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BUOYANCY OF A FLOAT SUBMERGED IN A FLUID MEDIUM
Filed June 9, 1950 3 Sheets-Sheet 1

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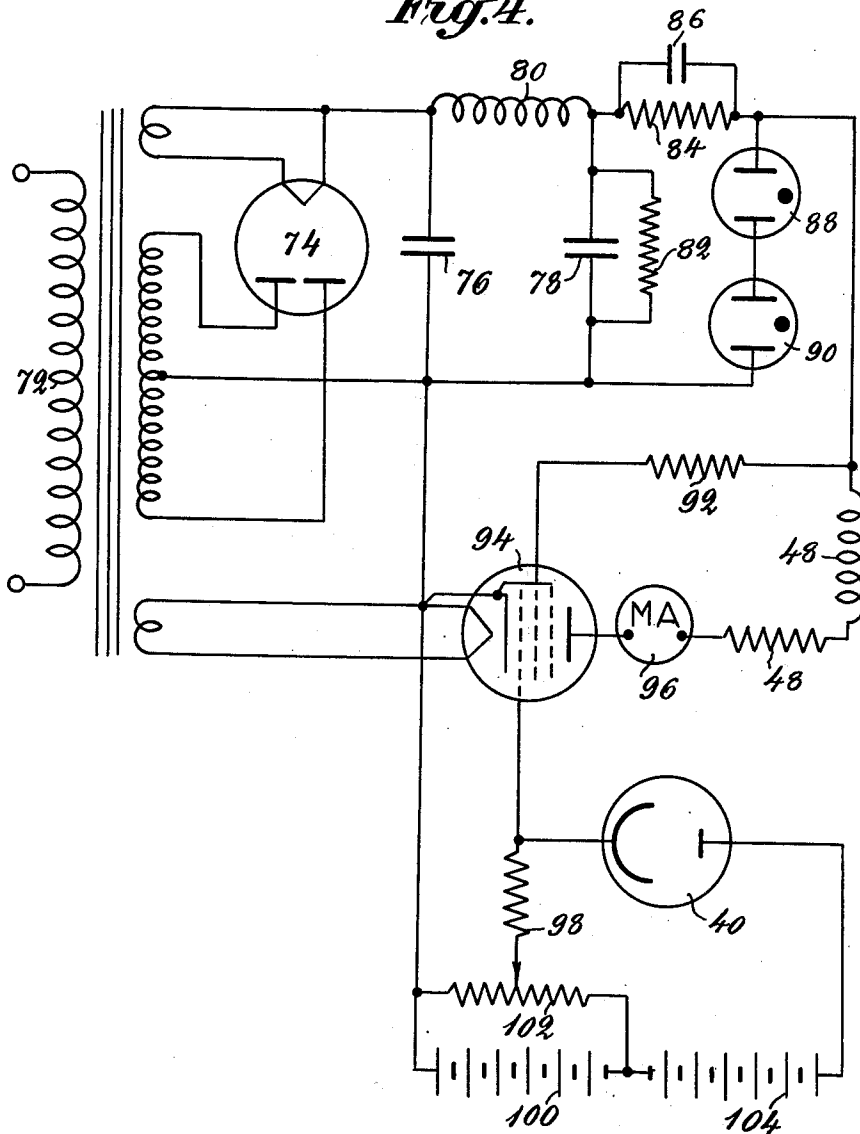
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Fig. 4.



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Fig. 5.

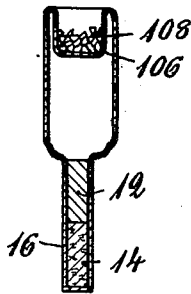


Fig. 6.

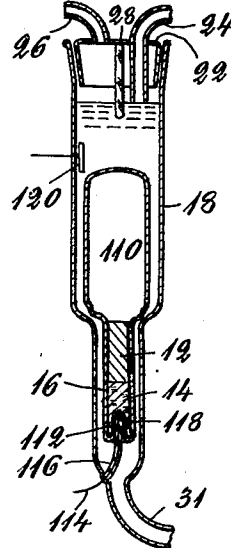


Fig. 7.

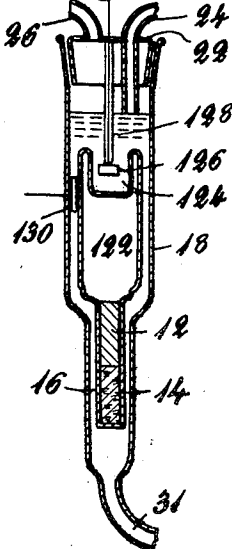
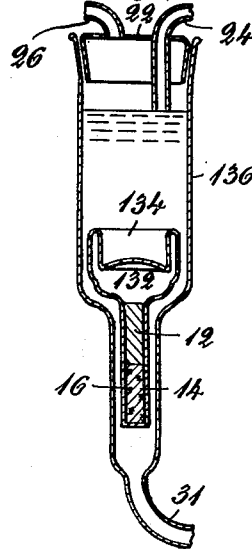


Fig. 8.



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UNITED STATES PATENT OFFICE

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PHOTOELECTRIC APPARATUS FOR DETERMINING THE EFFECTIVE BUOYANCY OF A FLOAT SUBMERGED IN A FLUID MEDIUM

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7 Claims. (Cl. 73—32)

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The present invention relates to the measurement of the lifting effect on a float and is of special interest in density determinations.

The primary object of the invention is to eliminate the errors caused by the surface tension effects on the thread suspending the sinker of a Westphal balance.

Another object of the invention is to make possible density measurements in which the medium to be measured is enclosed in a chamber which is closed from the surrounding atmosphere.

Another object of the invention is to make possible density measurements of gaseous media at different pressures.

When in the following specification and in the annexed claims the term float is used, it is intended not only to comprise bodies the average density of which is less than the density of the medium to be measured but also bodies with an average density greater than the medium to be measured.

The invention will be fully understood from the following description with reference to the accompanying drawings in which:

Figure 1 is a longitudinal, vertical, sectional view through an apparatus suitable for carrying the invention into effect;

Figure 2 is an enlarged transverse, vertical, sectional view through the suspension device at the right arm of the balance;

Figure 3 is a horizontal view on the central part of the balance-beam;

Figure 4 is a wiring diagram of the amplifying circuit;

Figure 5 is a longitudinal, vertical, sectional view through a float adapted for density measurements of solid particles;

Figure 6 is a longitudinal, vertical, sectional view through a float adapted for measurements of gas quantities, formed by electrode reactions;

Figure 7 is a longitudinal, vertical, sectional view through a float adapted for measurements of density changes caused by electrode reactions;

Figure 8 is a longitudinal, vertical, sectional view through a float adapted for sedimentation measurements in suspensions.

In order that the invention may be fully understood it will in the following be described in connection with a measurement of the density of a liquid, the density of which will be denoted by d .

Although, in the following description reference will be made to such a type of measurements, it will be understood that the present invention is not limited thereto.

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Referring more particularly to Fig. 1 of the drawings, numeral 10 indicates a float, preferably made of glass, containing a permanent magnet 12, that is supported by a cylinder of cork 14, and the latter is completely surrounded by black paper 16.

The float 10 is enclosed in the glass-vessel 18, that is surrounded by the thermostat jacket 20. The thermostat water enters through the inlet tube 19 and leaves the jacket 20 through the outlet tube 21. The vessel 18 is closed by a ground lid 22 through which passes a tube 24, the tube 26 ending at the lid, and the glass-rod 28. The vessel 18 is filled from the funnel 30 through the tube 31, and emptied through the tube 32 by turning the three-way stopcock 34.

The light from the lamp 36 is concentrated by the lens 38, and passes through the lower part of the vessel 18. There the light-beam is partly shaded by the float 10. The passing light falls upon the light-sensitive screen of the photo-tube 40, which is connected to the amplifying circuit 42, to be described in detail below in connection with Figure 4. From the circuit 42 the resulting direct current flows through the leads 44 via the balance-beam 46 to the coil 48, which is suspended from the right arm of the balance 50. The balance is fixed to a plate 52, which rests on a steady support, not shown in the figure.

An ordinary pan 54 with weights 55 is suspended from the left arm of the balance and that side is also provided with a damping device of ordinary construction, not shown in the figure. The balance can be referred to as a modified analytical balance of normal accuracy, 0.1 mg.

The jacket 20 is rigidly fixed to a steady support. The same holds for the lamp-house 37, in which the lamp 36 and the lens 38 are fixed and for the phototube 40. The above mentioned supports are not shown in the drawings. The circuit 42 is advantageously standing at the floor while the rest of apparatus is placed on a table, in order to avoid magnetic forces from the transformer in the circuit 42.

Referring to Fig. 2 of the drawings the numeral 46 denotes the balance-beam and 44 the two leads carrying the direct current to the coil. 56 denotes the support of the right terminal knife edge and 58 the right terminal knife edge. Two helices 60 of a very fine copper-wire connect the upper and lower parts of the leads 44. This connection has a negligible influence on the movements of the balance. 62 denotes a stainless steel wire which supports the coil.

Referring to Fig. 3 of the drawings, 46 denotes

as before the balance-beam, 64 is the fulcrum and 66 the support of the fulcrum. 68 and 70 are two helices of a very fine copperwire which connect the parts of the leads 44 which are fixed to the balance-beam 46. The helices 68 and 70 are wound in opposite directions in order to have a negligible influence on the movements of the balance.

Referring to Figure 4 of the drawings 72 denotes a transformer (prim. 220 v., sec. 600, 6.4 and 6.4 v.) which feeds the rectifier 74 with the main supply of 600 v. and 6.4 v. filament voltage. In addition the transformer 72 supplies the pentode 94 with the filament voltage 6.4. The pulsating direct current from the rectifier 74 is passed into a smoothing circuit consisting of two capacitors 76 and 78 of 8 μ f. each and the inductance 80 of 15 Hy. 82 is a resistance of 0.5 megohm for discharging the capacitors when breaking. The resistance 84 of 1 kohm and the capacitor 86 of 64 μ f. form a damping circuit for the current through the coil 48. The two glow discharge tubes 88 and 90 (RCA, VR 150) of 150 v. each form a voltage regulator. 92 is a resistance of 10 kohms in the screen grid circuit of the pentode 94 (6F6). The main current passes through the coil 48, consisting of an inductance and a resistance of 10 kohms, and through a milliamperemeter 96 to the anode of the pentode 94. The control grid is connected to the phototube 40 (RCA 925) and the resistor 98 of 150 megohms. The control grid bias is obtained from the dry battery 100 of 132 v. over the potentiometer 102 of 2 megohms. The dry battery 104 of 175 v. supplies the necessary voltage across the phototube 40.

In the following description of the method of operation of an embodiment of the invention, the float 10 is assumed to have an average density less than the densities of the reference medium and of the medium to be measured.

The operation of the device of Figs. 1, 2, 3 and 4 is now to be described by way of example in connection with a density determination of a liquid. The float 10 is first weighed in air of known density, suitably by suspending it from the coil by copper wires, as weighing on an ordinary balance may be erroneous due to ferromagnetic materials often included in the balance construction. After lifting the balance beam from its fulcrum, the float 10 is placed in the vessel 18, the lid 22 placed in position, the tube 24 connected with an aspirator, the thermostat jacket inlet tube 19 connected to the pressure side of a pump circulating water from a thermostat to which the outlet tube 21 is connected. The funnel 30 is then filled with a suitable reference liquid with an accurately known density at the actual temperature e. g. water, the stopcock 34 is turned so as to let the liquid flow into the vessel 18, whereby the suction at the tube 24 secures a constant level of the liquid in the vessel 18. The tube 26, which is left open, prevents any changes of the pressure due to the suction. The aspirator connected to the tube 24 is shut off as soon as the funnel 30 is emptied. The float is prevented from swimming up to the surface of the liquid by the glass-rod 28 in order to avoid too great a distance between the magnet 12 and the coil 48.

When the float 10 is in contact with the glass-rod 28 the lightbeam from the lamp 36 is not screened off by said float and the phototube 40 gets full illumination. The resistance of said phototube is greatly diminished and the control grid of the pentode 94 gets a more positive voltage

with respect to the cathode, said voltage being supplied by the battery 104. Consequently a relatively strong current will flow through the pentode 94 and through the coil 48. Said current generates a strong vertical electromagnetic field attracting the magnet 12 of the float 10. The float 10 moves downwards and screens off said lightbeam more and more. This results in a diminishing illumination of the phototube 40 and a corresponding decrease of the control grid voltage followed by a diminishing current through the coil 48. Owing to the inertia of the float 10, it will overshoot the equilibrium position and screen off the lightbeam to such an extent that the resulting magnetic force becomes less than the buoyancy and accordingly the float 10 will start an upward movement. This tendency to an undamped oscillating motion is suppressed by the damping circuit consisting of the resistance 84 and the capacitor 86. After a few oscillations the float is resting in an equilibrium position. It is to be noted that even small variations of the line voltage supplying the primary side of the transformer 72 and the lamp 36 will cause disturbing and uncontrolled oscillations of the float 10. In order to avoid this said two elements are fed from a constant-voltage transformer not shown in the drawings. Moreover the two glow discharge tubes 88 and 90 in connection with the resistance 84 form an additional voltage regulator.

By means of the variable resistance 102 the relation between the illumination of the phototube 40 and the current through the coil 48 can be changed within certain limits.

When the float 10 has reached its equilibrium position the balance-beam is lowered upon its fulcrum and the weighing is accomplished without influencing the final magnetic attraction force in equilibrium position, said force being the magnitude measured by the weighing operations. With the sliding contact of potentiometer 102 in the extreme position to the left as viewed in Fig. 4, the grid and the cathode of tube 94 have the same voltage and accordingly even minute illumination of the phototube 40 will cause a strong current through the coil 48. This potentiometer adjustment is used when measuring dark colored or nearly opaque liquids. For more lightly colored or clear liquids, the sliding contact is moved to the right of said potentiometer 102 to give a more or less negative bias voltage on the grid with respect to the cathode. In this case more light is required to activate the pentode 94 and thereby the coil 48. At the start of the weighing operation an increase of the current through coil 48 can be achieved by moving the contact to the extreme left in order to bring down the float 10 from its position in contact with the glass rod 28 to the vicinity of the equilibrium position. On the other hand, the reduction in light sensitivity by moving the contact to the right in Fig. 4 has been found to give a better damping of the oscillations of the float 10.

The dead weight of the coil 48 and its supporting structure, with no current through the coil, is known from prior measurements or may be determined by a further measurement. The difference between the apparent weight of the coil 48, when measured as above described with current therethrough to maintain the float 10 in equilibrium, and its actual dead weight gives the apparent weight of the float 10 in the reference liquid. Denoting the apparent weight of the float 10 in air with A, the density of air with α , the apparent

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weight of the float in the reference liquid with W , the density of the reference liquid with w , and the density of the material of the weights with b , the following expression holds for the volume V of the float 10:

$$V = \frac{(A-W)(b-a)}{b(w-a)} \quad (1)$$

It should be pointed out that in this equation the force of gravity is considered positive downwards. As in this case the average density of the float 10 is less than the density of the liquid the weight W should be inserted in the above equation with negative sign. With numeral values for the symbols A and W of Equation 1 thus measured, and values for the symbols a , b and w taken from tables of physical constants, all symbols at the right side of Equation 1 may be replaced by numerical values and the equation may be solved to determine the volume V of the float 10.

The reference liquid is now withdrawn from the vessel 18 through the tubes 31 and 32 by turning the stopcock 34 in the proper way. The vessel 18 is rinsed and filled with the liquid to be measured as described for the reference liquid. The determination of the apparent weight of the float 10 in the liquid to be measured is made in exactly the same way as described for the reference liquid.

Denoting the apparent weight of float 10 in the liquid to be measured with L , the following expression holds for the density d of said liquid:

$$d = w - \frac{(L-W)(b-a)}{bV} \quad (2)$$

The symbols in this equation denote the same quantities as in the preceding equation. As the average density of the float 10 is less than the density of the liquid the weights L and W should be inserted in Equation 2 with negative sign. The numerical values for all symbols at the right of Equation 2 are now known and may be substituted in the equation to determine the density d of the sample liquid.

In the opposite case, when the average density of the float is higher than the densities of the media, the center of the coil 48 should be placed above the upper end of the magnet and the circuit reversed so as to give a diminishing current through said coil at an increasing illumination of the phototube 40. The apparent weights of the float 10 in the media are then directed downwards and should be inserted in the above equations with positive sign.

The invention has now been described mainly as an apparatus for density determinations of liquids. It is of course also possible to give the float the shape of a container for solid material, the density of which is to be determined, e. g. crystals, metal powders or similar materials. Referring more particularly to Fig. 5 the numerals 12, 14 and 16 denote the same elements as in Fig. 1. 106 denotes a container in which the solid particles are placed. The apparent weight of the empty float is determined in a liquid of known density, the solid particles 108 are introduced in the container 106 and the apparent weight of this system is determined. The difference between these apparent weights is the apparent weight of the solid particles in said liquid. Knowing the apparent weight of the solid particles in air of known density the density of said particles may be calculated in the ordinary way.

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The invention has now been described mainly as an apparatus for density determinations. However, the invention as such is of course not limited to this range of utilization, but is related to the apparatus as such independent of the purpose for which it is to be used. For instance, the apparatus can be used for the following purposes described in detail in connection with the Figures 6, 7 and 8. In said figures all numerals not specified in the following description denote exactly the same elements as in Figure 1.

Referring more particularly to Fig. 6 110 is a float provided with a cavity 112 at the lower end. In said cavity there is inserted the electrode 114 with the glass insulation 116. 120 is another electrode. Both electrodes are immersed in the electrolytic solution filling the vessel 18. Electrolysis of said solution including gas formation at the electrode 114 may be followed by measuring the lifting effect on the float 110 caused by the gas bubble 118.

Referring more particularly to Fig. 7 122 is a float with a cavity 124 at the upper end. In said cavity there is inserted the electrode 126 with the glass insulation 128. 130 is another electrode. Both electrodes are immersed in the liquid filling the vessel 18. Applying a voltage between the two electrodes density changes caused by electrode reactions in the neighbourhood of the electrode 126 may be studied by measuring the variations of the lifting effect on the float 122.

Referring more particularly to Fig. 8 132 is a float with the cavity 134 at the upper end, said cavity having the shape of a sedimentation pan. The vessel 136 contains the suspension to be studied. The accumulation of the suspended particles in the cavity 134 may be studied by measuring the variations of the lifting effect on the float 132.

We claim:

1. Apparatus for measuring the lifting effects on a float of a liquid in which the float is completely submerged, said apparatus comprising a balance including a balance-beam with a scale pan suspended from one end thereof and an annular coil suspended from the other end, a chamber for containing a liquid and having a portion extending through the opening of said annular coil, a float within said chamber and including a body of magnetic material, and means for establishing a current through said coil to maintain said float in a balanced state of equilibrium immersed in liquid within said chamber; said means comprising an amplifier having said coil in the output circuit thereof, a photoelectric cell in the input circuit of said amplifier, and a light source for directing upon said photoelectric cell a light beam which traverses said chamber and is intercepted to greater or less extent in accordance with the buoyancy of the float.

2. Apparatus as recited in claim 1, wherein said chamber includes means for establishing therein a predetermined liquid level, and means for maintaining said float in position below said liquid level.

3. Apparatus as recited in claim 1, wherein said amplifier includes manually adjustable means for varying the current change through said coil upon movement of said float with respect to the light beam to said photoelectric cell.

4. Apparatus as recited in claim 1 wherein said float has a cavity in the upper end thereof.

5. Apparatus as recited in claim 4, wherein electrodes are provided in said chamber, one of

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said electrodes being positioned in the cavity in the upper portion of said float.

6. Apparatus as recited in claim 1, wherein electrodes are provided in said chamber below the liquid level therein.

7. Apparatus as recited in claim 6 wherein said float is provided with a cavity in the lower end thereof, and one of said electrodes is positioned within said cavity.

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