Density Measurement with the Mettler/Paar DMA 40

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Liquid density can be measured using the Mettler/Paar DMA 40 Digital Densitometer, which consists of a U-shaped tube horizontally immersed in a water-filled chamber. The temperature of the chamber can be controlled by connecting the densitometer to the Fisher Constant Temperature Circulator Water Bath.

The densitometer does not show the density directly; instead, it displays the "weight" of the tube filled with the fluid of interest. At a given temperature, the square of this weight reading is a linear function of the density:

$$\frac{\rho_l - \rho_a}{\rho_w - \rho_a} = \frac{W_l^2 - W_a^2}{W_w^2 - W_a^2} \tag{1}$$

or

$$\rho_l = \frac{W_l^2 - W_a^2}{W_w^2 - W_a^2}(\rho_w - \rho_a) + \rho_a \tag{2}$$

where ρ is density, W is the weight reading. Subscripts l, a, w represent that the fluid is the liquid, air, and distilled water, respectively. Note: all terms in Eq. 2 must be at the same temperature. Thus, to calculate the liquid density (ρ_l), it is necessary to calibrate the densitometer with air and distilled water. Density of air and distilled water can be obtained from the CRC handbook (Weast, 1986). At 1 atm, the density of air is:

$$\rho_a = 0.001293/(1 + 0.00367T) \tag{3}$$

and the density of distilled water is:

$$\rho_w = 1.30753\times10^{-8}T^3 - 5.44149\times10^{-6}T^2 - 6.00025\times10^{-6}T + 1.00039 \tag{4}$$

where T is in °C, and ρ in g/ml. Equation 4 is a fitted curve based on data from CRC handbook.

The following steps are recommended for accurate density measurements:

Set the constant temperature bath

Turn on the water bath circulator, adjusting the temperature control knob to the temperature desired. It will take time to reach equilibrium. Continually check the thermometer and fine-tune using the control knob until the desired temperature is

reached. The actual temperature during each measurement should be recorded. If densities over a range of temperatures are required, start from the lowest temperature and increase slowly to the highest temperature desired, making intermediate measurements as needed. Errors from evaporation and/or gas bubble formation should be avoided.

Clean the U-tube

Before any calibration or measurement, the tube must be completely clean. To remove oil, wash the tube thoroughly by injecting toluene followed by acetone until the outflow is colorless (hold a beaker at the lower outflow port to collect effluent). Use a 3-cc plastic syringe to force out the rest of acetone from the tube, then use the built-in pump to dry the tube by pumping air through it for at least one minute. Turn off the pump.

Calibrate the densitometer

The densitometer should be calibrated periodically, although it is not required each time a measurement is taken.

1. Clean the tube as described above.

2. Measure weight reading for air (W_a): With nothing inside the tube, set the water bath to the desired temperature. Allow the reading to stabilize (changes in the five-digit read-out should be no more than ±1 in the least significant digit) before recording the weight. Weights should be recorded with the built-in light and pump turned off to eliminate heating and unwanted fluctuations. If the temperature is lower than ambient, condensation can occur. Blow air through the tube to remove any moisture, then turn the pump off and take the weight reading as quickly as possibly. Measure W_a over the desired temperature range (10-70°C should be adequate in most cases).

3. Measure weight reading for distilled water (W_w): Fill a 3-cc plastic syringe with distilled water from which gas has been removed under vacuum. Eject the extra air from syringe. Attach the syringe (without a needle) to the upper port of the U-tube. Inject water slowly into the tube until it begins to overflow from the lower port, collecting the overflow in a small beaker. It is essential that there are no air bubbles anywhere in the tube. Injecting the water slowly can reduce air bubble trapping. Use the built-in light to check for air bubbles. If air bubbles are trapped, inject more water to displace them out. The syringe can be used to remove the water after measurements are completed. Flush the tube with acetone and dry by pumping air through it.

Calibrations should be compared to the following empirical equation that are based on previous experience:

$$W_a = -1.94283T + 3.26449 \times 10^4 \qquad (5)$$

$$W_w = -4.65068\times10^{-2}T^2 - 2.69663T + 4.30630\times10^4 \quad (6)$$

where T is in °C.

Measure liquid density

1. Clean the tube as described above.

2. With the U-tube and sample at ambient temperature, fill a 3-cc plastic syringe with about 2 ml of the liquid to be measured, attach the syringe to the U-tube's upper port, and fill the tube slowly (as described above for distilled water). Leave the syringe attached during the measurement to reduce evaporation and to serve a source of additional liquid, if needed. Turn the light on to check for air bubbles. If air bubbles are observed, displace them by injecting additional liquid. Turn out the light before recording measurements.

3. Adjust water bath temperature to the desired temperature. After the temperature has equilibrated and the read-out has stabilized (changes in the five-digit read-out of no more than ±1 in the least significant digit) record W_l. Reset the temperature and repeat as needed. At each step, turn the light on to check for bubble formation. If gas bubbles begin to form, discontinue measurements. Turn out the light before recording measurements. If the temperature is reduced, it may be necessary to inject additional liquid to keep the tube completely full.

4. After measurements are completed, withdraw the liquid into the syringe. Use toluene followed by acetone to clean the tube, then dry it with the pump. Turn the densitometer and water bath off. Please readjust the temperature knob on water bath to 20°C.

Calculate density

Use Eqs. 3 and 4 to calculate densities of air and water; weights of air and water are either measured or obtained from Eqs. 4 and 5. Use Eq. 2 to calculate liquid density at the corresponding temperature based on measured weight reading for liquid. A worksheet (MS-Excel format) is available for these calculations.

Reference

Weast, R.C.: *CRC Handbook of Chemistry and Physics*, 68th ed. (1987) CRC Press, Inc.