Magnetic float densitometer — A modified version

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Four major modifications have been introduced in the magnetic float densitometer of F J Millero’s Design. Namely, Pt-point in place of blue fused glass at the lower end of the float; light focusing arrangement to add in view instead of using magnifying glass only; modified electrical circuitry and introduction of ferrite core inside the cylinder to increase the efficiency of the coils. These modifications have improved the working of the float considerably. Operation and taking observations have become simpler.

There are several methods to measure the densities of liquids and salt solutions such as by density bottle, pyknometer, dilatometer etc. None of these methods give very accurate density values of solutions, at least, in the very dilute solution range. The reasons being that these methods have three fundamental drawbacks. In the first place it is difficult to secure a constant and definite temperature inside a considerable volume of unstirred liquid. Secondly, because of variations in the humidity of their surfaces, glass vessels are always difficult to weigh with the utmost accuracy. Thirdly, the apparatus, with its contents, puts a considerable load upon the balance arm and so reduces the sensitivity of balance. All these three unfavourable effects increase with increasing size of the apparatus and hence it is useless to attempt to get the accurate values with a large apparatus.

In 1894 Kohlrausch and Hallwach¹ gave displacement method to measure the densities of liquids and salt solutions. Hallwach’s refinement of the displacement method escapes these three objections. Unfortunately a fresh difficulty of pronounced surface tension at liquid gas surface arose. Kohlrauch and Hallwasch² reduced this surface tension effect by depositing platinum black on the suspension wire. The surface tension effect of the suspension wire was reduced but not completely eliminated. But this method gave much better results as compared to other ordinary methods.

The submerged sinker method of Pisati and Reggiani¹ had no suspension wire and so had no problem of surface tension at liquid gas surface. The submerged sinker method is thus superior to the displacement method. Its one drawback lies in the difficulty of varying the buoyancy of the sinker by small amounts. If this variation in buoyancy is to be secured by the addition or removal of weights, then it is necessary to use weights as small as hundredth of a milligram which is evidently impractical. This difficulty was overcome by Lamb and Lee⁴ by using external electromagnetic attraction in vertical direction by using electric current outside the bulb of the sinker, in which a soft iron core was placed. Various other workers⁵–⁸ have modified this method by using a magnetic core inside the float; however, in principle, the method being the same. Millero⁹ further improved the method and made it more sensitive and modest in cost. We have further improved Millero’s model of densitometer by making four changes in his design. These modifications are: blue fused glass has been replaced by a sharp platinum point at the bottom of the float; light focusing arrangement has been introduced to add in view of the platinum point instead of using magnifying glass only; a modified electrical circuitry has been incorporated in the design and lastly Ferrite core inside the solid cylinder concentric to the coils and cylinder itself has been used. These changes have improved the working and efficiency of the instrument considerably and enabled the observer to use it
conveniently. The details of the principle involved and different components used therein, are being given here.

Magnetic Float Densitometer

This densitometer has been designed to measure the densities of various salt-solutions in aqueous and few non-aqueous solvent media. The description of the design and improvement made therein is divided into four categories (i) description of magnetic float densitometer; (ii) circuit diagrams; (iii) working and procedure and (iv) calibration and measurement of densities of solutions.

Description

The basic design and different components used in the densitometer are almost the same as that given earlier by Millero except few changes which are needed for the modification.

The float is made of Pyrex glass. A permanent magnet is introduced before sealing it. Blue glass used at the lower end of the float by Millero was not giving clear visibility of the field so it is replaced by a fine platinum point. With the aid of light focusing arrangement, this platinum wire helps in ascertaining the position of the float when it touches the bottom. To make the float fit for running in the solutions of various density values, few Pb-shots were added to adjust the weight of the float so that a critical density value (\(W=77.4240\)g and \(p = 0.94\)g/mL for our purpose) was obtained for adjusting the buoyancy force of the solution.

The solution container was also made of Pyrex glass. The design of the container is so chosen as to make the float to move freely up and down inside it. The top of the container has a glass cover fitted with a stop cock.

The support and levelling platform are made of brass. The support has a hole drilled into it to hold the solution container. The bottom of the hole has a cross-window for viewing the platinum point of the float, when it touches the bottom of the solution container. Two windings made of enameled Cu wire are provided in brass support under the cross window. One winding which is near the cross-window works as pull down solenoid and other, just little downward, works as main solenoid. To increase the efficiency of the coil a ferrite core is also introduced at the center of the brass support. The upper part of this ferrite core is surrounded by pull down solenoid and lower, by the main solenoid (Fig. 1). The ferrite core concentrates the magnetic lines of force at the center and thus provides sufficient magnetic attraction on the float. If only coils were used, as done by Millero, very weak attraction force was available which was not too sufficient to control the motion of the float properly.

A telescope is used to view the movement of the float when its platinum point touches the bottom of the solution container. To assist in observing the platinum point by telescope, light focusing device opposite the telescope is used. A focussed light is made to fall on the glass window of the densitometer with its help. This arrangement was not provided earlier in Millero’s model.

Circuit diagram (modified electric circuitry)

The whole circuit diagram is divided into three sections, namely, (i) Selection of number of turns of main solenoid section, (ii) Operation of the coils section and (iii) Battery ON/OFF section. Each section consists of six pin-push buttons. The battery section uses a set of two push buttons while the other two sections; each uses a set of three push buttons.

Selection of number of turns in the main solenoid

For changing the range and sensitivity of the instrument, the provision of changing the number of turns in the main solenoid is given. For this, the selection of 100, 200 or 700 turns can be done by
merely using a push button of this section. If button no. 1 is pressed down, it will connect the instrument to 100 turns, while others remain disconnected. Similarly button no. 2, if pressed down, connects the instrument to 200 turns, while others remain disconnected. In the present diagram, the selection of 700 turns is shown by push button no. 3 pressed downward, others are disconnected.

The resistance bridge used to change the current in main solenoid has been inserted in the main line between main solenoid and push buttons. The values of the components used in the bridge are same as that used earlier by Millero.

Joint operation of main and pull down solenoid

This section of electrical circuit provides the joint operation of the pull down and main solenoid. The section comprises of a set of three push buttons. Button no. 1, if pressed down, makes the pull down solenoid 'ON' (shown in Fig. 2 but not given). Button no. 2, if pressed down, makes both the coils 'ON' (shown in Fig. 3 but not given) while button no. 3, if pressed down, disconnects
Joint Operation of Main and Pull Down Solenoid

Selection of No. of Turns of Main Solenoid

Battery ON/OFF Section

This section consists of a set of two push buttons. Push button no. 1, if pressed down, makes both the batteries ‘OFF’. While push button no. 2, if pressed down, makes both the batteries ‘ON’. Thus observations are taken at push button no. 2 pressed down. The voltage for pull down solenoid is supplied by a 1.5V Eveready 6G Dry cell and for main solenoid, by two 12V Exide batteries used in parallel. The complete modified electric circuit can be obtained by the addition of Figs 2-4 to Fig. 5 through the corresponding coloured wires.

The laboratory set-up for operation of magnetic float densitometer is shown in Fig. 5.

Working

Suppose \( V \) and \( W \) are the volume and weight of the float and \( v \) and \( w \) are the volume and weight of platinum respectively. If the float with a platinum weight floats, completely immersed, in a solution of density \( \rho \) then according to Archimedes principle, the volume of the solution displaced will be equal to the sum of the volume \( V \) of the float and the volume \( v \) of the platinum weight, and the weight of the solution displaced will be equal to the sum of the weight \( W \) of the float and \( w \) of the platinum weight. That is,

\[
\text{Volume of the solution displaced} = V + v \\
\text{Weight of the solution displaced} = \rho (V + v)
\]

Therefore

\[
\rho(V+v) = W + w \\
\text{(1)}
\]

Now when current is passed in the main solenoid, a vertical attractive electromagnetic force is developed that pulls down the float to the bottom of the solution container. The current is adjusted in such a manner that the platinum point attached to the float touches the bottom of the solution container. The force exerted by the main solenoid is given by a constant times \( I \), the current passing through it. Let this constant be represented by \( f \) and named as ‘weight equivalent of current’. Now the effective weight of the float will be \( W + w + (f \times I) \) and Eq. (1) becomes

\[
\rho(V+v) = W + w + (f \times I) \\
\text{(2)}
\]
If \( \rho_p \) is the density of platinum weight, \( v = w/\rho_p \). Therefore

\[
\rho(V+w/\rho_p) = W + w + (f \times I)
\] ... (3)

Before measuring the density of solution, the densitometer is calibrated with pure water. For its calibration, platinum weights are added to the float so that it is just immersed in pure water. An attractive magnetic force is then exerted by passing current through the main solenoid so that the platinum point of the float touches the bottom of the solution container. This current is measured and is named as ‘hold down current’. Eq. (3) can be written for water as

\[
\rho_{H_2O}(V+w/\rho_p) = W + w + (f \times I)
\]

On rearranging

\[
w(1 - \rho_{H_2O}/\rho_p) = (-f \times I) + \rho_{H_2O} V - W
\] ... (4)

or

\[
w = \frac{-[f(1 - \rho_{H_2O}/\rho_p)] \times I + (\rho_{H_2O} V - W)(1 - \rho_{H_2O}/\rho_p)}{\rho_{H_2O} - \rho_p}
\]

This equation now resembles with \( Y = mX + C \) where

\[
m = -f(1 - \rho_{H_2O}/\rho_p) = \text{Slope of the line}
\]

and

\[
C = (\rho_{H_2O} V - W)(1 - \rho_{H_2O}/\rho_p) = \text{Intercept of the line on Y-axis}
\]

The system is calibrated at 25°C by measuring the hold down current when various platinum weights are added to the float. A graph is then plotted between the weights, \( w \) and the corresponding hold down current, \( I \). Using the known value of density of water and the density of platinum at 25°C, the value of the weight equivalent of current, \( f \), is calculated by using the slope of the line. Similarly using weight of the
Table 1—Calibration of magnetic float densitometer in pure water at 25°C

<table>
<thead>
<tr>
<th>Weights added, w (g)</th>
<th>Voltage drop across one ohm resistor, mV</th>
<th>Current, I (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.500</td>
<td>670</td>
<td>670</td>
</tr>
<tr>
<td>4.550</td>
<td>640</td>
<td>640</td>
</tr>
<tr>
<td>4.600</td>
<td>606</td>
<td>606</td>
</tr>
<tr>
<td>4.650</td>
<td>582</td>
<td>582</td>
</tr>
<tr>
<td>4.700</td>
<td>560</td>
<td>560</td>
</tr>
<tr>
<td>4.750</td>
<td>524</td>
<td>524</td>
</tr>
<tr>
<td>4.800</td>
<td>496</td>
<td>496</td>
</tr>
<tr>
<td>4.850</td>
<td>460</td>
<td>460</td>
</tr>
<tr>
<td>4.900</td>
<td>436</td>
<td>436</td>
</tr>
</tbody>
</table>

Fig. 6—Calibration curve

float \((W=77.4240\, g.)\) and intercept of the line, the volume of the float \(V\) at 25°C is calculated.

Now the densitometer is run in the solution of unknown density. The observations are taken as before. Various weights and corresponding hold down currents are noted. The density of the solution is, then, calculated by using Eq. (3) in the form

\[
\rho = \frac{(W + w + f x I)}{(V + w + \rho_{Pt})} \quad \ldots \ (5)
\]

The weight equivalent of current of the magnetic float densitometer is very important in deciding the range and sensitivity of the instrument. It can be varied by using various number of turns of copper wire in the main solenoid, for which the provision of different windings 100, 200 and 700 turns has been made in it. Thus by selecting proper value of number of turns, the suitable value of \(f\) can be selected which provides necessary range and sensitivity of the system. The main solenoid being little farther from the float, is not able to pull the float down. To assist in bringing the float in the region of magnetic field of main solenoid, another coil, just a little above it, is used. This coil, called the pull down solenoid, when switched ‘ON’ pulls the float down and brings it near another coil. Then the main solenoid takes control over the float and the action of pull down solenoid is finished. The attraction force exerted by the coils was very weak in Millero’s model as he had used coils without any core. This could not give sufficient concentration of magnetic lines of force at the center. Consequently the magnetic force of attraction was weak. We have inserted a ferrite core by drilling a hole into the brass support so that it fits exactly at the center and is surrounded by the coils. This system provides sufficient magnetic attraction for float. Though this instrument is suitable to measure the density of the solutions at different temperatures, we have set it for measuring the densities at 25°C only for our research work.

Procedure

The magnetic float was first weighed. The instrument was calibrated with double distilled water at 25°C. For this, the water was taken in the solution container. The system was kept in ‘Toshniwal constant temperature bath’ to maintain the equilibrium of water at 25±0.1°C. The weights were added to the float and the corresponding hold down current was measured by the method given below.

The keys K1 and K2 were kept closed. The number of turns in the main solenoid was selected by the top section of the circuit. We selected 700 turns by pressing push button no. 3 down (see, Fig. 4). Both the batteries were switched on by operating the battery section (Push button no. 2 pressed down). Then the middle section of the circuit was operated. This section controls the operation of both the coils. By pressing button no.1, pull down solenoid is ‘ON’. Push button no. 2 makes both the coils ‘ON’ and push button no. 3 breaks the circuit of pull down solenoid and only the main solenoid remains ‘ON’. The observations were taken at push button no. 3. The resistance bridge was adjusted by selecting proper values of the components so that the float just touched the bottom of the solution container. This was viewed
by telescope and light focusing arrangement. The reading of the voltage drop (in terms of millivolts) across one ohm resistor was taken by Philips Multimeter. This directly gave the magnitude of the current (in mA) flowing in the circuit, resistance being unity. Thus observations were taken for various weights on the float and noting the corresponding hold down current. The observations recorded are shown in Table 1.

Calibration and measurement of density of solution

A graph was plotted in weights, \( w \), versus current, \( I \) and shown in Fig. 6. The weight equivalent of current, \( f \), was calculated from the slope of the line \((m = -1.724 \text{ g/A})\) and volume of the float \( V \) was calculated by the intercept of the line on \( Y \)-axis as explained earlier. Here \( \rho_{\text{Pt}}^{25} \), the density of the platinum and \( \rho_{\text{H}_2\text{O}}^{25} \), the density of water at 25°C were taken from the literature\(^{10,11} \) as \( \rho_{\text{Pt}}^{25} = 21.482 \text{ g/mL} \) and \( \rho_{\text{H}_2\text{O}}^{25} = 0.99707 \text{ g/mL} \). The values of the weight equivalent of current and the volume of the float were found out to be \( f = 1.644 \text{ g/A} \) and \( V = 82.365 \text{ mL} \) at 25°C. After calibrating the system, the density of any unknown solution can be determined by Eq. (5) using the values of \( f \) and \( V \). The instrument was verified by known standard solutions of sodium chloride. The results were found to be in good agreement with the values reported earlier\(^9,12 \). The densities of several aqueous and non-aqueous solutions of tetraalkylammonium iodide salts were also determined using this technique.

Acknowledgement

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References

2 Kohlrausch F & Hallwach W, Wied Ann, 56 (1895) 184.
3 Pisati S & Reggiani N, Rend Reale Accad Lincei, 14(7) (1890) 19.