

21GRD06 MetCCUS

Paper on the measurement of the thermophysical properties of CO₂ mixtures for CCUS (with target uncertainties: for density better than 0.1 %, for specific heat capacity better than 1 %, for viscosity less than 3 %, for speed of sound in liquid better than 0.05 %, for gas phase at high temperature 0.03 %) submitted to an open access peer-reviewed journal

D7 - A4.1.5

Organisation name of the lead participant for the deliverable:

Istituto Nazionale di Ricerca Metrologica
and

S. Lago (INRiM), P. A Giuliano Albo (INRiM) and A. Quattrone (INRiM),
A. Moreau (UVa), X. Peredes (UVa), F. Vélez (UVa),

Due date of the deliverable:

01.04.2025

Actual submission date of the deliverable:

23.10.2025

Confidentiality Status: PU - Public, fully open (remember to deposit public deliverables in a trusted repository)

Deliverable Cover Sheet

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or EURAMET. Neither the European Union nor the granting authority can be held responsible for them.

European Partnership



Co-funded by
the European Union

The project has received funding from the European Partnership on Metrology, co-financed from the European Union's Horizon Europe Research and Innovation Programme and by the Participating States.

**METROLOGY
PARTNERSHIP**



1 Thermodynamic properties of carbon dioxide and amine
2 binary mixtures for CCUS

3 S. Lago^a, A. Moreau^b, A. Quattrone^a, X. Paredes^b, F. Vélez^b, P. A. Giuliano
4 Albo^a

5 ^a*Istituto Nazionale di Ricerca Metrologica (INRiM), Strada delle Cacce 91, 10135 Torino,*
6 *Italy*

7 ^b*TermoCal Research Group, Bioeconomy Research Institute BioEcoUVa, University of*
8 *Valladolid, Paseo del Cauce 59, 47011 Valladolid, Spain.*

9 **Abstract**

10 Accurate knowledge of the thermophysical properties of CO₂-rich systems is
11 crucial for ensuring the successful deployment of CCUS technologies across Eu-
12 rope. Understanding the thermophysical properties of carbon dioxide mixtures
13 with a range of potential impurities reveals gaps between the experimental data
14 required for the systems design and operation.

15 In this context, important experimental properties were measured for CO₂ +
16 monoethanolamine and CO₂ + diethanolamine binary mixtures, supporting the
17 development of more refined and accurate formulations of dedicated equations
18 of state.

19 **1. Materials for CCUS**

20 Monoethanolamine (MEA) and diethanolamine (DEA) are, among the most
21 common alkanolamines, used in sour gas absorption technology. Their abil-
22 ity to chemically absorb carbon dioxide via exothermic reactions makes them
23 vital components in carbon capture, utilization, and storage (CCUS) technolo-
24 gies. Furthermore, MEA and DEA serve as benchmarks in evaluating new
25 CO₂ absorbent materials. Their established performance, combined with well-
26 documented limitations, make them reference points for thermodynamic mod-
27 elling and optimization of next-generation solvents. Current research in CCUS
28 aims to discover or develop alternative solvents with improved thermal sta-
29 bility, reduced regeneration energy, and lower corrosiveness, while maintaining
30 comparable absorption capacities. In this context, a deeper thermodynamic un-

Email address: s.lago@inrim.it (S. Lago)

31 derstanding of these substances contributes to the ongoing effort to optimize
 32 CCUS technologies and transition toward more sustainable industrial practices.

33 2. Density measurements

34 For density ρ measurements, a vibrating tube densimeter was used. The
 35 working principle is based on the electromagnetic excitation of a U-shaped
 36 Hastelloy tube which contains a fluid inside, where the fundamental oscilla-
 37 tion period is function of the total mass of the system related with the fluid
 38 density. The periods were measured using a Keysight 53220A universal fre-
 39 quency counter, with 10^{-6} ms standard uncertainty over periods around 4 ms.
 40 In Fig. 1 it is possible to see an example to experimental results of density as
 41 function of pressure for MEA + CO₂ mixtures with $\alpha = 0.15 \text{ mol}_{\text{CO}_2}/\text{mol}_{\text{MEA}}$

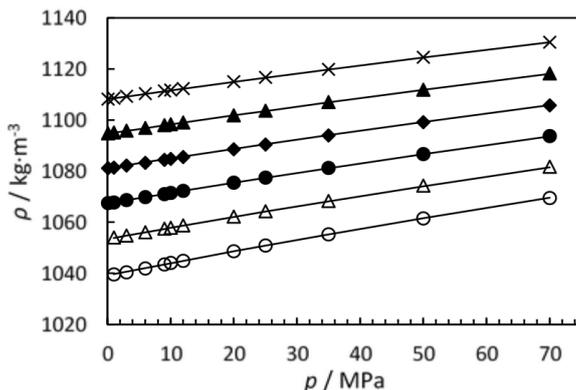


Figure 1: Experimental density as function of pressure for MEA + CO₂ mixtures: $\alpha = 0.15 \text{ mol}_{\text{CO}_2}/\text{mol}_{\text{MEA}}$; at temperatures: (x) 293.15 K; (▲) 313.15 K; (◆) 333.15 K; (●) 353.15 K; (△) 373.15 K; (○) 393.15 K. Lines represent the calculated values using modified Tammann-Tait equation.

42 Mixtures uncertainty analysis showed an expanded relative uncertainty bet-
 43 ter than 0.3 % for a 95.5 % level of confidence.

44 Density measurements of pure MEA, pure DEA, binary systems MEA + CO₂
 45 and binary systems DEA + CO₂ were performed at pressures from 0.1 MPa to
 46 70 MPa, six temperatures ranging from (293.15 K – 393.15 K) for MEA binary
 47 mixtures and four temperatures ranging from (313.15 K – 373.15 K) for DEA

48 binary mixtures. In all cases, densities were measured at three CO₂ loadings
 49 $\alpha = (0.15, 0.2 \text{ and } 0.3) \text{ mol}_{\text{CO}_2}/\text{mol}_{\text{amine}}$.

50 3. Speed of sound measurements

51 Speed of sound was measured using the traditional double *pulse-echo* method.
 52 This technique is based on a direct measurement of the transit time of a pulse
 53 signal, propagating over an independently known distance within the fluid.

54 This work presents speed of sound experimental results in samples of pure
 55 monoethanolamine, and in mixtures of MEA + CO₂ in three different con-
 56 centrations, with $\alpha = (0.15, 0.20 \text{ and } 0.30) \text{ mol}_{\text{CO}_2}/\text{mol}_{\text{MEA}}$; besides of pure
 57 diethanolamine, and in two binary mixtures composed of DEA + CO₂, with
 58 $\alpha = (0.15 \text{ and } 0.20) \text{ mol}_{\text{CO}_2}/\text{mol}_{\text{DEA}}$. Measurements were carried out in the
 59 temperature range between 293.15 and 393.15 K and for several pressures up to
 60 60 MPa, depending from the mixtures or pure fluid. In Fig. 2 it is possible to
 61 see the experimental speed of sound results as function of pressure for MEA +
 62 CO₂ mixture with $\alpha = 0.15 \text{ mol}_{\text{CO}_2}/\text{mol}_{\text{MEA}}$.

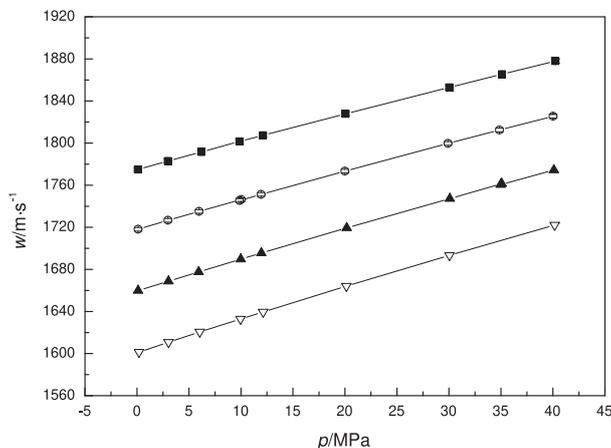


Figure 2: Experimental speed of sound as function of pressure for MEA + CO₂ mixture with $\alpha = 0.15 \text{ mol}_{\text{CO}_2}/\text{mol}_{\text{MEA}}$; (■) 313.15 K; (○) 333.15 K; (▲) 353.15; (▽) 373.15 K.

63 The uncertainty of the speed of sound measurements was 0.33 % as maximum
 64 value, obtained combining the contributions of the uncertainties of the quantities
 65 used to determine it.

66 **4. Conclusion**

67 The present work, part of a European Project “Metrology Support for Car-
68 bon Capture Utilisation and Storage” MetCCUS, aims to provide validated ref-
69 erence measurements and ensure the traceability of the results for thermophys-
70 ical parameters of binary mixtures of carbon dioxide and amines. The authors
71 are confident that these results will be useful for developing a more refined and
72 accurate formulation of a dedicated equations of state.

73 **5. Acknowledgements**

74 The research leading to these results has received funding from the European
75 Union on the basis of Decision No. 912/2009/EC in the frame of the EPM
76 “Metrology Support for Carbon Capture Utilisation and Storage” MetCCUS
77 (21GRD06 MetCCUS).