAND	NIMT	Chompoonoot Hirunyapruk chompoonoot@nimt.or.th Tel. +66 2577 5100 ext. 2203 Fax. +66 2577 5095
Saudi Standards, Metrology and Quality Organization Riyadh - Mohammedia District - Prince Turki bin Abdul Aziz Street - in front of King Saud University - Building No. 4 - National Center for measurement and calibration (NMCC). PO Box 3437 Riyadh 11471 Kingdom of Saudi Arabia	SASO	Faisal A. Alsulaiman f.sulaiman@saso.gov.sa r.yousefi@saso.gov.sa Mob.:00966500005288 . Tel:00966112529294.

3 Travelling standards (hydrometer samples)

For this comparison, two set of hydrometers were circulated among participant laboratories in a scheme of two loops.

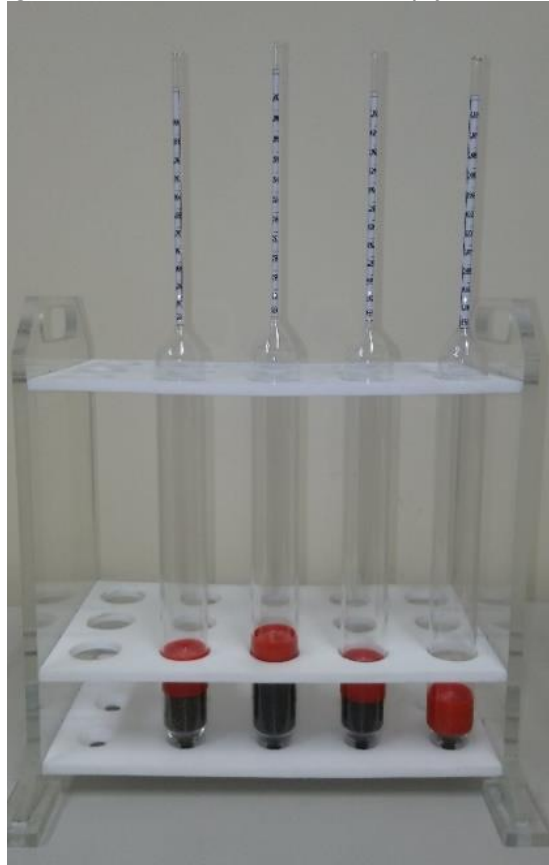
INM supplied a set of four different hydrometers which were circulated among INM, CENAM, CESMEC, INTI, IBMETRO, INEN, LACOMET and LATU (loop A). Additionally, in order to save time, NIMT supplied a second set of hydrometers with similar characteristics which was circulated and measured by NIMT, SASO, INM and CENAM (loop B). The hydrometers have the following characteristics.

Table 2. Data of the traveling standards for the SIM density comparison.

Characteristic	Hydrometer 1	Hydrometer 2	Hydrometer 3	Hydrometer 4
Manufacturer	Ludwig Schneider	Ludwig Schneider	Ludwig Schneider	Ludwig Schneider
Serial Number (loop A)	14550345	12496642	14550350	15607975 (broken) 15607973
Serial Number (loop B)	17649696	17674015	16648278	15607972
Range	0.600 0 g cm ⁻³ - 0.610 0 g cm ⁻³	0.990 0 g cm ⁻³ - 1.000 0 g cm ⁻³	1.090 0 g cm ⁻³ - 1.100 0 g cm ⁻³	1.290 0 g cm ⁻³ - 1.300 0 g cm ⁻³
Resolution	0.000 1 g cm ⁻³	0.000 1 g cm ⁻³	0.000 1 g cm ⁻³	0.000 1 g cm ⁻³
Reference Temperature	20 °C	20 °C	20 °C	20 °C

Hydrometer weight (Approx.)	89 g	148 g	161 g	194 g
Hydrometer Length	400 mm	400 mm	400 mm	400 mm

Figure 1. Set of transfer standards (Hydrometers)



4. Nominal values for the hydrometers calibrations

The nominal values including surface tension values for typically used buoyant liquids for the calibration of the hydrometers are listed in table 3.

Table 3. Selected values for the calibration of the hydrometers for the SIM Comparison.

Loop A				
Characteristic	Hydrometer 1	Hydrometer 2	Hydrometer 3	Hydrometer 4
Serial Number	14550345	12496642	14550350	15607975 (broken) 15607973
Range	0.600 0 g cm ⁻³ - 0.610 0 g cm ⁻³	0.990 0 g cm ⁻³ - 1.000 0 g cm ⁻³	1.090 0 g cm ⁻³ - 1.100 0 g cm ⁻³	1.290 0 g cm ⁻³ - 1.300 0 g cm ⁻³
Surface Tension	15 mN m ⁻¹	35 mN m ⁻¹	35 mN m ⁻¹	35 mN m ⁻¹
Reference Temperature	20 °C	20 °C	20 °C	20 °C

Measuring Points	0.601 0 g cm ⁻³ 0.605 0 g cm ⁻³ 0.609 0 g cm ⁻³	0.991 0 g cm ⁻³ 0.995 0 g cm ⁻³ 0.999 0 g cm ⁻³	1.091 0 g cm ⁻³ 1.095 0 g cm ⁻³ 1.099 0 g cm ⁻³	1.291 0 g cm ⁻³ 1.295 0 g cm ⁻³ 1.299 0 g cm ⁻³
Loop B				
Characteristic	Hydrometer 1	Hydrometer 2	Hydrometer 3	Hydrometer 4
Serial Number	17649696	17674015	16648278	15607972
Range	0.600 0 g cm ⁻³ - 0.610 0 g cm ⁻³	0,9900 g cm ⁻³ - 1,0000 g cm ⁻³	1,0900 g cm ⁻³ - 1,1000 g cm ⁻³	1,2900 g cm ⁻³ - 1,3000 g cm ⁻³
Surface Tension	15 mN m ⁻¹	35 mN m ⁻¹	35 mN m ⁻¹	35 mN m ⁻¹
Reference Temperature	20 °C	20 °C	20 °C	20 °C
Measuring Points	0.600 0 g cm ⁻³ 0.605 0 g cm ⁻³ 0.610 0 g cm ⁻³	0.990 0 g cm ⁻³ 0.995 0 g cm ⁻³ 1.000 0 g cm ⁻³	1.090 0 g cm ⁻³ 1.095 0 g cm ⁻³ 1.100 0 g cm ⁻³	1.290 0 g cm ⁻³ 1.295 0 g cm ⁻³ 1.300 0 g cm ⁻³

Note: The nominal values selected for the measurements for the first loop were slightly different from those selected for the measurements for the second loop.

5. Circulation and date of measurements

Participants were divided into two loops for the circulation of the travelling standards. Travelling standards were hand-carried among participants according to the schedule in table 4.

Table 4. Dates of measurement of the travelling standards

Participants	Date of Measurements by Participant laboratories
Loop A	
CENAM	2016 November
INM	2017 June
CESMEC	2017 July
INTI *	2017 August
IBMETRO	2017 September
INEN	2017 October
LACOMET	2018 May
CENAM	2018 August
LATU	2018 September
INM	2021 April
Loop B	
NIMT	2019 November
SASO	2020 March
INM	2021 July
CENAM	2021 December

* INTI decided to withdraw from the comparison after making their measurements.

5. Traceability of results reported by participants

For the calibration of the hydrometers, all laboratories used their own hydrostatic weighing system, and all laboratories determined the corrections to the specific indications (at 20 °C) of the travelling standards by Cuckow's method [6].

In table 5 are shown the reference liquids used by participants as density standards for the calibration of the travelling standards, the mean value of the densities and the surface tensions reported by the participants, the sources of traceability reported by participants, and the balance used by participants for the weighing in liquid.

Table 5. Liquids used by participants in their hydrostatic weighing system

Acronym	Liquid	Density Standard	Traceability	Balance used for weighing in liquid
CENAM	Pentadecane Aprox. Density 769 kg m^{-3} Aprox. Surface tensión 27 mN m^{-1}	Two zerodur spheres approx. mass 1 kg	PTB – Germany	Mettler-Toledo Type AT400 d = 0.1 mg
INM	Nonane Aprox. Density 717 kg m^{-3} Aprox. Surface tension 23 mN m^{-1}	Two fused silica cylinders approx. mass 321 g	PTB – Germany	Mettler-Toledo Type XPE404S d = 0.1 mg
CESMEC	Cyclohexane Aprox. Denisty 778 kg m^{-3} Aprox. Surface tension 35 mN m^{-1}	Fused silica cylinder approx. mass 220.4 g.	PTB – Germany	Shimadzu Type AUW320 d = 0.1 mg
IBMETRO	Water Aprox. Density 998 kg m^{-3} Aprox. 72 mN m^{-1}	N/A	Tanaka's equation	Mettler-Toledo Type XS 204 d = 0.1 mg
INEN	Water Aprox. Density 998 kg m^{-3} Aprox. Surface tension 72 mN m^{-1}	N/A	Tanaka's equation	Mettler-Toledo Type XP504 d = 0.1 mg
LACOMET	Water Aprox. Density 998 kg m^{-3} Aprox. Surface tension 72 mN m^{-1}	N/A	Tanaka's equation	Sartorius CCE1005 d = 0.01 mg
LATU	n-Tridecane Aprox. Density 756 kg m^{-3} Aprox Surface tension 27 mN m^{-1}	Quartz cylinder approx. mass 217 g	PTB – Germany	Mettler-Toledo Type AG204 d = 0.1 mg
NIMT	n-Tridecane Aprox. Density	Density standard Silicon cylinder	NMIJ – Japan	Mettler-Toledo Type XP504

	756 kg m ⁻³ Aprox Surface tension 24 mN m ⁻¹	approx. mass 220 g		d = 0.1 mg
SASO	n-Tridecane Aprox. Density 756 kg m ⁻³ Aprox Surface tension 26 mN m ⁻¹	Silicon sphere approx. mass 200 g	PTB – Germany	Sartorius MSA524S-100-DA d = 0.1 mg

Note: Certain commercial equipment, instruments, or materials are identified in this report to foster understanding. Such identification does not imply recommendation or endorsement by any of the participating organizations nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

6. Results as reported by participants

For each hydrometer, the protocol specified three nominal values for which the participants had to report the density corrections and the associated uncertainties at the specific temperature of 20 °C.

Table 6. Density corrections and associated uncertainties for the calibration of the hydrometers as reported by participants of loop A

Serial No. 14550345						
Nominal value	601 kg m ⁻³		605 kg m ⁻³		609 kg m ⁻³	
	Correction	Unc. <i>k</i> = 2	Correction	Unc. <i>k</i> = 2	Correction	Unc. <i>k</i> = 2
	kg m ⁻³	kg m ⁻³	kg m ⁻³	kg m ⁻³	kg m ⁻³	kg m ⁻³
CENAM _{A1}	0.046	0.019	0.026	0.019	0.002	0.019
INMA _{A1}	0.074	0.034	0.053	0.034	0.020	0.034
CESMEC	0.060	0.050	-0.140	0.050	0.230	0.050
IBMETRO	-0.023	0.026	-0.069	0.026	-0.059	0.026
INEN	-0.270	0.040	-0.280	0.040	-0.310	0.040
LACOMET	-0.017	0.079	-0.058	0.079	-0.052	0.079
CENAM _{A2}	0.053	0.022	0.040	0.022	0.021	0.022
LATU	-0.127	0.040	-0.146	0.040	-0.102	0.040
INMA _{A2}	0.027	0.049	0.012	0.049	0.000	0.049

Serial No. 12496642						
Nominal value	991 kg m ⁻³		995 kg m ⁻³		999 kg m ⁻³	
	Correction	Unc. <i>k</i> = 2	Correction	Unc. <i>k</i> = 2	Correction	Unc. <i>k</i> = 2
	kg m ⁻³	kg m ⁻³	kg m ⁻³	kg m ⁻³	kg m ⁻³	kg m ⁻³
CENAM _{A1}	0.000	0.024	-0.005	0.025	0.009	0.025
INMA _{A1}	-0.015	0.054	-0.014	0.054	0.002	0.054
CESMEC	-0.036	0.050	0.071	0.050	0.029	0.050
IBMETRO	-0.037	0.035	-0.049	0.035	-0.042	0.035
INEN	-0.520	0.050	-0.520	0.050	-0.510	0.050
LACOMET	-0.360	0.080	-0.300	0.080	-0.240	0.080

CENAM _{A2}	-0.009	0.025	-0.005	0.025	-0.001	0.025
LATU	-0.014	0.039	-0.006	0.039	-0.001	0.039
INM _{A2}	-0.051	0.079	-0.043	0.079	-0.023	0.079

Serial No. 14550350

Nominal value	1 091 kg m ⁻³		1 095 kg m ⁻³		1 099 kg m ⁻³	
	Correction	Unc. <i>k</i> = 2	Correction	Unc. <i>k</i> = 2	Correction	Unc. <i>k</i> = 2
	kg m ⁻³	kg m ⁻³	kg m ⁻³	kg m ⁻³	kg m ⁻³	kg m ⁻³
CENAM _{A1}	-0.320	0.026	-0.322	0.026	-0.342	0.026
INM _{A1}	-0.320	0.058	-0.310	0.058	-0.352	0.058
CESMEC	-0.097	0.050	-0.185	0.050	-0.093	0.050
IBMETRO	-0.422	0.037	-0.445	0.037	-0.392	0.037
INEN	-0.790	0.050	-0.790	0.050	-0.810	0.050
LACOMET	-0.600	0.078	-0.650	0.078	-0.630	0.078
CENAM _{A2}	-0.321	0.026	-0.327	0.026	-0.337	0.026
LATU	-0.370	0.039	-0.362	0.039	-0.380	0.039
INM _{A2}	-0.380	0.087	-0.379	0.087	-0.377	0.087

Serial No. 15607975

Nominal value	1 291 kg m ⁻³		1 295 kg m ⁻³		1 299 kg m ⁻³	
	Correction	Unc. <i>k</i> = 2	Correction	Unc. <i>k</i> = 2	Correction	Unc. <i>k</i> = 2
	kg m ⁻³	kg m ⁻³	kg m ⁻³	kg m ⁻³	kg m ⁻³	kg m ⁻³
CENAM _{A1}	-0.246	0.029	-0.246	0.030	-0.272	0.029
INM _{A1}	-0.227	0.068	-0.215	0.068	-0.264	0.068
CESMEC	Broken					
IBMETRO						
INEN						
LACOMET						
CENAM _{A2}						
LATU						
INM _{A2}						

Serial No. 15607973

Nominal value	1 291 kg m ⁻³		1 295 kg m ⁻³		1 299 kg m ⁻³	
	Correction kg m ⁻³	Unc. <i>k</i> = 2 kg m ⁻³	Correction kg m ⁻³	Unc. <i>k</i> = 2 kg m ⁻³	Correction kg m ⁻³	Unc. <i>k</i> = 2 kg m ⁻³
CENAM _{A1}						
INM _{A1}	-0.289	0.068	-0.284	0.068	-0.313	0.068
CESMEC	0.043	0.050	0.014	0.050	-0.213	0.050
IBMETRO	-0.474	0.040	-0.474	0.040	-0.403	0.040
INEN	-0.820	0.090	-0.860	0.090	-0.820	0.090
LACOMET	-0.640	0.098	-0.660	0.098	-0.600	0.098
CENAM _{A2}	-0.297	0.030	-0.293	0.030	-0.294	0.030
LATU	-0.371	0.038	-0.358	0.038	-0.344	0.038
INM _{A2}	Broken					

Table 7. Density corrections and associated uncertainties of the calibration of the hydrometers as reported by participants of loop B

Serial No.	17649696					
Nominal value	600	kg m ⁻³	605	kg m ⁻³	610	kg m ⁻³
	Correction	Unc. $k = 2$	Correction	Unc. $k = 2$	Correction	Unc. $k = 2$
	kg m ⁻³	kg m ⁻³	kg m ⁻³	kg m ⁻³	kg m ⁻³	kg m ⁻³
NIMT	0.019	0.050	0.000	0.050	-0.010	0.050
SASO	0.067	0.035	0.061	0.035	0.049	0.035
INM _{B1}	0.019	0.050	0.006	0.050	-0.006	0.050
CENAM _{B1}	0.027	0.021	0.045	0.021	0.040	0.021

Serial No.	17674015					
Nominal value	990	kg m ⁻³	995	kg m ⁻³	1 000	kg m ⁻³
	Correction	Unc. $k = 2$	Correction	Unc. $k = 2$	Correction	Unc. $k = 2$
	kg m ⁻³	kg m ⁻³	kg m ⁻³	kg m ⁻³	kg m ⁻³	kg m ⁻³
NIMT	0.020	0.065	0.018	0.065	0.014	0.065
SASO	-0.020	0.056	-0.030	0.056	-0.005	0.056
INM _{B1}	-0.003	0.080	-0.010	0.080	0.002	0.080
CENAM _{B1}	0.039	0.025	0.060	0.025	0.075	0.025

Serial No.	16648278					
Nominal value	1 090	kg m ⁻³	1 095	kg m ⁻³	1 100	kg m ⁻³
	Correction	Unc. $k = 2$	Correction	Unc. $k = 2$	Correction	Unc. $k = 2$
	kg m ⁻³	kg m ⁻³	kg m ⁻³	kg m ⁻³	kg m ⁻³	kg m ⁻³
NIMT	-0.348	0.071	-0.364	0.071	-0.368	0.071
SASO	-0.332	0.062	-0.342	0.062	-0.352	0.062
INM _{B1}	-0.366	0.086	-0.379	0.086	-0.374	0.086
CENAM _{B1}	-0.289	0.025	-0.303	0.025	-0.301	0.025

Serial No.	15607972					
Nominal value	1 290	kg m ⁻³	1 295	kg m ⁻³	1 300	kg m ⁻³
	Correction	Unc. $k = 2$	Correction	Unc. $k = 2$	Correction	Unc. $k = 2$
	kg m ⁻³	kg m ⁻³	kg m ⁻³	kg m ⁻³	kg m ⁻³	kg m ⁻³
NIMT	-0.306	0.078	-0.308	0.078	-0.307	0.078
SASO	-0.385	0.073	-0.373	0.073	-0.359	0.073
INM _{B1}	-0.357	0.102	-0.343	0.102	-0.336	0.102
CENAM _{B1}	-0.247	0.027	-0.238	0.027	-0.231	0.027

In order to calculate representative results for CENAM and INM, a mean value for each nominal value and the associated uncertainty were calculated as follows,

$$X_{CENAM A} = 0.5 X_{CENAM A1} + 0.5 X_{CENAM A2} \quad (1)$$

$$u(X_{CENAM A}) = \left((0.5 u(X_{CENAM A1}))^2 + (0.5 u(X_{CENAM A2}))^2 + 0.5 u(X_{CENAM A1})u(X_{CENAM A2}) \right)^{1/2} \quad (2)$$

$$X_{INM A} = 0.5 X_{INM A1} + 0.5 X_{INM A2} \quad (3)$$

$$u(X_{INM A}) = \left((0.5 u(X_{INM A1}))^2 + (0.5 u(X_{INM A2}))^2 + 0.5 u(X_{INM A1})u(X_{INM A2}) \right)^{1/2} \quad (4)$$

where

$X_{CENAM A}$	is the representative value of CENAM for Loop A (for the specific nominal value)
$X_{CENAM A1}$	is the first measurement result of CENAM for loop A
$X_{CENAM A2}$	is the second measurement result of CENAM for loop A
$X_{INM A}$	is the representative value of INM for Loop A (for the specific nominal value)
$X_{INM A1}$	is the first measurement result of INM for loop A
$X_{INM A2}$	is the second measurement result of INM for loop A
$u(X_{i jk})$	is the standard uncertainty associated to the value X of the laboratory “ i ” of the loop “ j ”, and “ k ” means the first or second measurement

The above calculation assumes a fully correlation between the first and the second measurement for each Institute, however, the statistical consistency of CENAM and INM results were checked with the criterion of the normalized error, ($E_n \leq 1$) and there were no found a statistical difference between first and second measurements for both Institutes.

$$E_n(X_{CENAM A}) = \frac{|X_{CENAM A1} - X_{CENAM A2}|}{2\sqrt{u^2(X_{CENAM A1}) + u^2(X_{CENAM A2})}} \quad (5)$$

$$E_n(X_{INM A}) = \frac{|X_{INM A1} - X_{INM A2}|}{2\sqrt{u^2(X_{INM A1}) + u^2(X_{INM A2})}} \quad (6)$$

8. Degree of equivalence among participant laboratories

In order to compare results reported by participants among NMIs of loop A, density differences between results reported by participants and results reported by CENAM as well as the associated uncertainties were calculated as follows,

$$d(X_{iA}) = X_{iA} - X_{CENAM A} \quad (7)$$

$$u(d(X_{iA})) = (u^2(X_{iA}) + u^2(X_{CENAM A}))^{\frac{1}{2}} \quad (8)$$

where

$d(X_{iA})$	Density difference between the result reported by laboratory “ i ” of loop A and CENAM result for the same loop
X_{iA}	density correction reported by laboratory “ i ” of loop A
$X_{CENAM A}$	Mean correction reported by CENAM for loop A
$u(d(X_{iA}))$	standard uncertainty associated to $d(X_{iA})$
$u(X_{iA})$	standard uncertainty associated to X_{iA}

As nominal values measured by participants of loop A are slightly different from those measured by participants of loop B (see tables 6 and 7), in order to calculate the corresponding corrections at the same nominal values measured for participants of loop A, a linear function (9) was calculated by hydrometer for all participants of loop B,

$$X_{iB}(\rho_q) = a_i \rho_k + b_i - \varepsilon_i \quad (9)$$

The density differences between participant laboratories and CENAM for loop B, at the same nominal values of loop A (ρ_k), were estimated with the linear functions as follow,

$$d(X_{iB}) = X_{iB} - CENAM_B = (a_{iB} - a_{CENAM B}) \rho_k - (b_{iB} - b_{CENAM B}) - \varepsilon_i + \varepsilon_{CENAM B} \quad (10)$$

The standard uncertainty of the differences calculated by linear approximation were calculated by the following,

$$u(d(X_{iB})) = (u^2(X_{iB}) + u^2(CENAM_B) + u^2(fitt_{iB}) + u^2(fitt_{CENAM B}))^{\frac{1}{2}} \quad (11)$$

where

$X_{iB}(\rho_q)$	is the representative linear function for laboratory “i” of loop B (at the nominal density q)
$CENAM_B$	is the representative linear function for CENAM for the loop B (at the same nominal density)
ρ_k	is the nominal value of density which matches with nominal value (k) selected in loop A
a_i	is the slope of the linear function for laboratory “i” of loop B
b_i	is the intercept of the linear function for laboratory “i” of loop B
ε_i	is the error of the fitting function for laboratory “i” of loop B
$a_{CENAM B}$	is the slope of the linear function for CENAM of loop B
$b_{CENAM B}$	is the intercept of the linear function for CENAM of loop B
$\varepsilon_{CENAM B}$	is the error of the fitting function for CENAM of loop B
$d(X_{iB})$	is the density difference between calculated result of laboratory “i” of loop B and calculated result of CENAM for the same loop at specific nominal value of density
$u(d(X_{iB}))$	is the standard uncertainty associated to $d(X_{iB})$
$u(fitt_{iB})$	is the standard uncertainty due to the adjusting error of the linear function for laboratory “i” of loop B
$u(fitt_{CENAM B})$	is the standard uncertainty due to the adjusting error of the linear function of CENAM results for loop B

The degree of equivalence between participant laboratory “i” and participant laboratory “j” from the same loop or from different loop (k), are calculated from the differences of participant laboratories and CENAM as follow,

$$d(X_{ik}, X_{jk}) = d(X_{ik}) - d(X_{jk}) \quad (12)$$

The standard uncertainty of the degree of the equivalence between participant laboratory “i” and participant laboratory “j”, both from the loop A are calculated as,

$$u\left(d(X_{iA}, X_{jA})\right) = \left(u^2(d(X_{iA})) + u^2(d(X_{jA})) - 2u^2(X_{CENAM A}) + u^2(X_{CENAM REP})\right)^{\frac{1}{2}} \quad (13)$$

From available differences between $CENAM_{A1}$ and $CENAM_{A2}$ the standard uncertainty due to CENAM reproducibility was estimated as $u(X_{CENAM REP}) = 0.005 \text{ kg m}^{-3}$ for the entire range of measurements and from both loops.

The standard uncertainty of the degree of the equivalence between participant laboratory “i” and participant laboratory “j”, both from the loop B are calculated as,

$$\begin{aligned} u\left(d(X_{iB}, X_{jB})\right) &= \left(u^2(d(X_{iB})) + u^2(d(X_{jB})) - 2(u^2(X_{CENAM B}) + u^2(fitt_{CENAM B}))\right. \\ &\quad \left.+ u^2(X_{CENAM REP})\right)^{\frac{1}{2}} \end{aligned} \quad (14)$$

Finally, the standard uncertainty of the degree of the equivalence between participant laboratory “i” and participant laboratory “j”, both from different loops are calculated as

$$\begin{aligned} u\left(d(X_{iA}, X_{jB})\right) &= \left(u^2(d(X_{iA})) + u^2(d(X_{jB})) - u^2(X_{CENAM A}) - u^2(X_{CENAM B}) - u^2(fitt_{CENAM B})\right. \\ &\quad \left.+ u^2(X_{CENAM REP})\right)^{\frac{1}{2}} \end{aligned} \quad (15)$$

In order to check consistency among participant laboratories, the normalized error of the density difference (E_n) were calculated as follow,

$$E_n = \frac{d(X_{ik}, X_{jk})}{U(d(X_{ik}, X_{jk}))} \quad (16)$$

Where $U(d(X_{ik}, X_{jk}))$ is the expanded uncertainty of the density difference,

$$U(d(X_{ik}, X_{jk})) = 2 u(d(X_{ik}, X_{jk})) \quad (17)$$

The criterion for the normalized error is the following:

$E_n \leq 1$ Results are consistent at 95 % of confidence level.

$E_n > 1$ Results are not consistent at 95 % of confidence level.

9. Conclusions

For this comparison nine National Metrology Institutes agreed to take part in a supplementary comparison on the calibration of hydrometers of high accuracy, where seven NMIs are members of SIM, one is a member of APMP and the other is a member of GULFMET.

For this supplementary comparison CENAM – Mexico and NMI - Colombia acted as pilot and copilot laboratories correspondingly.

Nine hydrometers of high accuracy in the range of 600 kg m^{-3} to $1\,300 \text{ kg m}^{-3}$ were circulated among participant laboratories within the period of November 2016 to December 2021. The participant laboratories were divided into two loops, where CENAM and INM took part in both loops.

From measurement results reported by participant laboratories, only one of loop A was completely consistent with measurement results of pilot laboratory and only one of the loop B was completely consistent with pilot laboratory. The other participant laboratory was not completely consistent with pilot laboratory, where at least one normalized error calculated with (6) was greater than 1, see tables 8 to 11 and figures 2 to 13 of Annex A. From 108 density differences calculated among results of participant laboratories and results of pilot laboratory, only the 48 % were consistent.

Density differences, their associated uncertainties and normalized errors between participant laboratories were calculated and the results are listed in tables 12 to 23.

Considering that $|x_i - x_j| = |x_j - x_i|$, from 432 independent density differences calculated among participant laboratories, only 39 % were consistent among them.

There is analysis and work to do within participant laboratories in order to reduce systematic errors and improve measurement results in the calibration of hydrometers of high accuracy.

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Annex A

Density differences between results reported by participants and results reported by CENAM, $d(X_{ik})$, their expanded uncertainties $U(d(X_{ik}))$ and normalized error, (E_n) at 95 % of confidence level.

Table 8. Density differences for the range of 600 – 610 kg m⁻³

	601 kg m ⁻³	Unc. $k = 2$	E_n	605 kg m ⁻³	Unc. $k = 2$	E_n	609 kg m ⁻³	Unc. $k = 2$	E_n
INM 1	0.001	0.046	0.02	0.000	0.046	0.00	-0.001	0.046	0.02
CESMEC	0.011	0.054	0.20	-0.173	0.054	3.19	0.219	0.054	4.05
IBMETRO	-0.073	0.033	2.17	-0.101	0.033	3.02	-0.070	0.033	2.10
INEN	-0.319	0.045	7.10	-0.313	0.045	6.95	-0.321	0.045	7.15
LACOMET	-0.066	0.082	0.81	-0.091	0.082	1.11	-0.063	0.082	0.77
LATU	-0.176	0.045	3.95	-0.179	0.045	4.00	-0.113	0.045	2.54
NIMT	-0.018	0.055	0.33	-0.035	0.055	0.63	-0.051	0.055	0.93
SASO	0.034	0.042	0.80	0.021	0.042	0.51	0.009	0.042	0.22
INM 2	-0.017	0.056	0.30	-0.032	0.057	0.56	-0.047	0.056	0.83

Table 9. Density differences for the range of 990 – 1 000 kg m⁻³

NMI	991 kg m ⁻³	Unc. $k = 2$	E_n	995 kg m ⁻³	Unc. $k = 2$	E_n	999 kg m ⁻³	Unc. $k = 2$	E_n
INM 1	-0.028	0.071	0.40	-0.023	0.071	0.33	-0.014	0.071	0.20
CESMEC	-0.031	0.056	0.56	0.076	0.056	1.37	0.025	0.056	0.46
IBMETRO	-0.032	0.043	0.75	-0.044	0.043	1.01	-0.045	0.043	1.05
INEN	-0.515	0.056	9.26	-0.515	0.056	9.21	-0.514	0.056	9.18
LACOMET	-0.356	0.084	4.25	-0.295	0.084	3.52	-0.244	0.084	2.91
LATU	-0.010	0.046	0.21	-0.001	0.046	0.02	-0.005	0.046	0.10
NIMT	-0.024	0.070	0.35	-0.041	0.070	0.59	-0.058	0.070	0.83
SASO	-0.068	0.063	1.07	-0.076	0.063	1.21	-0.085	0.063	1.34
INM 2	-0.049	0.085	0.58	-0.062	0.085	0.72	-0.074	0.085	0.88

Table 10. Density differences for the range of 1 090 – 1 100 kg m⁻³

NMI	1091 kg m ⁻³	Unc. <i>k</i> = 2	<i>E_n</i>	1095 kg m ⁻³	Unc. <i>k</i> = 2	<i>E_n</i>	1099 kg m ⁻³	Unc. <i>k</i> = 2	<i>E_n</i>
INM 1	-0.030	0.077	0.39	-0.020	0.077	0.26	-0.025	0.077	0.32
CESMEC	0.224	0.056	3.97	0.139	0.056	2.47	0.247	0.056	4.37
IBMETRO	-0.102	0.045	2.26	-0.121	0.045	2.67	-0.052	0.045	1.15
INEN	-0.470	0.056	8.33	-0.466	0.056	8.26	-0.470	0.056	8.35
LACOMET	-0.280	0.082	3.40	-0.326	0.082	3.96	-0.291	0.082	3.53
LATU	-0.050	0.047	1.06	-0.038	0.047	0.80	-0.041	0.047	0.86
NIMT	-0.059	0.075	0.78	-0.062	0.075	0.83	-0.066	0.075	0.87
SASO	-0.041	0.067	0.62	-0.044	0.067	0.66	-0.047	0.067	0.71
INM 2	-0.077	0.092	0.84	-0.075	0.092	0.82	-0.074	0.092	0.80

Table 11. Density differences for the range of 1 290 – 1 300 kg m⁻³

	1291 kg m ⁻³	Unc. <i>k</i> = 2	<i>E_n</i>	1295 kg m ⁻³	Unc. <i>k</i> = 2	<i>E_n</i>	1299 kg m ⁻³	Unc. <i>k</i> = 2	<i>E_n</i>
INM 1	0.008	0.053	0.14	0.009	0.053	0.16	-0.019	0.053	0.36
CESMEC	0.340	0.041	8.23	0.307	0.041	7.44	0.081	0.041	1.96
IBMETRO	-0.177	0.035	5.05	-0.181	0.035	5.16	-0.109	0.035	3.09
INEN	-0.523	0.067	7.80	-0.567	0.067	8.46	-0.526	0.067	7.84
LACOMET	-0.344	0.072	4.74	-0.368	0.072	5.07	-0.306	0.072	4.22
LATU	-0.075	0.034	2.18	-0.066	0.034	1.91	-0.050	0.034	1.46
NIMT	-0.061	0.082	0.75	-0.068	0.082	0.83	-0.075	0.082	0.91
SASO	-0.138	0.078	1.77	-0.134	0.078	1.72	-0.130	0.078	1.67
INM 2	-0.108	0.107	1.01	-0.106	0.107	1.00	-0.105	0.107	0.98

The density differences (in kg m^{-3}) between results reported by participant laboratories and CENAM results are graphed in the Figures 2 to 13. Uncertainty bars are presented at 95 % of confidence level.

Figure 2. Density differences for 601 kg m^{-3}

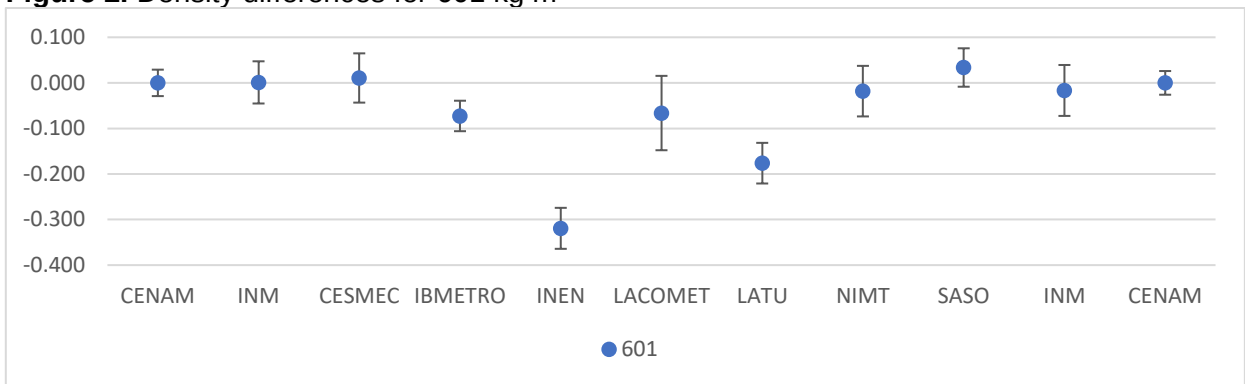


Figure 3. Density differences for 605 kg m^{-3}

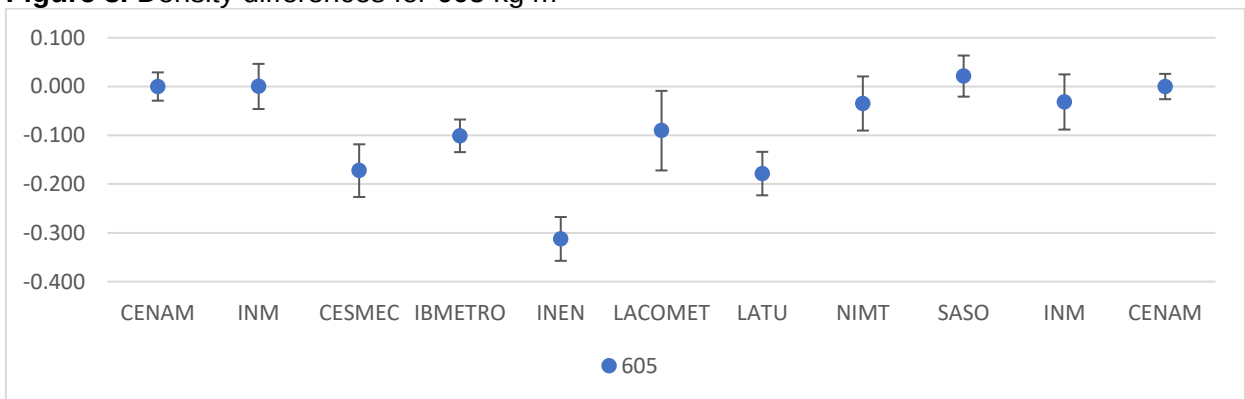


Figure 4. Density differences for 609 kg m^{-3}

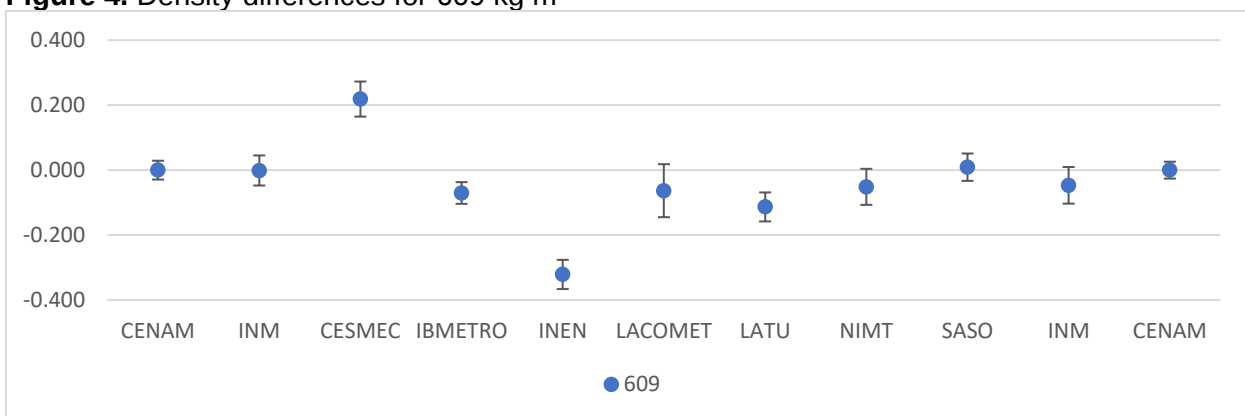


Figure 5. Density differences for 991 kg m^{-3}

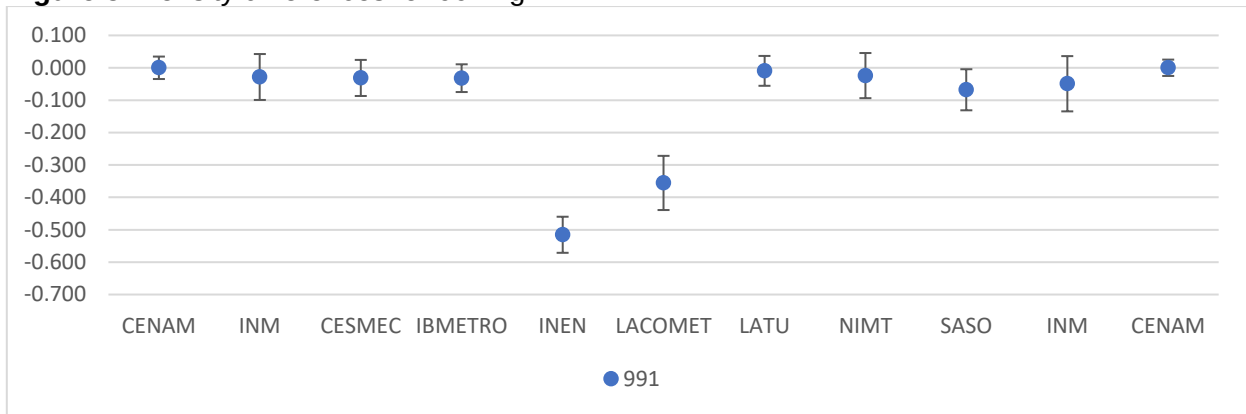


Figure 6. Density differences for 995 kg m^{-3}

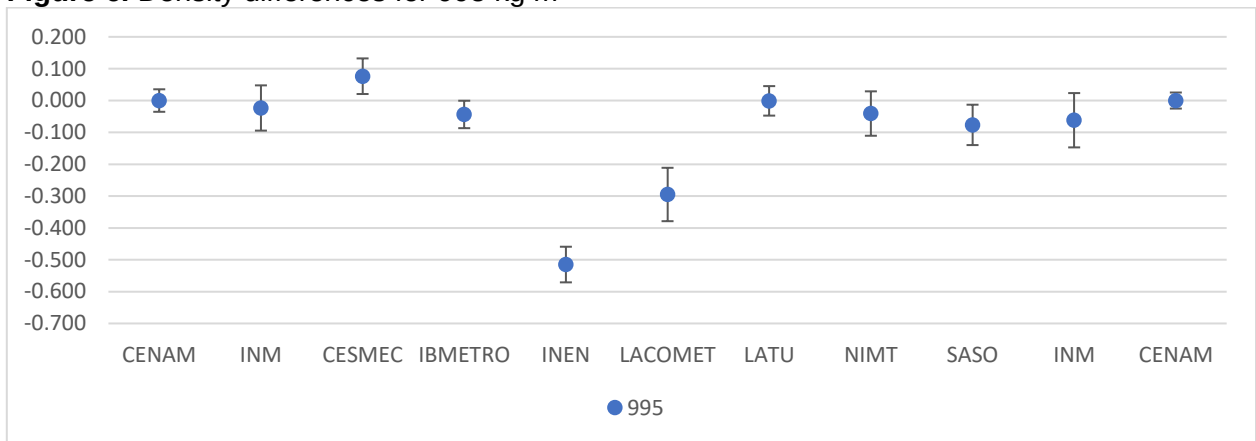


Figure 7. Density differences for 999 kg m^{-3}

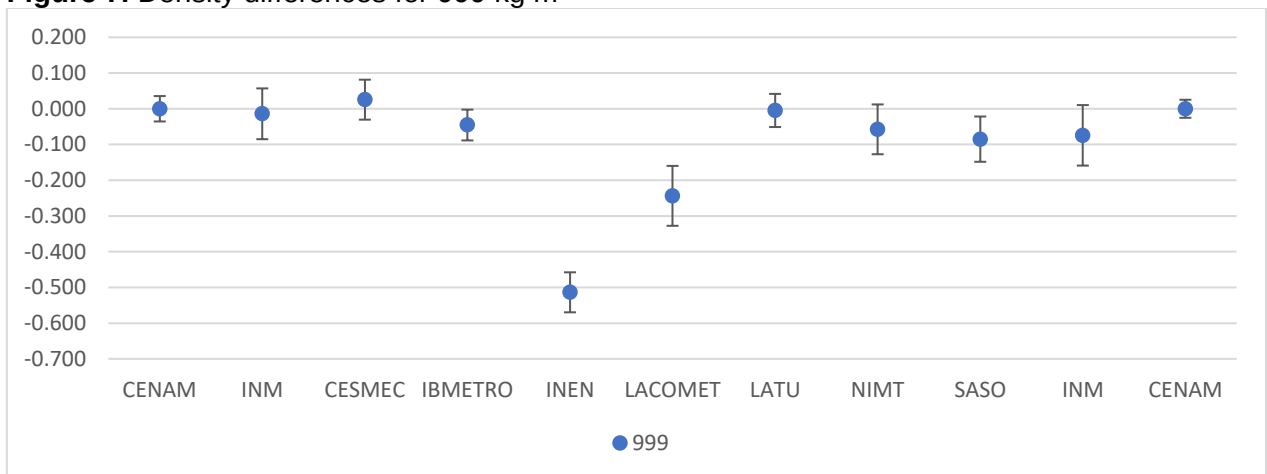


Figure 8. Density differences for 1 091 kg m⁻³

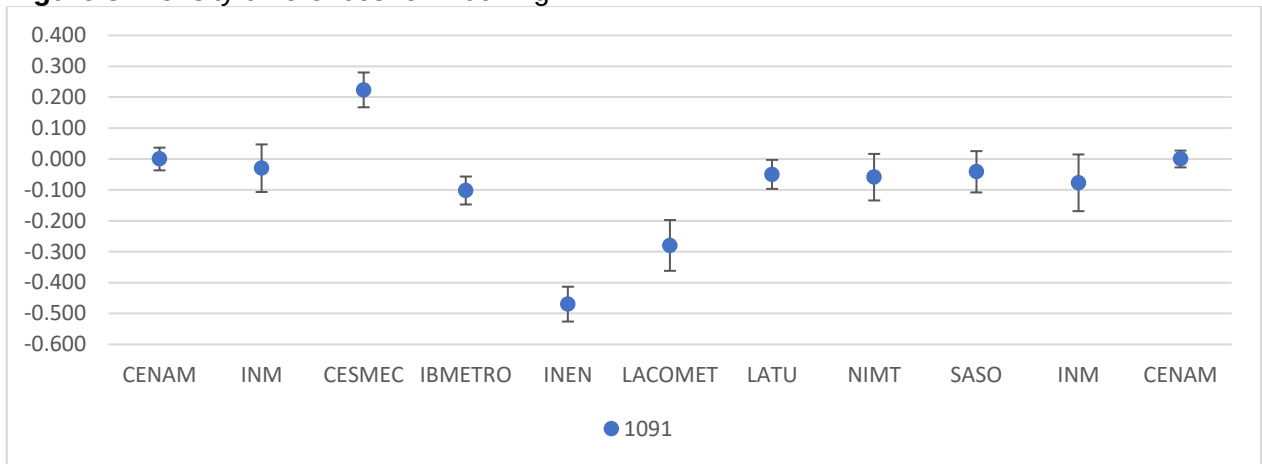


Figure 9. Density differences for 1 095 kg m⁻³

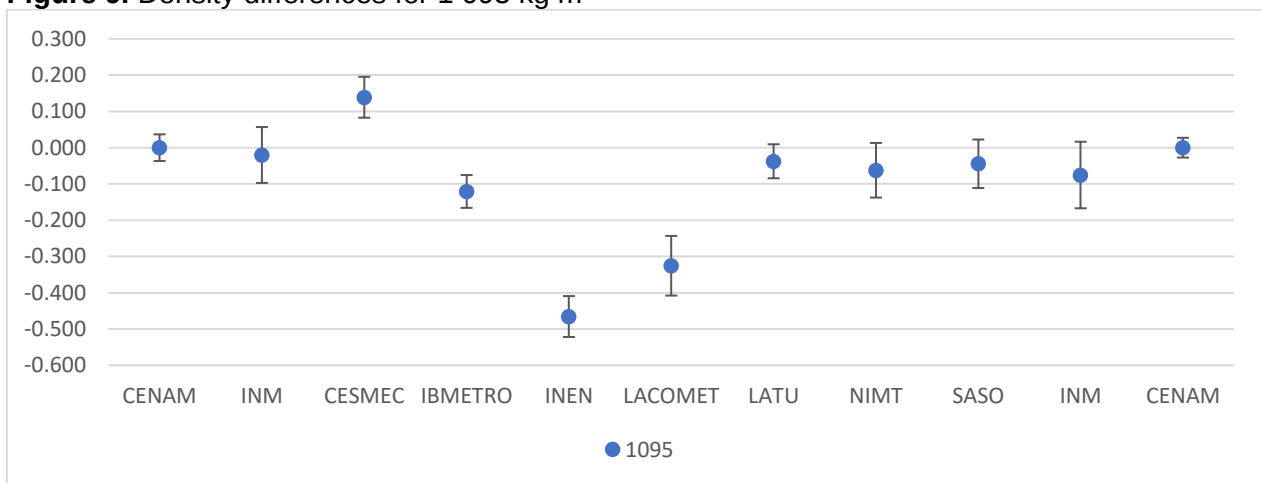


Figure 10. Density differences for 1 099 kg m⁻³

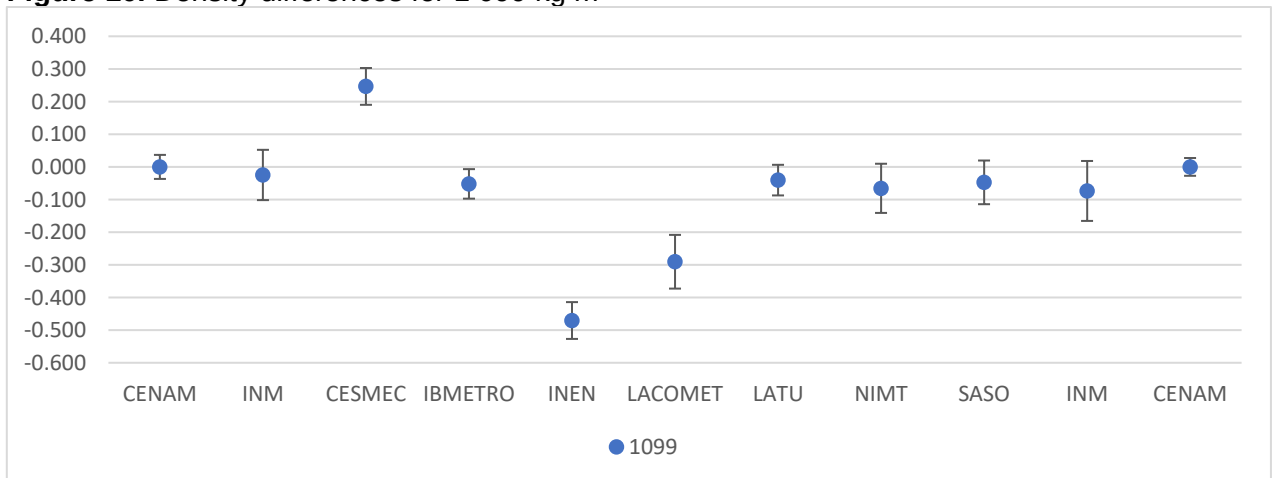


Figure 11. Density differences for 1 291 kg m⁻³

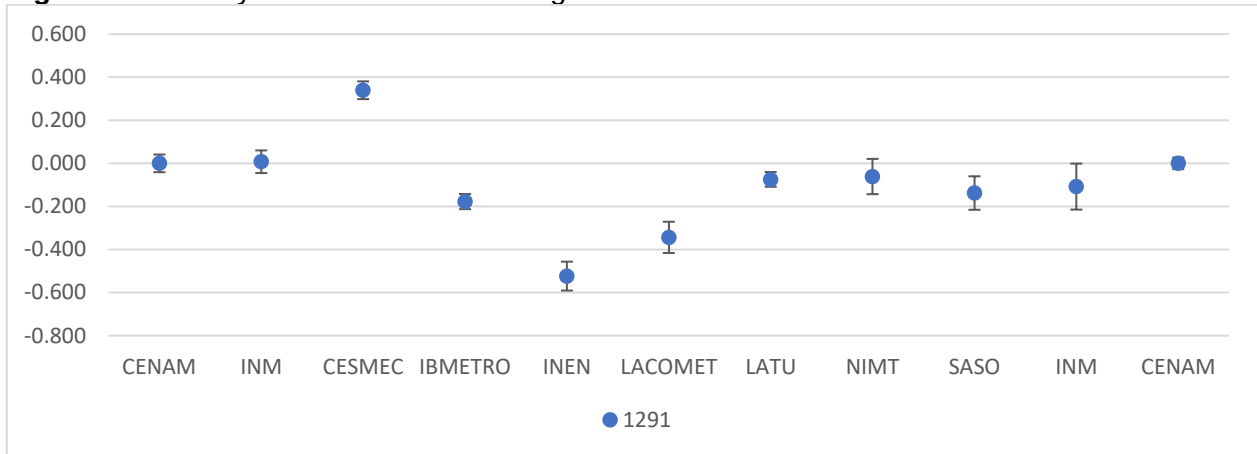


Figure 12. Density differences for 1 295 kg m⁻³

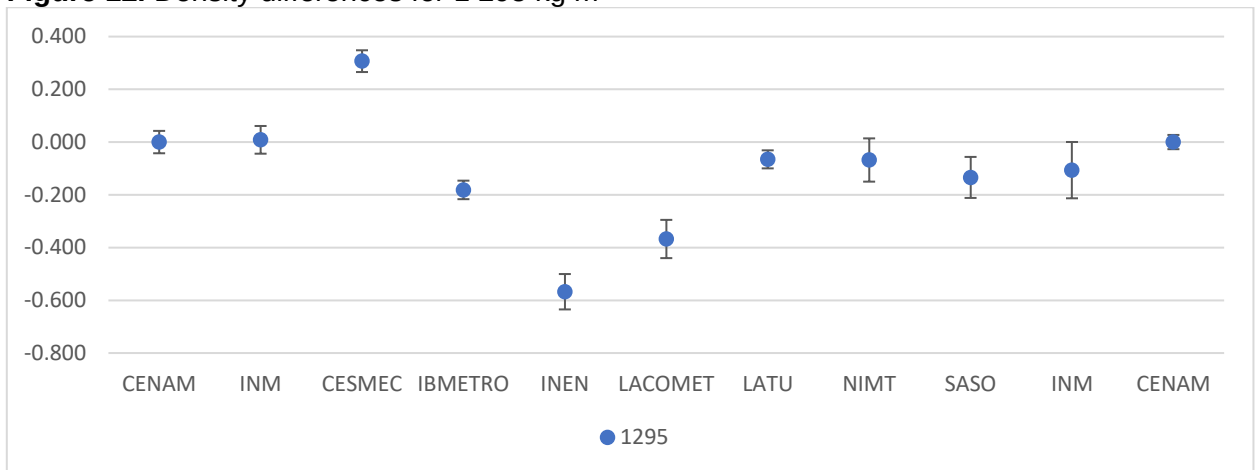
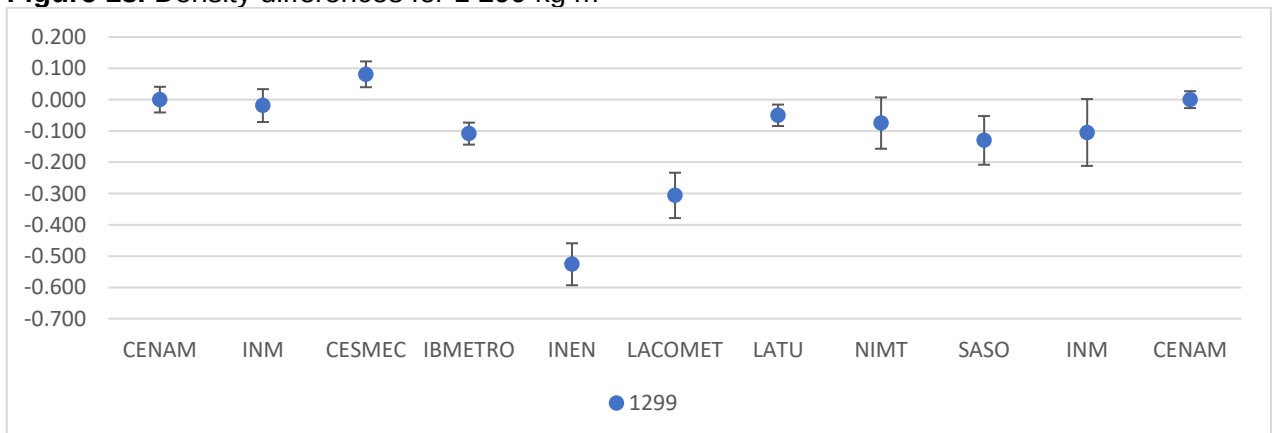


Figure 13. Density differences for 1 299 kg m⁻³



Annex B. Density differences among participant laboratories $d(X_{ik}, X_{jk})$, their expanded uncertainties $U(d(X_{ik}, X_{jk}))$, and normalized error, (E_n) at 95 % of confidence level.

Note: INM A are results of INM – Colombia for loop A and INM B are results of INM Colombia for loop B.

Table 12. Density differences for the nominal value of 601 kg m⁻³

Density differences among NMIs, Diff (kg m ⁻³)									
	INM A	CESMEC	IBMETRO	INEN	LACOMET	LATU	NIMT	SASO	INM B
INM A		-0.010	0.074	0.320	0.067	0.177	0.019	-0.033	0.018
CESMEC	0.010		0.083	0.330	0.077	0.187	0.029	-0.023	0.027
IBMETRO	-0.074	-0.083		0.247	-0.006	0.104	-0.054	-0.106	-0.056
INEN	-0.320	-0.330	-0.247		-0.253	-0.143	-0.301	-0.353	-0.303
LACOMET	-0.067	-0.077	0.006	0.253		0.110	-0.048	-0.100	-0.050
LATU	-0.177	-0.187	-0.104	0.143	-0.110		-0.158	-0.210	-0.160
NIMT	-0.019	-0.029	0.054	0.301	0.048	0.158		-0.052	-0.002
SASO	0.033	0.023	0.106	0.353	0.100	0.210	0.052		0.050
INM B	-0.018	-0.027	0.056	0.303	0.050	0.160	0.002	-0.050	

Expanded uncertainties associated to density differences, $U, k = 2$ (kg m ⁻³)									
	INM A	CESMEC	IBMETRO	INEN	LACOMET	LATU	NIMT	SASO	INM B
INM A		0.066	0.050	0.059	0.090	0.058	0.068	0.057	0.068
CESMEC	0.066		0.058	0.065	0.094	0.065	0.073	0.064	0.074
IBMETRO	0.050	0.058		0.049	0.084	0.049	0.060	0.048	0.060
INEN	0.059	0.065	0.049		0.089	0.057	0.067	0.056	0.067
LACOMET	0.090	0.094	0.084	0.089		0.089	0.095	0.088	0.096
LATU	0.058	0.065	0.049	0.057	0.089		0.067	0.056	0.067
NIMT	0.068	0.073	0.060	0.067	0.095	0.067		0.062	0.072
SASO	0.057	0.064	0.048	0.056	0.088	0.056	0.062		0.063
INM B	0.068	0.074	0.060	0.067	0.096	0.067	0.072	0.063	

Normalized error, E_n									
	INM A	CESMEC	IBMETRO	INEN	LACOMET	LATU	NIMT	SASO	INM B
INM A		0.15	1.46	5.46	0.75	3.04	0.28	0.57	0.26
CESMEC	0.15		1.45	5.08	0.82	2.89	0.39	0.36	0.37
IBMETRO	1.46	1.45		5.02	0.08	2.12	0.91	2.23	0.93
INEN	5.46	5.08	5.02		2.84	2.50	4.50	6.27	4.50
LACOMET	0.75	0.82	0.08	2.84		1.24	0.50	1.13	0.52
LATU	3.04	2.89	2.12	2.50	1.24		2.37	3.75	2.38
NIMT	0.28	0.39	0.91	4.50	0.50	2.37		0.84	0.02
SASO	0.57	0.36	2.23	6.27	1.13	3.75	0.84		0.81
INM B	0.26	0.37	0.93	4.50	0.52	2.38	0.02	0.81	

Table 13. Density differences for the nominal value of 605 kg m⁻³

Density differences among NMIs, Diff (kg m ⁻³)									
	INM A	CESMEC	IBMETRO	INEN	LACOMET	LATU	NIMT	SASO	INM B
INM A		0.173	0.101	0.313	0.091	0.179	0.035	-0.021	0.032
CESMEC	-0.173		-0.071	0.140	-0.082	0.006	-0.138	-0.194	-0.141
IBMETRO	-0.101	0.071		0.211	-0.011	0.077	-0.066	-0.122	-0.069
INEN	-0.313	-0.140	-0.211		-0.222	-0.134	-0.278	-0.334	-0.281
LACOMET	-0.091	0.082	0.011	0.222		0.088	-0.056	-0.112	-0.059
LATU	-0.179	-0.006	-0.077	0.134	-0.088		-0.144	-0.200	-0.147
NIMT	-0.035	0.138	0.066	0.278	0.056	0.144		-0.056	-0.003
SASO	0.021	0.194	0.122	0.334	0.112	0.200	0.056		0.053
INM B	-0.032	0.141	0.069	0.281	0.059	0.147	0.003	-0.053	

Expanded uncertainties associated to density differences, U , $k = 2$ (kg m ⁻³)									
	INM A	CESMEC	IBMETRO	INEN	LACOMET	LATU	NIMT	SASO	INM B
INM A		0.066	0.050	0.059	0.090	0.058	0.068	0.057	0.069
CESMEC	0.066		0.058	0.065	0.094	0.065	0.073	0.064	0.074
IBMETRO	0.050	0.058		0.049	0.084	0.049	0.060	0.048	0.061
INEN	0.059	0.065	0.049		0.089	0.057	0.067	0.056	0.068

LACOMET	0.090	0.094	0.084	0.089		0.089	0.095	0.088	0.096
LATU	0.058	0.065	0.049	0.057	0.089		0.067	0.056	0.068
NIMT	0.068	0.073	0.060	0.067	0.095	0.067		0.062	0.073
SASO	0.057	0.064	0.048	0.056	0.088	0.056	0.062		0.063
INM B	0.069	0.074	0.061	0.068	0.096	0.068	0.073	0.063	

Normalized error, E_n

	INM A	CESMEC	IBMETRO	INEN	LACOMET	LATU	NIMT	SASO	INM B
INM A		2.62	2.01	5.33	1.01	3.06	0.52	0.37	0.46
CESMEC	2.62		1.24	2.16	0.87	0.09	1.88	3.04	1.90
IBMETRO	2.01	1.24		4.31	0.13	1.59	1.11	2.57	1.14
INEN	5.33	2.16	4.31		2.49	2.34	4.15	5.93	4.14
LACOMET	1.01	0.87	0.13	2.49		0.99	0.58	1.27	0.61
LATU	3.06	0.09	1.59	2.34	0.99		2.16	3.57	2.17
NIMT	0.52	1.88	1.11	4.15	0.58	2.16		0.90	0.04
SASO	0.37	3.04	2.57	5.93	1.27	3.57	0.90		0.84
INM B	0.46	1.90	1.14	4.14	0.61	2.17	0.04	0.84	

Table 14. Density differences for the nominal value of 609 kg m⁻³

Density differences among NMIs, Diff (kg m⁻³)

	INM A	CESMEC	IBMETRO	INEN	LACOMET	LATU	NIMT	SASO	INM B
INM A		-0.220	0.069	0.320	0.062	0.112	0.050	-0.010	0.046
CESMEC	0.220		0.289	0.540	0.282	0.332	0.270	0.210	0.266
IBMETRO	-0.069	-0.289		0.251	-0.007	0.043	-0.019	-0.079	-0.024
INEN	-0.320	-0.540	-0.251		-0.258	-0.208	-0.270	-0.330	-0.274
LACOMET	-0.062	-0.282	0.007	0.258		0.050	-0.012	-0.072	-0.016
LATU	-0.112	-0.332	-0.043	0.208	-0.050		-0.062	-0.122	-0.066
NIMT	-0.050	-0.270	0.019	0.270	0.012	0.062		-0.061	-0.005
SASO	0.010	-0.210	0.079	0.330	0.072	0.122	0.061		0.056
INM B	-0.046	-0.266	0.024	0.274	0.016	0.066	0.005	-0.056	

Expanded uncertainties associated to density differences, U , $k = 2$ (kg m^{-3})

	INM A	CESMEC	IBMETRO	INEN	LACOMET	LATU	NIMT	SASO	INM B
INM A		0.066	0.050	0.059	0.090	0.058	0.068	0.057	0.069
CESMEC	0.066		0.058	0.065	0.094	0.065	0.073	0.064	0.074
IBMETRO	0.050	0.058		0.049	0.084	0.049	0.060	0.048	0.061
INEN	0.059	0.065	0.049		0.089	0.057	0.067	0.056	0.068
LACOMET	0.090	0.094	0.084	0.089		0.089	0.095	0.088	0.096
LATU	0.058	0.065	0.049	0.057	0.089		0.067	0.056	0.067
NIMT	0.068	0.073	0.060	0.067	0.095	0.067		0.062	0.073
SASO	0.057	0.064	0.048	0.056	0.088	0.056	0.062		0.063
INM B	0.069	0.074	0.061	0.068	0.096	0.067	0.073	0.063	

Normalized error, E_n

	INM A	CESMEC	IBMETRO	INEN	LACOMET	LATU	NIMT	SASO	INM B
INM A		3.34	1.38	5.46	0.69	1.92	0.74	0.18	0.67
CESMEC	3.34		5.02	8.32	3.00	5.14	3.69	3.29	3.59
IBMETRO	1.38	5.02		5.11	0.08	0.88	0.32	1.67	0.39
INEN	5.46	8.32	5.11		2.89	3.63	4.04	5.87	4.06
LACOMET	0.69	3.00	0.08	2.89		0.56	0.12	0.82	0.17
LATU	1.92	5.14	0.88	3.63	0.56		0.93	2.19	0.99
NIMT	0.74	3.69	0.32	4.04	0.12	0.93		0.97	0.06
SASO	0.18	3.29	1.67	5.87	0.82	2.19	0.97		0.89
INM B	0.67	3.59	0.39	4.06	0.17	0.99	0.06	0.89	

Table 15. Density differences for the nominal value of 991 kg m^{-3}

Density differences among NMIs, Diff (kg m^{-3})

	INM A	CESMEC	IBMETRO	INEN	LACOMET	LATU	NIMT	SASO	INM B
INM A		0.003	0.004	0.487	0.327	-0.019	-0.004	0.039	0.021
CESMEC	-0.003		0.001	0.484	0.324	-0.022	-0.007	0.036	0.018
IBMETRO	-0.004	-0.001		0.483	0.323	-0.023	-0.008	0.036	0.017
INEN	-0.487	-0.484	-0.483		-0.160	-0.506	-0.491	-0.448	-0.466

LACOMET	-0.327	-0.324	-0.323	0.160		-0.346	-0.331	-0.288	-0.306
LATU	0.019	0.022	0.023	0.506	0.346		0.015	0.058	0.040
NIMT	0.004	0.007	0.008	0.491	0.331	-0.015		0.044	0.025
SASO	-0.039	-0.036	-0.036	0.448	0.288	-0.058	-0.044		-0.019
INM B	-0.021	-0.018	-0.017	0.466	0.306	-0.040	-0.025	0.019	

Expanded uncertainties associated to density differences, U , $k = 2$ (kg m^{-3})

	INM A	CESMEC	IBMETRO	INEN	LACOMET	LATU	NIMT	SASO	INM B
INM A		0.084	0.076	0.084	0.105	0.078	0.094	0.090	0.106
CESMEC	0.084		0.062	0.072	0.095	0.064	0.083	0.078	0.097
IBMETRO	0.076	0.062		0.062	0.088	0.054	0.075	0.070	0.090
INEN	0.084	0.072	0.062		0.095	0.064	0.083	0.078	0.097
LACOMET	0.105	0.095	0.088	0.095		0.090	0.104	0.100	0.115
LATU	0.078	0.064	0.054	0.064	0.090		0.077	0.072	0.092
NIMT	0.094	0.083	0.075	0.083	0.104	0.077		0.087	0.104
SASO	0.090	0.078	0.070	0.078	0.100	0.072	0.087		0.100
INM B	0.106	0.097	0.090	0.097	0.115	0.092	0.104	0.100	

Normalized error, E_n

	INM A	CESMEC	IBMETRO	INEN	LACOMET	LATU	NIMT	SASO	INM B
INM A		0.03	0.05	5.81	3.13	0.24	0.05	0.44	0.20
CESMEC	0.03		0.01	6.77	3.41	0.34	0.09	0.47	0.18
IBMETRO	0.05	0.01		7.80	3.68	0.42	0.11	0.51	0.19
INEN	5.81	6.77	7.80		1.69	7.87	5.89	5.72	4.81
LACOMET	3.13	3.41	3.68	1.69		3.86	3.18	2.87	2.66
LATU	0.24	0.34	0.42	7.87	3.86		0.19	0.81	0.43
NIMT	0.05	0.09	0.11	5.89	3.18	0.19		0.50	0.24
SASO	0.44	0.47	0.51	5.72	2.87	0.81	0.50		0.19
INM B	0.20	0.18	0.19	4.81	2.66	0.43	0.24	0.19	

Table 16. Density differences for the nominal value of 995 kg m⁻³

Density differences among NMIs, Diff (kg m ⁻³)									
	INM A	CESMEC	IBMETRO	INEN	LACOMET	LATU	NIMT	SASO	INM B
INM A		-0.100	0.020	0.492	0.272	-0.022	0.017	0.053	0.038
CESMEC	0.100		0.120	0.591	0.371	0.077	0.117	0.153	0.138
IBMETRO	-0.020	-0.120		0.471	0.251	-0.043	-0.003	0.033	0.018
INEN	-0.492	-0.591	-0.471		-0.220	-0.514	-0.474	-0.439	-0.453
LACOMET	-0.272	-0.371	-0.251	0.220		-0.294	-0.254	-0.219	-0.233
LATU	0.022	-0.077	0.043	0.514	0.294		0.040	0.075	0.061
NIMT	-0.017	-0.117	0.003	0.474	0.254	-0.040		0.036	0.021
SASO	-0.053	-0.153	-0.033	0.439	0.219	-0.075	-0.036		-0.015
INM B	-0.038	-0.138	-0.018	0.453	0.233	-0.061	-0.021	0.015	

Expanded uncertainties associated to density differences, U , $k = 2$ (kg m ⁻³)									
	INM A	CESMEC	IBMETRO	INEN	LACOMET	LATU	NIMT	SASO	INM B
INM A		0.084	0.076	0.084	0.105	0.078	0.094	0.090	0.106
CESMEC	0.084		0.062	0.072	0.095	0.065	0.084	0.078	0.097
IBMETRO	0.076	0.062		0.062	0.088	0.054	0.076	0.070	0.090
INEN	0.084	0.072	0.062		0.095	0.065	0.084	0.078	0.097
LACOMET	0.105	0.095	0.088	0.095		0.090	0.104	0.100	0.115
LATU	0.078	0.065	0.054	0.065	0.090		0.078	0.072	0.092
NIMT	0.094	0.084	0.076	0.084	0.104	0.078		0.087	0.104
SASO	0.090	0.078	0.070	0.078	0.100	0.072	0.087		0.100
INM B	0.106	0.097	0.090	0.097	0.115	0.092	0.104	0.100	

Normalized error, E_n									
	INM A	CESMEC	IBMETRO	INEN	LACOMET	LATU	NIMT	SASO	INM B
INM A		1.19	0.27	5.84	2.59	0.29	0.18	0.59	0.36
CESMEC	1.19		1.92	8.23	3.90	1.20	1.40	1.95	1.43
IBMETRO	0.27	1.92		7.55	2.85	0.79	0.04	0.47	0.20
INEN	5.84	8.23	7.55		2.31	7.95	5.67	5.59	4.67
LACOMET	2.59	3.90	2.85	2.31		3.27	2.44	2.18	2.02

LATU	0.29	1.20	0.79	7.95	3.27		0.51	1.05	0.66
NIMT	0.18	1.40	0.04	5.67	2.44	0.51		0.41	0.20
SASO	0.59	1.95	0.47	5.59	2.18	1.05	0.41		0.15
INM B	0.36	1.43	0.20	4.67	2.02	0.66	0.20	0.15	

Table 17. Density differences for the nominal value of 999 kg m^{-3}

Density differences among NMIs, Diff (kg m^{-3})									
	INM A	CESMEC	IBMETRO	INEN	LACOMET	LATU	NIMT	SASO	INM B
INM A		-0.040	0.031	0.500	0.230	-0.009	0.043	0.071	0.060
CESMEC	0.040		0.071	0.539	0.269	0.030	0.083	0.111	0.100
IBMETRO	-0.031	-0.071		0.468	0.198	-0.041	0.012	0.040	0.029
INEN	-0.500	-0.539	-0.468		-0.270	-0.509	-0.456	-0.429	-0.439
LACOMET	-0.230	-0.269	-0.198	0.270		-0.239	-0.186	-0.159	-0.169
LATU	0.009	-0.030	0.041	0.509	0.239		0.053	0.080	0.070
NIMT	-0.043	-0.083	-0.012	0.456	0.186	-0.053		0.028	0.017
SASO	-0.071	-0.111	-0.040	0.429	0.159	-0.080	-0.028		-0.011
INM B	-0.060	-0.100	-0.029	0.439	0.169	-0.070	-0.017	0.011	

Expanded uncertainties associated to density differences, $U, k = 2$ (kg m^{-3})									
	INM A	CESMEC	IBMETRO	INEN	LACOMET	LATU	NIMT	SASO	INM B
INM A		0.084	0.076	0.084	0.105	0.078	0.094	0.090	0.106
CESMEC	0.084		0.062	0.072	0.095	0.065	0.084	0.078	0.096
IBMETRO	0.076	0.062		0.062	0.088	0.054	0.076	0.070	0.090
INEN	0.084	0.072	0.062		0.095	0.065	0.084	0.078	0.096
LACOMET	0.105	0.095	0.088	0.095		0.090	0.104	0.100	0.115
LATU	0.078	0.065	0.054	0.065	0.090		0.078	0.072	0.091
NIMT	0.094	0.084	0.076	0.084	0.104	0.078		0.087	0.103
SASO	0.090	0.078	0.070	0.078	0.100	0.072	0.087		0.099
INM B	0.106	0.096	0.090	0.096	0.115	0.091	0.103	0.099	

Normalized error, E_n

	INM A	CESMEC	IBMETRO	INEN	LACOMET	LATU	NIMT	SASO	INM B
INM A		0.47	0.41	5.93	2.19	0.12	0.46	0.79	0.57
CESMEC	0.47		1.13	7.50	2.83	0.47	0.99	1.41	1.04
IBMETRO	0.41	1.13		7.49	2.24	0.75	0.16	0.57	0.32
INEN	5.93	7.50	7.49		2.83	7.86	5.45	5.47	4.56
LACOMET	2.19	2.83	2.24	2.83		2.66	1.78	1.58	1.47
LATU	0.12	0.47	0.75	7.86	2.66		0.68	1.12	0.76
NIMT	0.46	0.99	0.16	5.45	1.78	0.68		0.32	0.16
SASO	0.79	1.41	0.57	5.47	1.58	1.12	0.32		0.11
INM B	0.57	1.04	0.32	4.56	1.47	0.76	0.16	0.11	

Table 18. Density differences for the nominal value of 1 091 kg m⁻³

Density differences among NMIs, Diff (kg m⁻³)

	INM A	CESMEC	IBMETRO	INEN	LACOMET	LATU	NIMT	SASO	INM B
INM A		-0.253	0.072	0.440	0.250	0.020	0.029	0.012	0.047
CESMEC	0.253		0.326	0.693	0.503	0.273	0.282	0.265	0.301
IBMETRO	-0.072	-0.326		0.368	0.178	-0.052	-0.043	-0.061	-0.025
INEN	-0.440	-0.693	-0.368		-0.190	-0.420	-0.411	-0.428	-0.393
LACOMET	-0.250	-0.503	-0.178	0.190		-0.230	-0.221	-0.238	-0.203
LATU	-0.020	-0.273	0.052	0.420	0.230		0.009	-0.008	0.027
NIMT	-0.029	-0.282	0.043	0.411	0.221	-0.009		-0.017	0.018
SASO	-0.012	-0.265	0.061	0.428	0.238	0.008	0.017		0.036
INM B	-0.047	-0.301	0.025	0.393	0.203	-0.027	-0.018	-0.036	

Expanded uncertainties associated to density differences, $U, k = 2$ (kg m⁻³)

	INM A	CESMEC	IBMETRO	INEN	LACOMET	LATU	NIMT	SASO	INM B
INM A		0.089	0.082	0.089	0.107	0.083	0.103	0.097	0.115
CESMEC	0.089		0.063	0.072	0.093	0.064	0.088	0.081	0.103
IBMETRO	0.082	0.063		0.063	0.087	0.055	0.082	0.074	0.097
INEN	0.089	0.072	0.063		0.093	0.064	0.088	0.081	0.103

LACOMET	0.107	0.093	0.087	0.093		0.088	0.107	0.101	0.119
LATU	0.083	0.064	0.055	0.064	0.088		0.082	0.075	0.098
NIMT	0.103	0.088	0.082	0.088	0.107	0.082		0.094	0.113
SASO	0.097	0.081	0.074	0.081	0.101	0.075	0.094		0.107
INM B	0.115	0.103	0.097	0.103	0.119	0.098	0.113	0.107	

Normalized error, E_n

	INM A	CESMEC	IBMETRO	INEN	LACOMET	LATU	NIMT	SASO	INM B
INM A		2.86	0.88	4.96	2.34	0.24	0.28	0.12	0.41
CESMEC	2.86		5.16	9.70	5.40	4.25	3.20	3.27	2.93
IBMETRO	0.88	5.16		5.83	2.04	0.95	0.53	0.82	0.26
INEN	4.96	9.70	5.83		2.04	6.53	4.66	5.28	3.83
LACOMET	2.34	5.40	2.04	2.04		2.62	2.07	2.36	1.71
LATU	0.24	4.25	0.95	6.53	2.62		0.11	0.11	0.28
NIMT	0.28	3.20	0.53	4.66	2.07	0.11		0.19	0.16
SASO	0.12	3.27	0.82	5.28	2.36	0.11	0.19		0.33
INM B	0.41	2.93	0.26	3.83	1.71	0.28	0.16	0.33	

Table 19. Density differences for the nominal value of 1 095 kg m⁻³

Density differences among NMIs, Diff (kg m⁻³)

	INM A	CESMEC	IBMETRO	INEN	LACOMET	LATU	NIMT	SASO	INM B
INM A		-0.159	0.101	0.445	0.305	0.017	0.042	0.024	0.055
CESMEC	0.159		0.260	0.605	0.465	0.177	0.201	0.183	0.214
IBMETRO	-0.101	-0.260		0.345	0.205	-0.083	-0.058	-0.076	-0.045
INEN	-0.445	-0.605	-0.345		-0.140	-0.428	-0.403	-0.421	-0.390
LACOMET	-0.305	-0.465	-0.205	0.140		-0.288	-0.263	-0.281	-0.250
LATU	-0.017	-0.177	0.083	0.428	0.288		0.025	0.007	0.038
NIMT	-0.042	-0.201	0.058	0.403	0.263	-0.025		-0.018	0.013
SASO	-0.024	-0.183	0.076	0.421	0.281	-0.007	0.018		0.031
INM B	-0.055	-0.214	0.045	0.390	0.250	-0.038	-0.013	-0.031	

Expanded uncertainties associated to density differences, U , $k = 2$ (kg m^{-3})

	INM A	CESMEC	IBMETRO	INEN	LACOMET	LATU	NIMT	SASO	INM B
INM A		0.089	0.082	0.089	0.107	0.083	0.103	0.097	0.115
CESMEC	0.089		0.063	0.072	0.093	0.064	0.088	0.081	0.103
IBMETRO	0.082	0.063		0.063	0.087	0.055	0.082	0.074	0.097
INEN	0.089	0.072	0.063		0.093	0.064	0.088	0.081	0.103
LACOMET	0.107	0.093	0.087	0.093		0.088	0.107	0.101	0.119
LATU	0.083	0.064	0.055	0.064	0.088		0.082	0.075	0.098
NIMT	0.103	0.088	0.082	0.088	0.107	0.082		0.094	0.113
SASO	0.097	0.081	0.074	0.081	0.101	0.075	0.094		0.107
INM B	0.115	0.103	0.097	0.103	0.119	0.098	0.113	0.107	

Normalized error, E_n

	INM A	CESMEC	IBMETRO	INEN	LACOMET	LATU	NIMT	SASO	INM B
INM A		1.79	1.22	5.02	2.85	0.21	0.41	0.25	0.48
CESMEC	1.79		4.12	8.45	4.98	2.75	2.28	2.26	2.09
IBMETRO	1.22	4.12		5.46	2.35	1.52	0.72	1.03	0.47
INEN	5.02	8.45	5.46		1.50	6.66	4.57	5.19	3.80
LACOMET	2.85	4.98	2.35	1.50		3.28	2.47	2.79	2.11
LATU	0.21	2.75	1.52	6.66	3.28		0.30	0.09	0.39
NIMT	0.41	2.28	0.72	4.57	2.47	0.30		0.19	0.12
SASO	0.25	2.26	1.03	5.19	2.79	0.09	0.19		0.29
INM B	0.48	2.09	0.47	3.80	2.11	0.39	0.12	0.29	

Table 20. Density differences for the nominal value of $1\,099\text{ kg m}^{-3}$

Density differences among NMIs, Diff (kg m^{-3})

	INM A	CESMEC	IBMETRO	INEN	LACOMET	LATU	NIMT	SASO	INM B
INM A		-0.271	0.027	0.446	0.266	0.016	0.041	0.023	0.049
CESMEC	0.271		0.299	0.717	0.537	0.287	0.312	0.294	0.320
IBMETRO	-0.027	-0.299		0.418	0.238	-0.012	0.014	-0.005	0.022
INEN	-0.446	-0.717	-0.418		-0.180	-0.430	-0.405	-0.423	-0.397

LACOMET	-0.266	-0.537	-0.238	0.180		-0.250	-0.225	-0.243	-0.217
LATU	-0.016	-0.287	0.012	0.430	0.250		0.025	0.007	0.033
NIMT	-0.041	-0.312	-0.014	0.405	0.225	-0.025		-0.018	0.008
SASO	-0.023	-0.294	0.005	0.423	0.243	-0.007	0.018		0.026
INM B	-0.049	-0.320	-0.022	0.397	0.217	-0.033	-0.008	-0.026	

Expanded uncertainties associated to density differences, U , $k = 2$ (kg m^{-3})

	INM A	CESMEC	IBMETRO	INEN	LACOMET	LATU	NIMT	SASO	INM B
INM A		0.089	0.082	0.089	0.107	0.083	0.103	0.097	0.115
CESMEC	0.089		0.063	0.072	0.093	0.064	0.088	0.081	0.103
IBMETRO	0.082	0.063		0.063	0.087	0.055	0.082	0.074	0.097
INEN	0.089	0.072	0.063		0.093	0.064	0.088	0.081	0.103
LACOMET	0.107	0.093	0.087	0.093		0.088	0.107	0.101	0.119
LATU	0.083	0.064	0.055	0.064	0.088		0.082	0.075	0.098
NIMT	0.103	0.088	0.082	0.088	0.107	0.082		0.094	0.113
SASO	0.097	0.081	0.074	0.081	0.101	0.075	0.094		0.107
INM B	0.115	0.103	0.097	0.103	0.119	0.098	0.113	0.107	

Normalized error, E_n

	INM A	CESMEC	IBMETRO	INEN	LACOMET	LATU	NIMT	SASO	INM B
INM A		3.06	0.33	5.02	2.48	0.19	0.40	0.23	0.42
CESMEC	3.06		4.73	10.03	5.76	4.46	3.54	3.62	3.12
IBMETRO	0.33	4.73		6.63	2.74	0.21	0.17	0.06	0.22
INEN	5.02	10.03	6.63		1.93	6.69	4.59	5.22	3.87
LACOMET	2.48	5.76	2.74	1.93		2.85	2.11	2.41	1.83
LATU	0.19	4.46	0.21	6.69	2.85		0.30	0.09	0.34
NIMT	0.40	3.54	0.17	4.59	2.11	0.30		0.20	0.07
SASO	0.23	3.62	0.06	5.22	2.41	0.09	0.20		0.25
INM B	0.42	3.12	0.22	3.87	1.83	0.34	0.07	0.25	

Table 21. Density differences for the nominal value of $1\,291\text{ kg m}^{-3}$

Density differences among NMIs, Diff (kg m^{-3})									
	INM A	CESMEC	IBMETRO	INEN	LACOMET	LATU	NIMT	SASO	INM B
INM A		-0.332	0.185	0.531	0.351	0.082	0.069	0.145	0.115
CESMEC	0.332		0.517	0.863	0.683	0.414	0.401	0.477	0.447
IBMETRO	-0.185	-0.517		0.346	0.166	-0.103	-0.116	-0.040	-0.070
INEN	-0.531	-0.863	-0.346		-0.180	-0.449	-0.462	-0.386	-0.416
LACOMET	-0.351	-0.683	-0.166	0.180		-0.269	-0.282	-0.206	-0.236
LATU	-0.082	-0.414	0.103	0.449	0.269		-0.013	0.063	0.033
NIMT	-0.069	-0.401	0.116	0.462	0.282	0.013		0.077	0.047
SASO	-0.145	-0.477	0.040	0.386	0.206	-0.063	-0.077		-0.030
INM B	-0.115	-0.447	0.070	0.416	0.236	-0.033	-0.047	0.030	

Expanded uncertainties associated to density differences, $U, k = 2$ (kg m^{-3})									
	INM A	CESMEC	IBMETRO	INEN	LACOMET	LATU	NIMT	SASO	INM B
INM A		0.054	0.049	0.075	0.080	0.049	0.090	0.086	0.113
CESMEC	0.054		0.037	0.068	0.073	0.036	0.084	0.080	0.109
IBMETRO	0.049	0.037		0.065	0.070	0.029	0.081	0.077	0.106
INEN	0.075	0.068	0.065		0.090	0.064	0.099	0.096	0.121
LACOMET	0.080	0.073	0.070	0.090		0.070	0.103	0.100	0.124
LATU	0.049	0.036	0.029	0.064	0.070		0.081	0.077	0.106
NIMT	0.090	0.084	0.081	0.099	0.103	0.081		0.106	0.129
SASO	0.086	0.080	0.077	0.096	0.100	0.077	0.106		0.126
INM B	0.113	0.109	0.106	0.121	0.124	0.106	0.129	0.126	

Normalized error, E_n									
	INM A	CESMEC	IBMETRO	INEN	LACOMET	LATU	NIMT	SASO	INM B
INM A		6.17	3.75	7.04	4.37	1.69	0.76	1.68	1.02
CESMEC	6.17		13.99	12.68	9.31	11.46	4.76	5.96	4.12
IBMETRO	3.75	13.99		5.36	2.37	3.56	1.43	0.51	0.65
INEN	7.04	12.68	5.36		1.99	7.01	4.65	4.02	3.44

LACOMET	4.37	9.31	2.37	1.99		3.86	2.74	2.06	1.90
LATU	1.69	11.46	3.56	7.01	3.86		0.16	0.83	0.32
NIMT	0.76	4.76	1.43	4.65	2.74	0.16		0.72	0.36
SASO	1.68	5.96	0.51	4.02	2.06	0.83	0.72		0.24
INM B	1.02	4.12	0.65	3.44	1.90	0.32	0.36	0.24	

Table 22. Density differences for the nominal value of 1 295 kg m⁻³

Density differences among NMIs, Diff (kg m ⁻³)									
	INM A	CESMEC	IBMETRO	INEN	LACOMET	LATU	NIMT	SASO	INM B
INM A		-0.298	0.190	0.576	0.376	0.074	0.077	0.143	0.115
CESMEC	0.298		0.488	0.874	0.674	0.372	0.375	0.441	0.413
IBMETRO	-0.190	-0.488		0.386	0.186	-0.116	-0.113	-0.047	-0.075
INEN	-0.576	-0.874	-0.386		-0.200	-0.502	-0.499	-0.433	-0.461
LACOMET	-0.376	-0.674	-0.186	0.200		-0.302	-0.299	-0.233	-0.261
LATU	-0.074	-0.372	0.116	0.502	0.302		0.003	0.069	0.041
NIMT	-0.077	-0.375	0.113	0.499	0.299	-0.003		0.066	0.038
SASO	-0.143	-0.441	0.047	0.433	0.233	-0.069	-0.066		-0.028
INM B	-0.115	-0.413	0.075	0.461	0.261	-0.041	-0.038	0.028	

Expanded uncertainties associated to density differences, $U, k = 2$ (kg m ⁻³)									
	INM A	CESMEC	IBMETRO	INEN	LACOMET	LATU	NIMT	SASO	INM B
INM A		0.054	0.049	0.075	0.080	0.049	0.090	0.086	0.113
CESMEC	0.054		0.037	0.068	0.073	0.036	0.084	0.080	0.109
IBMETRO	0.049	0.037		0.065	0.070	0.029	0.081	0.077	0.106
INEN	0.075	0.068	0.065		0.090	0.064	0.099	0.096	0.121
LACOMET	0.080	0.073	0.070	0.090		0.070	0.103	0.100	0.124
LATU	0.049	0.036	0.029	0.064	0.070		0.081	0.077	0.106
NIMT	0.090	0.084	0.081	0.099	0.103	0.081		0.106	0.129
SASO	0.086	0.080	0.077	0.096	0.100	0.077	0.106		0.126
INM B	0.113	0.109	0.106	0.121	0.124	0.106	0.129	0.126	

Normalized error, E_n									
	INM A	CESMEC	IBMETRO	INEN	LACOMET	LATU	NIMT	SASO	INM B
INM A		5.54	3.85	7.63	4.68	1.52	0.85	1.65	1.01
CESMEC	5.54		13.20	12.84	9.19	10.31	4.45	5.51	3.81
IBMETRO	3.85	13.20		5.98	2.65	4.00	1.39	0.61	0.70
INEN	7.63	12.84	5.98		2.21	7.84	5.02	4.52	3.82
LACOMET	4.68	9.19	2.65	2.21		4.33	2.90	2.34	2.11
LATU	1.52	10.31	4.00	7.84	4.33		0.03	0.89	0.39
NIMT	0.85	4.45	1.39	5.02	2.90	0.03		0.62	0.30
SASO	1.65	5.51	0.61	4.52	2.34	0.89	0.62		0.22
INM B	1.01	3.81	0.70	3.82	2.11	0.39	0.30	0.22	

Table 23. Density differences for the nominal value of 1 299 kg m⁻³

Density differences among NMIs, Diff (kg m ⁻³)									
	INM A	CESMEC	IBMETRO	INEN	LACOMET	LATU	NIMT	SASO	INM B
INM A		-0.100	0.090	0.507	0.287	0.031	0.056	0.111	0.086
CESMEC	0.100		0.189	0.607	0.387	0.131	0.156	0.211	0.186
IBMETRO	-0.090	-0.189		0.417	0.197	-0.059	-0.034	0.022	-0.004
INEN	-0.507	-0.607	-0.417		-0.220	-0.476	-0.451	-0.396	-0.421
LACOMET	-0.287	-0.387	-0.197	0.220		-0.256	-0.231	-0.176	-0.201
LATU	-0.031	-0.131	0.059	0.476	0.256		0.025	0.080	0.055
NIMT	-0.056	-0.156	0.034	0.451	0.231	-0.025		0.055	0.030
SASO	-0.111	-0.211	-0.022	0.396	0.176	-0.080	-0.055		-0.025
INM B	-0.086	-0.186	0.004	0.421	0.201	-0.055	-0.030	0.025	

Expanded uncertainties associated to density differences, $U, k = 2$ (kg m ⁻³)									
	INM A	CESMEC	IBMETRO	INEN	LACOMET	LATU	NIMT	SASO	INM B
INM A		0.054	0.049	0.075	0.080	0.049	0.090	0.086	0.113
CESMEC	0.054		0.037	0.068	0.073	0.036	0.084	0.080	0.109
IBMETRO	0.049	0.037		0.065	0.070	0.029	0.081	0.077	0.106
INEN	0.075	0.068	0.065		0.090	0.064	0.099	0.096	0.121

LACOMET	0.080	0.073	0.070	0.090		0.070	0.103	0.100	0.124
LATU	0.049	0.036	0.029	0.064	0.070		0.081	0.077	0.106
NIMT	0.090	0.084	0.081	0.099	0.103	0.081		0.106	0.129
SASO	0.086	0.080	0.077	0.096	0.100	0.077	0.106		0.126
INM B	0.113	0.109	0.106	0.121	0.124	0.106	0.129	0.126	

Normalized error, E_n

	INM A	CESMEC	IBMETRO	INEN	LACOMET	LATU	NIMT	SASO	INM B
INM A		1.86	1.82	6.72	3.57	0.64	0.62	1.29	0.76
CESMEC	1.86		5.13	8.92	5.27	3.62	1.85	2.64	1.71
IBMETRO	1.82	5.13		6.47	2.82	2.02	0.41	0.28	0.03
INEN	6.72	8.92	6.47		2.43	7.43	4.54	4.12	3.49
LACOMET	3.57	5.27	2.82	2.43		3.67	2.24	1.76	1.62
LATU	0.64	3.62	2.02	7.43	3.67		0.31	1.05	0.52
NIMT	0.62	1.85	0.41	4.54	2.24	0.31		0.52	0.23
SASO	1.29	2.64	0.28	4.12	1.76	1.05	0.52		0.20
INM B	0.76	1.71	0.03	3.49	1.62	0.52	0.23	0.20	