Good Practice Guidance *Note*

Buoyancy Correction and Air Density Measurement

Introduction

This Guidance Note gives recommendations of good mass measurement practice in calculating air density and buoyancy corrections but should not be considered a comprehensive guide.

Need for the Determination of Air Density

- Air is dense
    - A cubic metre of air weighs approximately 1.2 kilograms
    - A 1 kilogram stainless steel weight displaces 150 mg of air
- The density of air can vary between about 1.1 kg m^{-3} and 1.3 kg m^{-3}, which is equivalent to a change of 25 mg in the weight of a stainless steel kilogram of volume 125 cm^3.

What is the Typical Density of the Air?

- Standard air density is 1.2 kg m^{-3}
    - This is the approximate density of air at 20 °C, 1013.25 mbar and 50% Relative Humidity
- For the range of density quoted in OIML R111 [1] (1.2 kg m^{-3} ± 10%)
    - Temperature is 20 °C ± 5 °C
    - Pressure is 1013.25 mbar ± 60 mbar
    - RH is 50% ± 30%
- For a temperature controlled lab the range of air densities experienced will be less (typically 1.2 kg m^{-3} ± 5%)

Determination of Air Density

- The usual method of determining air density is to measure temperature, pressure and humidity and calculate air density using the equation recommended by the Comité International des Poids et Mesures (CIPM) (derived by Giacomo [2] and modified by Davis [3]). The equation is not a perfect model of air density and introduces an uncertainty of approximately 1 part in 10^4.
- Typical routine measurement capabilities for the air density parameters are indicated as follows with the best measurement capabilities in brackets:
    - Temperature to 0.1 °C (0.01 °C)
    - Pressure to 0.5 mbar (0.05 mbar)
    - Relative Humidity to 5% (0.25 °C dew point)
- The above parameters give a typical value on the air density (including the uncertainty from the equation) of 1 part in 10^3 (2 parts in 10^4 best capability)
- For lower accuracy measurements the NIST (simplified) air density formula can be used:

$$AD = \frac{[(0.348444 \times P) - h(0.00252t - 0.020582)]}{(273.15 + t)}$$

Where AD = Air density (kg m^{-3})
P = Air pressure (mbar)
h = Relative humidity of the air (%rh)
t = Air temperature (°C)

There is a typical uncertainty of 4 parts in 10^4 on this equation over the range of air density of 1.2 kg m^{-3} ± 10%

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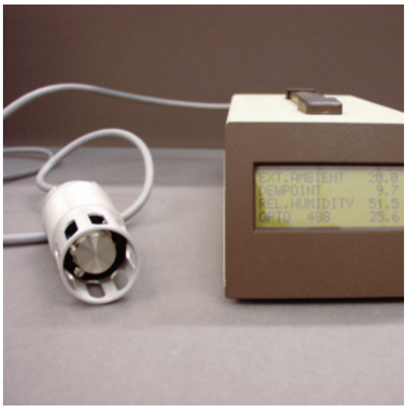
Druck Pressure Indicator



Protimeter Dew Point Meter

Edale model CD Thermometer

Figure 1: Typical Air Density Measurement Equipment

Air Density Artefacts

- The other common method for the determination of air density is to use artefacts of similar mass and surface area but different volumes.

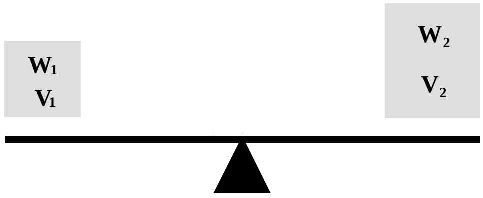
Figure 2: Air Density Artefacts

- The difference between the apparent weight of the artefacts is proportional to the density of the air in which they are compared.

Variation in Buoyancy Effect with Varying Air Density

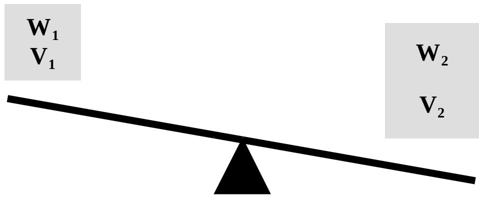
- **In Standard Air of density 1.2 kg m^{-3}**

W – Conventional mass (kg)
V – Volume (m^3)



If the conventional masses are equal ($W_1 = W_2$) the weights will balance in air of density 1.2 kg m^{-3}

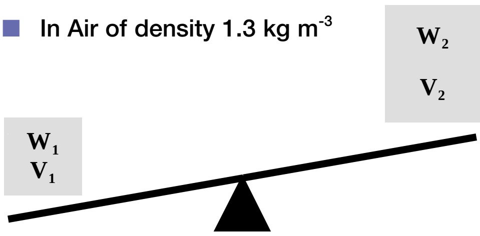
- **In Air of density 1.1 kg m^{-3}**



As the air becomes less dense the larger weight (W_2) will appear heavier

Apparent weight difference
= (V1 - V2) x (1.2 - 1.1) kg

- **In Air of density 1.3 kg m^{-3}**



As the air becomes more dense the larger weight (W_2) will appear lighter

Apparent weight difference
= (V_1 - V_2) x (1.2 - 1.3) kg

When Should I make a Buoyancy Correction?

- Always be aware of the magnitude of the buoyancy effect and take it into account in your uncertainty budget

Material Compared with Conventional Stainless Steel	Effective Buoyancy Correction (ppm)
Platinum-Iridium	-94
Brass	-8
Stainless Steel*	7.5
Aluminium	294
Silicon	365
Water	1050

Table 1: Buoyancy correction when comparing materials of dissimilar density in air

*A correction of up to 7.5 ppm may be necessary when comparing stainless steel weights of different densities

- Air buoyancy is most significant when:
  - Performing high accuracy mass calibration (weights of OIML Class E_2 and better)
  - For weights whose density is not close to 8000 kg m^{-3} (except small fractional weights)
  - For measurements of other materials and liquids
  - For measurements in environments other than normal air (density 1.1 kg m^{-3} to 1.3 kg m^{-3})

How do I make a Buoyancy Correction?

Comparing weight W of volume V_W with standard S of volume V_S in air of density AD.

- True mass basis (TM)

  $T_W = T_S + (V_W - V_S) \times AD$

- Conventional mass basis (CM)

  $C_W = C_S + (V_W - V_S) \times (AD\text{-}1.2)$

What do the OIML Specifications say?

- OIML R111 [1]
  - "The density of the material used for weights shall be such that a deviation of 10% from the specified air density (1.2 kg m^{-3}) does not produce an error exceeding one quarter of the maximum permissible error."
- Thus:
  - OIML tolerance for weights > 100 grams of class E_2 is 7810 kg m^{-3} to 8210 kg m^{-3}
  - Maximum error is: $T_S \times \left(\frac{1}{7810} - \frac{1}{8000}\right) \times (1.32 - 1.2)$
  - Or 0.365 mg on 1 kg (maximum allowable error 1.5 mg)
- But:
  - The normal uncertainty quoted on an E2 kilogram is 0.5 mg therefore the buoyancy error is significant
  - The buoyancy error is however, less significant in an air density range of 1.18 to 1.22 for a controlled laboratory environment.

Conventional and True Mass

- True mass
  - A measure of the amount of substance of an artefact
  - The constant of proportionality between F and g (F=mg)
  - Measured by comparison between the masses of artefacts (and defined by the mass of the international prototype kilogram)

- Conventional Mass
  - For a weight taken at 20 °C, the conventional value of mass is the mass of a reference weight of a density of 8000 kg m^{-3} which it balances in air of density 1.2 kg m^{-3} (OIML Recommendation R33 [4])
  - How they are related

    $M_T = M_C + (V_{8000} - V_W) \times 1.2$

- When should they be used?
  - Conventional mass
    - For all OIML class weights (generally)
    - For standard weights (or artefacts) whose density is close to 8000 kg m^{-3}
  - True Mass
    - For the highest accuracy mass calibration
    - For weights whose density is not close to 8000 kg m^{-3} (except small fractional weights)
    - For measurements of other materials and liquids
    - For measurements in environments other than normal air (density 1.1 kg m^{-3} to 1.3 kg m^{-3})

Figure 3: 1 kg of Stainless Steel compared with 1 kg of platinum-iridium

Related Good Practice Guides

- Guide to the measurement of mass and weight
- Guide to the measurement of pressure and vacuum
- Guide to the measurement of force
- Good Practice Guide on Cleaning, Handling and Storage of Weights
- Good Practice Guidance note on Thermal Effects on Balances and Weights

References

[1] International Organisation of Legal Metrology (OIML). International Recommendation No 111: 1994. Weights of classes E1, E2, F1, F2, M1, M2, M3.

[2] Giacomo P. “Equation for the density of moist air”. Metrologia, 1982, 18, 33-40.

[3] Davis RS. “Equation for the density of moist air”. Metrologia, 1992, 29, 67-70.

[4] International Organisation of Legal Metrology (OIML). International Recommendation No 33: 1979. Conventional value of the result of weighing in air.

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