CIPM MRA
Comparison reports

AFRIMETS.M.D-S2

Density of liquids

SUPPLEMENTARY COMPARISON

Any further distribution of this Report must be cited as:
M. Hamdy *et al* 2026 *CIPM MRA Comparison reports* **07012**
https://doi.org/10.59161/EWDP4945

Final Report

on AFRIMETS Supplementary Comparison

Density Determination of Liquid Samples Using Oscillation-Type Density meters

AFRIMETS.M. D-S2

Mohamed Hamdy[1], Beatrice Lugadiru[2], Jenitha Ishabaganzi[3], Mukwaya Simon Peter[4], Jonathan Omara[4], Rayan AlYousefi[5]

[1] National Institute of Standards (NIS), Tersa St., El-Haram, El-Giza, P. O. Box 136 -Code 12211 Giza –Egypt

[2] Kenya Bureau of Standards (KEBS), Popo Road, off Mombasa Road P.O Box 54974 Code 00200 Nairobi – Kenya

[3] Tanzania Bureau of Standards (TBS), P O Box 9524, Sam Nujoma Road / Morogoro Road, Ubungo, Dar es Salaam

[4] Uganda National Bureau of Standards (UNBS) Plot 2-12 By-Pass Link, Bweyogerere Industrial And Business Park, P.O Box 6329 Kampala

[5] Saudi Standard, Metrology and Quality Organization/ National Measurement and Calibration Center (SASO - NMCC) Riyadh - Al Muhammadiyah - in front of King Saud University PO. B 3437 Riyadh 11471

Pilot Laboratory: National Institute of Standards (NIS)-Egypt

Contact Person:

Dr. Eng. Mohamed Hamdy

Email: mohamed.hamdy@nis.sci.eg

Mobile: (+2)01001929796

NIS, Egypt

March, 2026

Supplementary Comparison AFRIMETS.M.D-S2

Abstract

This report presents the results of the supplementary comparison AFRIMETS.M. D-S2, which covers the determination of the density of two reference liquids (Fluorinert FC-40 and Distilled Water) at a temperature of 20 °C and an atmospheric pressure of 101 325 Pa.

Five National Metrology Institutes (NMIs) participated in the comparison, using oscillation-type density meters approved as national standards of density measurement in their respective countries. Measurements were performed between July 2023 and December 2024 using Anton Paar DSA 5000M Digital Density meter.

The stability and homogeneity of the reference liquids were verified by the Pilot Laboratory (NIS, Egypt), which found no significant drift or inhomogeneity during the measurement period. Therefore, the influence of these factors was considered negligible in the uncertainty evaluation.

Supplementary Comparison AFRIMETS.M. D-S2

Table of Contents

1. Introduction

This report presents the results of the supplementary comparison AFRIMETS.M.D-S2 on density determination of liquid samples using oscillation-type density meters. The National Institute of Standards (NIS) is the Pilot Laboratory and four national metrology institutes (NMIs) took part in the comparison as participants. In order to ensure that the supplementary comparison is carried out, density of the following transfer standards (reference liquids) was measured: (Fluorinert FC-40 and distilled water). The measurements were performed at temperature of 20 °C and atmospheric pressure 101325 Pa. Participating laboratories used the equipment approved in the participating countries as the state measurement standards of density. Measurements were carried out in the period from July 20, 2023 to December 24, 2024. The stability measurements were performed parallel to the measurements of the participants from July 23, 2024 to June 30, 2024. Uncertainties of the measurement results obtained by the pilot laboratory were confirmed by the results of the key comparison CCM.D-K2 [1].

2. Participant laboratories

The participant laboratories are listed in **Table 1**.

Table 1 List of the participating NMIs and technical contacts.

Laboratory (country)	Mailing address for the packages	Person responsible for the comparison
Egypt: NIS	**National Institute of Standards (NIS)** Tersa St., El-Haram, El-Giza, Egypt P. O.Box 136 Giza-Code 12211	**Dr. Mohamed Hamdy** Mohamed.hamdy@nis.sci.eg Tel.: +2 01001929796 Fax: +202 33867452
Kenya: KEBS	**Kenya Bureau of Standards (KEBS)** Popo Road, off Mombasa Road P.O Box 54974 Code 00200 Nairobi – Kenya	**Mrs. Beatrice Lugadiru** lugadirub@kebs.org Tel.: +254722377640 Fax: +254 020 6948000
Tanzania: TBS	**Tanzania Bureau of Standards (TBS)** P O Box 9524, Sam Nujoma Road / Morogoro Road, Ubungo, Dar es Salaam.	**Mrs. JENITHA ISHABAGANZI** Jenitha.ishabaganzi@tbs.go.tz Tel.: +255 756 453 679 Fax: +255 689 929 936
Uganda: UNBS	**Uganda National Bureau of Standards (UNBS)** Plot 2-12 By-Pass Link, Bweyogerere Industrial And Business Park, P.O Box 6329 Kampala	**Mr. Mukwaya Simon Peter** simon.mukwaya@unbs.go.ug Tel.: +256 704418960 **Mr. Jonathan Omara** jonathan.omara@unbs.go.ug Tel.: +256 0703 243087
Kingdom of Saudi Arabia: SASO-NMCC	**Saudi Standard, Metrology and Quality Organization/ National Measurement and Calibration Center (SASO-NMCC)** Riyadh - Al Muhammadiyah - in front of King Saud University PO. B 3437 Riyadh 11471	**Mr. Rayan AlYousefi** r.yousefi@saso.gov.sa Tel :+966 50 547 4746

3. Transfer Standards as Artifacts (Liquid samples)

In order to ensure quality and accuracy of the Supplementary Comparison, the Pilot Laboratory purchased and prepared at least 80 cm^3 of reference samples of (Fluorinert FC-40, distilled water). Nominal density values of the liquid samples used in this Comparison correspond to the nominal density values of liquid samples used in the Key Comparison CCM.D-K5.

Table 2 Physical constants of the liquids

Liquid	Nominal density in kg/m^3	Cubic thermal expansion in $kg/(m^3\ K)$	Uncertainty (k = 1) in $kg/(m^3\ K)$	Isothermal compressibility in $10^{-11}/Pa$	Uncertainty (k = 1) in $10^{-11}/Pa$
Distilled water	998	0.21	0.02	46	2.1
FC-40 (20 °C)	1866**	2.23**	0.06***	131	5*

* Measured

** From Datasheet 3M

*** Estimated from Datasheet 3M

The Pilot Laboratory carried out measurements of reference liquids, which were each mixed in a separate container. After the measurements, a control sample of 1000 cm3 was taken from each reference sample and put into glass bottles with sealed covers. Bottles with control samples were then labeled and stored in the Pilot Laboratory for testing the stability of its properties in time.

Reference liquids intended for measurements were put in glass bottles with nominal volumes of 80 cm^3, and then these bottles were distributed to the participating laboratories during the AFRIMETS meeting that held in Cairo at July 2023.

All glass bottles were labeled with an index of the liquid sample name as shown in **Figure 1** and **Figure 2**.

Figure 1 FC-40 Liquid sample for the comparison in a glass bottle with a nominal volume of 80 cm^3

Figure 2 Distilled Water Liquid sample for the comparison in a glass bottle with a nominal volume of 80 cm^3

4. Equipment and methods of measurement

Participating laboratories carried out density measurements of the liquid samples using equipment approved in the participating country as the State Measurement Standard of density.

Types and main characteristics of the measuring equipment used are given in the **Table 3**.

Table 3 Types and main characteristics of the measuring equipment

Participating Laboratory	Method of measurement	Measuring equipment	Traceability
NIS	Direct measurements	Density analyzer DSA 5000M, Anton Paar GmbH, 0 – 3 g/cm^3 d = 0.000001 g/cm^3	NIS-Silicon Sphere
KEBS	Direct measurements	Density analyzer DMA 5000M, Anton Paar GmbH, 0 – 3 g/cm^3 d = 0.000001 g/cm^3	PTB through ZMK, Germany
TBS	Direct measurements	Density analyzer DM 4500 M Anton Paar GmbH, 0 – 3 g/cm3 d = 0.00001 g/cm^3	Direct purchased WATER CRMs
UNBS	Direct measurements	SG-Ultra Max (Oscillating U-tube), 0 – 3 g/cm^3 d = 0.0001 g/cm^3	VWR Chemicals BDH
SASO-NMCC	Direct measurements	Density analyzer DMA 5000M, Anton Paar GmbH, 0 – 3 g/cm^3 d = 0.000001 g/cm^3	NMCC-Silicon Sphere

5. Inhomogeneity and changes of the liquid densities

Before the comparison started samples were taken to monitor the stability of the liquids. These stability checks were carried out by the digital density meter Anton Paar DSA 5000 M instrument at 20 °C. The instrument was calibrated with water and air. The stability measurements were performed parallel to the measurements of the participants from July 23, 2024 to June 30, 2024.

5.1) Distilled Water Stability Study:

Figure 3 shows the distilled water density stability study.

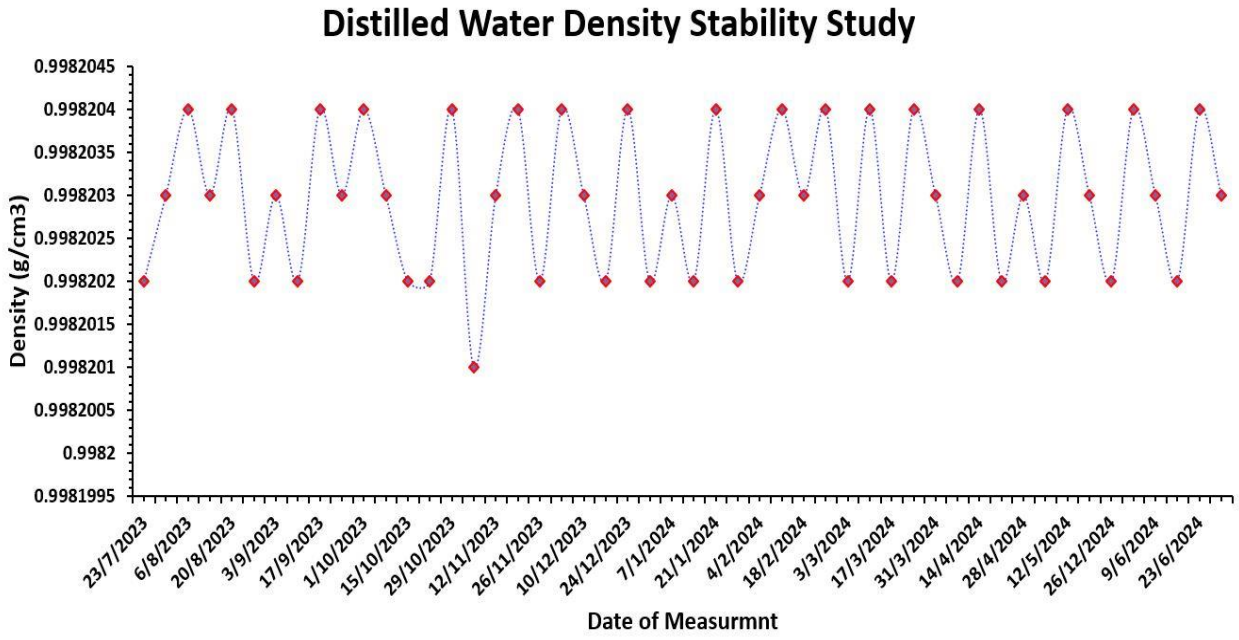

Figure 3 Stability of the density of the distilled water remained in the pilot laboratory

A regression analysis was conducted to evaluate the long-term stability of the density of the distilled water. The regression model produced a slope of **1.63×10^{-9}**, with a p-value of **0.852**, which is greater than the 0.05 significance level as shown in **Table 4**.

Table 4 Regression analysis for distilled water density stability study

ANOVA Single Factor

	df	SS	MS	F	Significance F
Regression	1	2.78×10^{-14}	2.78×10^{-14}	0.035159	0.852054
Residual	48	3.79×10^{-13}	7.89×10^{-13}		
Total	49	3.79×10^{-13}			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	0.998203	2.55×10^{-07}	3912656	9.3E-278	0.998202	0.998203	0.998202	0.998203
X Variable 1	1.63×10^{-09}	8.71×10^{-09}	0.187507	0.852054	-1.6×10^{-08}	1.91×10^{-08}	-1.6×10^{-08}	1.91×10^{-08}

The high p-value indicates that the slope is **not statistically different from zero**, and the 95% confidence interval for the slope includes zero. This demonstrates that there is **no significant trend or drift** in the measurement results over the evaluated period. The measurements are considered **stable**, and the observed variations are attributable to normal random measurement noise rather than systematic change over time.

5.2) FC-40 Stability Study

The stability study for the density of FC-40 is presented in **Figure 4**

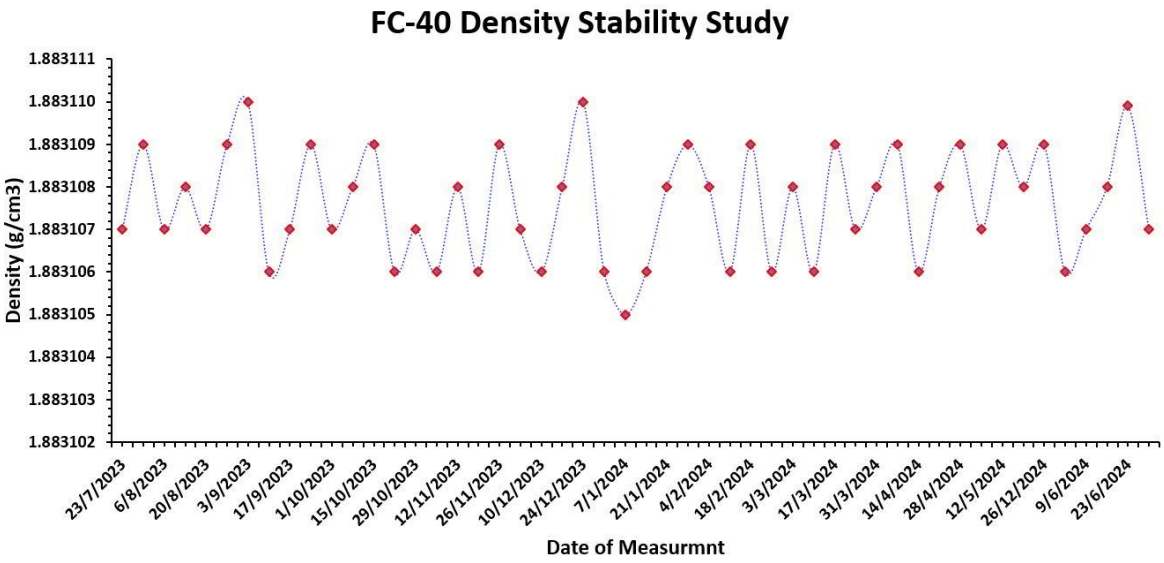

Figure 4 Stability of the density of the FC-40 remained in the pilot laboratory

A regression analysis was conducted to evaluate the long-term stability of the density of the FC-40. The regression model produced an F-value of **0.1204** with a corresponding significance level of **0.73011**, indicating that the model is **not statistically significant** as shown in **Table 5**.

Table 5 Regression analysis for FC-40 density stability study

ANOVA Single Factor

	df	SS	MS	F	Significance F
Regression	1	2.09×10^{-13}	2.09×10^{-13}	0.120403	0.730115
Residual	48	8.33×10^{-11}	1.74×10^{-12}		
Total	49	8.35×10^{-11}			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	1.883107	3.78×10^{-07}	4977673	8.9×10^{-283}	1.883107	1.883108	1.883107	1.883108
X Variable 1	4.48×10^{-09}	1.29×10^{-08}	0.346991	0.730115	-2.1×10^{-08}	3.04×10^{-08}	-2.1×10^{-08}	3.04×10^{-08}

The slope of the regression line was **4.5×10^{-9}**, with a p-value of **0.73011**, which is greater than the 0.05 threshold. The 95% confidence interval for the slope ranged from **-2×10^{-8}** to **3×10^{-8}**, confirming that the slope is **not significantly different from zero**. These results demonstrate that there is **no observable trend or drift** in the measurements results over the study period.

6. Measurement results and data analysis

This section contains measurement results submitted by the participating laboratories.

Standard uncertainty for the reported results of density measurements is calculated by dividing the submitted expanded uncertainty for 95 % probability by 2.

6.1 Distilled Water

The density of distilled water was measured once by each participating laboratory, with results normalized to 20 °C and 101 325 Pa.

Results of the distilled water density measurements and associated expanded uncertainties with coverage factor k=2 submitted by the participating laboratories are given in **Table 6**.

Table 6 Results of Distilled Water density measurements by partacipating laboratories and its expanded uncertainties

Participating Laboratory	Distilled Water at 20 °C and atmospheric pressure of 101325 Pa, g/cm^3 (Xi)	Expanded uncertainty K=2, g/cm^3 $U(Xi)$
NIS	0.998202	0.000012
KEBS	0.998213	0.000052
TBS	0.99799	0.00028
UNBS	0.9979	0.0004
SASO-NMCC	0.998205	0.000018

Results of the distilled water density measurements obtained by all participating laboratories at 20 °C and atmospheric pressure of 101325 Pa as well as the reference value (red dashed line) are shown in **Figure 5**. The uncertainties are for a confidence level of 95%.

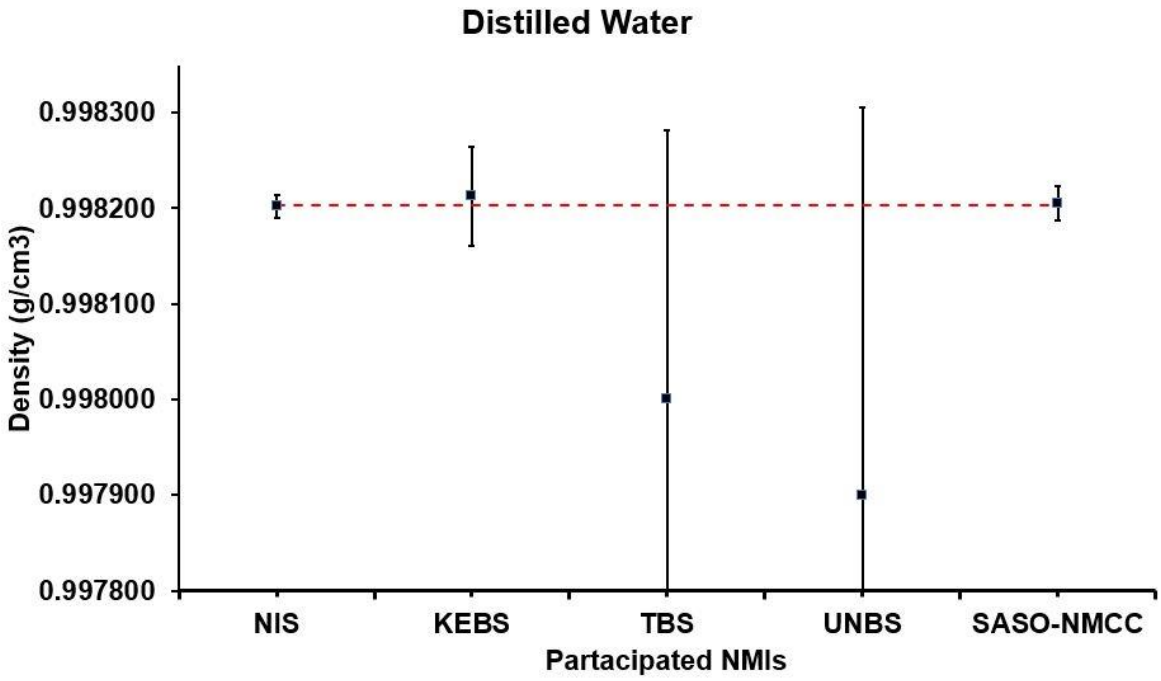

Figure 5 The distilled water reported density results with corresponding expanded uncertainty

- It can be observed that in **Figure 5**, all reported densities are close to the consensus value (approximately 0.998203 g/cm³). The results from NIS, KEBS and SASO-NMCC show smaller uncertainty ranges, demonstrating high measurement precision.

- TBS, and UNBS reported larger uncertainties, particularly TBS and UNBS, reflecting greater measurement variability.

- Despite these differences, all results overlap within their expanded uncertainty intervals **Figure 5**, indicating acceptable agreement and no significant outliers for distilled water.

6.2 FC-40

Density measurement of FC-40 was performed once. The results were normalized to a temperature of 20 °C and atmospheric pressure of 101325 Pa.

Results of the FC-40 density measurements and associated expanded uncertainties with coverage factor k=2 submitted by the participating laboratories are given in in **Table 7**.

Table 7 Results of FC-40 density measurements by partacipating laboratories and its expanded uncertainties

Participating Laboratory	FC-40 at 20 °C and atmospheric pressure of 101325 Pa, g/cm^3 (Xi)	Expanded uncertainty K=2, g/cm^3 $U(Xi)$
NIS	1.883107	0.000013
KEBS	1.883161	0.000053
TBS	1.86512	0.00028
UNBS	1.8797	0.0004
SASO-NMCC	1.883109	0.000010

Results of the FC-40 density measurements obtained by all participating laboratories at 20 °C and atmospheric pressure of 101325 Pa as well as the reference value (red dashed line) are shown in **Figure 6**. The uncertainties are for a confidence level of 95%.

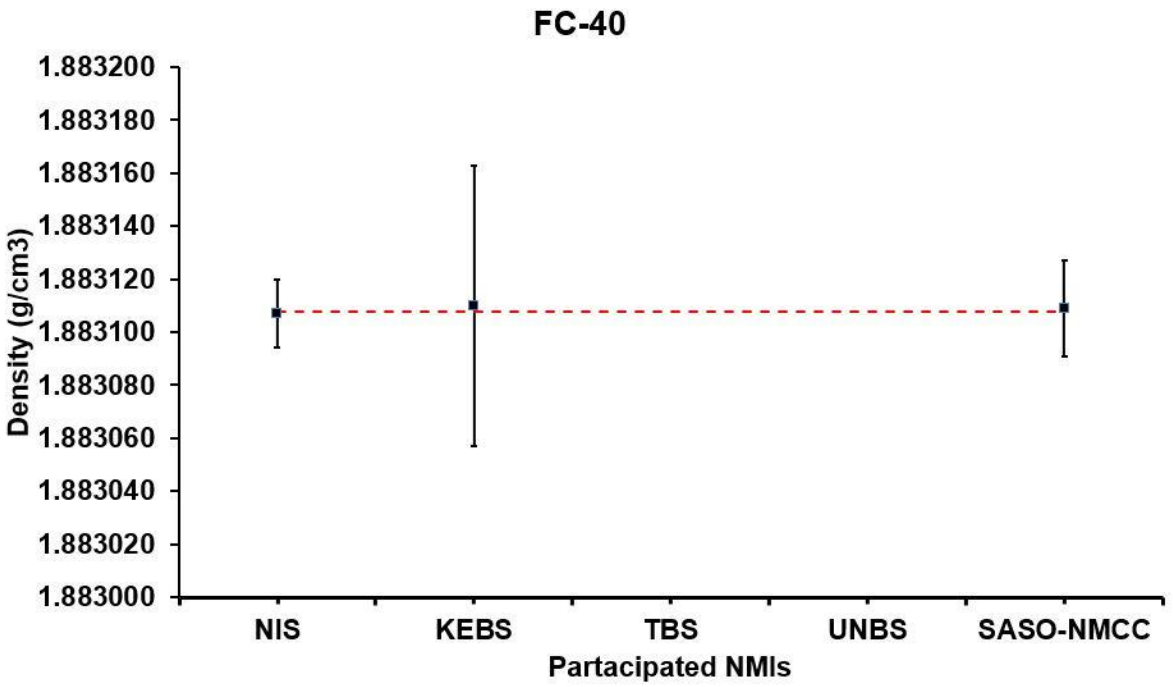

Figure 6 The FC-40 reported density results with corresponding expanded uncertainty

- The results from NIS, KEBS, and SASO-NMCC are in close agreement with the consensus value of approximately 1.883108 g/cm³, showing good consistency and relatively small expanded uncertainties.
- In contrast, the density values reported by TBS and UNBS deviate significantly from the consensus value and are therefore identified as outliers. Their results fall outside the expected range when considering the reported uncertainties, indicating potential systematic errors or measurement instability. These discrepancies may be attributed to temperature control issues, improper handling of the viscous FC-40 liquid, or differences in the applied measurement procedures.

7. Reference value of Supplementary Comparison

The reference value of the comparison was obtained from the use of least-squares adjustment.

7.1) Determine the weighted mean of the participating laboratories measurements, using the inverses of the squares of the associated standard uncertainties as shown in **Equation (1)**:

$$y = \frac{x_1/u^2(x_1) + \cdots + x_N/u^2(x_N)}{1/u^2(x_1) + \cdots + 1/u^2(x_N)} \qquad \textbf{(1)}$$

7.2) Determine the standard deviation u(y) associated with y from **Equation (2)**

$$\frac{1}{u^2(y)} = \frac{1}{u^2(x_1)} + \cdots + \frac{1}{u^2(x_N)} \qquad \textbf{(2)}$$

The estimated density values of standard liquids established as reference values of the Supplementary Comparison and associated standard uncertainties are given in Table 8.

Table 8 The reference values of the Supplementary Comparison and associated standard uncertainties

Liquid sample	Reference density values of liquid samples at 20 °C and atmospheric pressure of 101325 Pa, g/cm^3 (X_{ref})	Standard uncertainties of reference density values of liquid samples, g/cm^3 $u(X_{ref})$
Distilled Water	0.998203	0.000005
FC-40	1.883108	0.000005

8. Degrees of equivalence

The degree of equivalence *di* **[2]** for the result *Xi* of laboratory *i*, in relation to the reference value X_{ref}, was calculated using **Equation (3)** :

$$d_i = X_i - X_{ref} \qquad \textbf{(3)}$$

The expanded uncertainty $U(d_i)$ of the degree of equivalence was calculated using **Equation (4)**

$$U\left(d_i\right)=2\sqrt{u^2\left(X_i\right)+u^2\left(X_{ref}\right)} \qquad \textbf{(4)}$$

Where $u(X_i)$ and $u(X_{ref})$ are the standard uncertainties of density measurement results of a participating laboratory and the reference liquid density value respectively.

The participating laboratories degrees of equivalence in relation to the reference values and corresponding expanded uncertainties for two standard liquids are given in **Figure 7** and **Figure 8**.

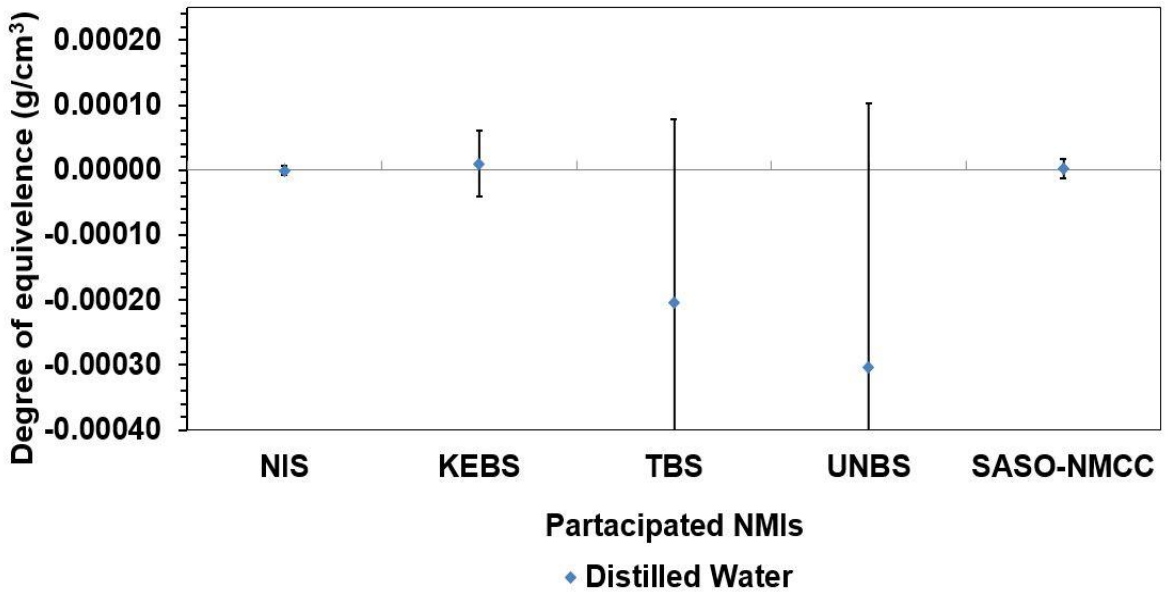

Figure 7 The participating laboratories degrees of equivalence in relation to the reference values and corresponding expanded uncertainties for distilled water density measurements

- NIS, KEBS, and SASO-NMCC results are consistent with the reference value, since their error bars overlap the zero line (meaning their results agree within uncertainty).
- TBS and UNBS show larger deviations from zero, indicating possible measurement discrepancies for distilled water density.
- The spread and uncertainty magnitude reflect each laboratory's measurement capability and consistency.

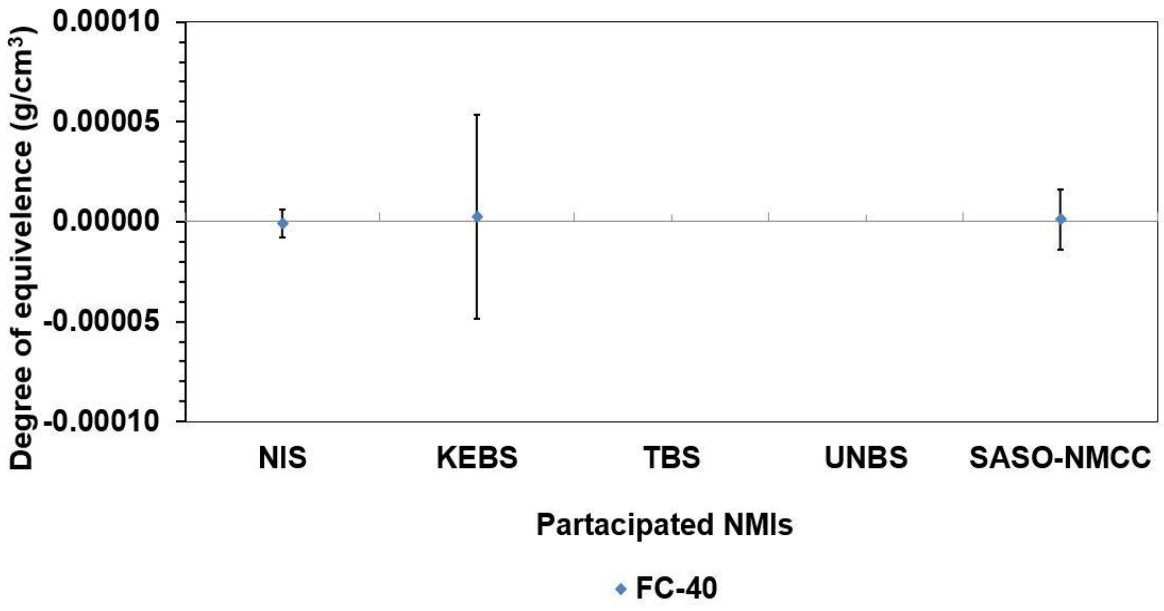

Figure 8 The participating laboratories degrees of equivalence in relation to the reference values and corresponding expanded uncertainties for FC-40 density measurements

- The results show that NIS, KEBS, and SASO-NMCC are in good agreement with the reference value, as their degrees of equivalence are close to zero and their uncertainty bars overlap the zero line.
- In contrast, TBS and UNBS results fall outside the equivalence range, indicating that their reported values significantly deviate from the reference value beyond their stated uncertainties.
- This means that TBS and UNBS are considered outliers in this comparison, suggesting possible issues such as calibration error, temperature instability, or improper handling of the FC-40 sample.
- Overall, except for TBS and UNBS, the remaining laboratories demonstrate good metrological compatibility in the determination of FC-40 density.

9. Confirmation of CMC data

the E_n criteria determined by Equation (5):

$$E_n = \frac{X_i - X_{\mathrm{Ref.}}}{\sqrt{u^2(X_i) - u^2(X_{\mathrm{Ref.}})}} \qquad \textbf{(5)}$$

If the condition Equation (5) is met less than 1 as shown in Equation (6)

$$E_n < 1 \qquad \textbf{(6)}$$

the minimum standard uncertainty **[3]** that can be declared by a participating Laboratory as CMC as shown in Equation

$$u(CMC) = u(X_i) \qquad \textbf{(7)}$$

Measurement results *Xi*, corresponding standard uncertainties *u(Xi)* submitted by the participating laboratories; in relation to the reference value of the supplementary Comparison X_{ref}; their standard uncertainties $u(X_{ref})$. Criteria values (En) and expanded uncertainties U(CMC) of the participating laboratories are given in **Table 9** and **Table 10.**

Table 9 Distilled Water En-Value

Distilled Water, 20 °C			
	X_{ref}, g/cm^3	$u(X_{ref})$, g/cm^3	
	0.998203	0.000005	
Laboratory	X_i, g/cm^3	$u(X_i)$, g/cm^3	**En**
NIS	0.998202	0.000006	0.08
KEBS	0.998213	0.000026	0.18
TBS	0.9980	0.000141	0.72
UNBS	0.9979	0.000203	0.75
SASO-NMCC	0.998205	0.000009	0.08

Table 10 FC-40 En-value

FC-40, 20 °C			
	X_{ref}, g/cm^3	$u(X_{ref})$, g/cm^3	
	1.883108	0.000005	
Laboratory	X_i, g/cm^3	$u(X_i)$, g/cm^3	En
NIS	1.883107	0.000006	0.05
KEBS	1.883110	0.000027	0.04
TBS	1.8651	0.000142	63.07
UNBS	1.8797	0.000211	8.05
SASO-NMCC	1.883109	0.000009	0.06

10.Conclusion

- The main objectives of this AFRIMETS supplementary comparison were the evaluation of the degree of equivalence between four participants from AFRIMETS NMIs (NIS, KEBS, TBS and UNBS) and one participant from GULFMET NMI (SASO-NMCC) in measuring the densities of two liquids (Distilled Water and FC-40). The measurements were performed at 20 °C and standards atmospheric pressure 101325 Pa.

- The stability and homogeneity of the reference liquids were verified by the Pilot Laboratory (NIS, Egypt), which found no significant drift or inhomogeneity during the measurement period. Therefore, the influence of these factors was considered negligible in the uncertainty evaluation.

- For distilled water sample can be observed that all reported densities are close to the consensus value (approximately 0.998203 g/cm³). The results from NIS and SASO-NMCC show smaller uncertainty ranges, indicating higher measurement precision. In contrast, TBS and UNBS exhibit larger uncertainty intervals, suggesting greater measurement variability. Despite these differences, all laboratories' results overlap within their expanded uncertainty intervals, demonstrating good overall agreement among participants.

- For FC-40 sample The results from NIS, KEBS, and SASO-NMCC are in close agreement with the consensus value of approximately 1.883108 g/cm³, showing good consistency and relatively small expanded uncertainties. In contrast, the density values reported by TBS and UNBS deviate significantly from the consensus value and are therefore identified as outliers. Their results

fall outside the expected range when considering the reported uncertainties, indicating potential systematic errors or measurement instability. These discrepancies may be attributed to temperature control issues, improper handling of the viscous FC-40 liquid, or differences in the applied measurement procedures.

- Overall, the comparison confirmed that the participating laboratories, with the exception of TBS and UNBS in FC-40 measurements, demonstrated metrological equivalence in the field of liquid density determination using oscillation-type density meters. The results provide a reliable basis for maintaining and supporting the participants' Calibration and Measurement Capabilities (CMCs) in density metrology within the AFRIMETS and GULFMETS regions.

11.References

[1] CCM Key Comparison CCM.D-K2. Comparison of liquid density standards. Final Report.

[2] G. Cox, The evaluation of key comparison data, Metrologia, 2002, vol. 39, pp. 589-595

[3] Guide to the expression of the uncertainty in measurement