

APPLICATIONS OF BUOYANCY*

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SUMMARY

Applications of the buoyancy effect: balance indicator, balance calibration, determination of the grain size distribution, measurement and control of the density of fluids and solids and of gas pressure are reviewed.

INTRODUCTION

Applications of buoyancy were already described by Archimedes (ref. 1). Buoyancy can be a useful tool for measuring density and pressure and may even be used as a method of grain size determination and of weighing. The following paper deals with those applications. Disturbances of weighings arising from buoyancy are discussed in another paper at this conference (ref. 2).

DENSITY AND PORE DETERMINATION

For density determination of liquids the well-known areometers (Fig. 1), Sikes hydrometer and Mohr's balance (Fig. 2) are designed. In the same way, microbalances and suspension balances (ref. 3) can be used as hydrostatic balances. For that purpose a solid body of known mass m_s and density ρ_s is weighed hanging in the liquid. The density of the liquid results from the reading m_i

$$\rho_l = \frac{m_s - m_i}{m_s} \rho_s \quad (1)$$

To determine the density of solids four weighings including two blank experiments in a liquid of known density are necessary

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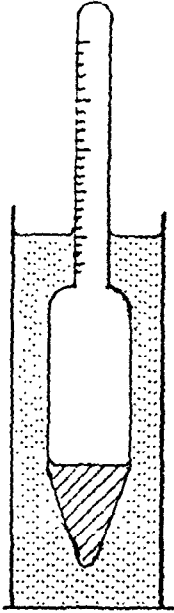


Fig. 1: Areometer.

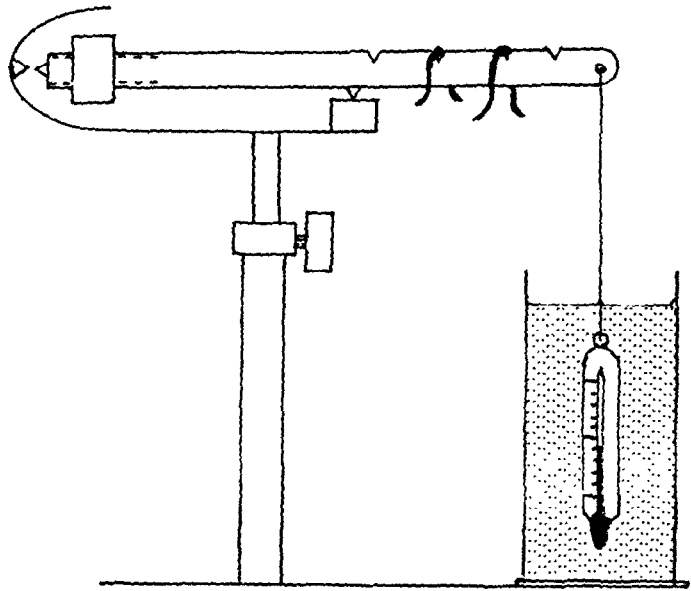


Fig. 2: Mohr's balance (design of Westphal).

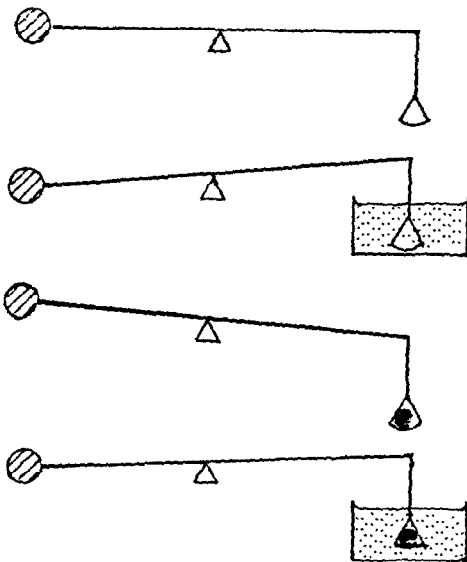


Fig. 3: Hydrostatic weighing.

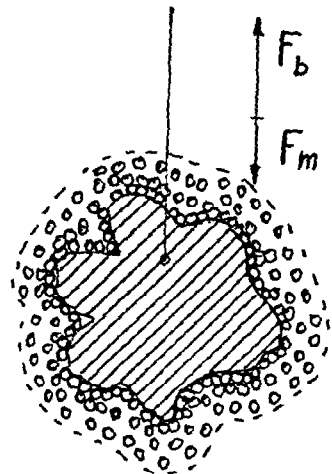


Fig. 5: Buoyancy of the adsorbate.

(Fig. 3). The density of the solid can be calculated using equation (1).

Kleinrahm and Wagner (ref. 4) designed an apparatus (Fig. 4) including Gast's magnetic suspension balance to determine the density of fluids even near phase boundaries, by performing comparison measurements with a gold-covered quartz balloon and a gold ring of the same surface area.

In thermogravimetry density determination of the solid sample in a gas is performed because very often this value is not sufficiently known. Furthermore, as a consequence of thermal treatment the density of the sample may vary. Indeed the density determination by buoyancy in a gas often results in values differing from those by competing methods. Buoyancy yields the density of the dried sample with degassed surface and void pore system.

To determine the density, the sample with known dry mass is compared with a counterweight of known density similar to the assumed density of the sample. Then, after degassing in vacuum, - pores must be completely depleted - the buoyancy is determined with nitrogen at room temperature or alternatively with helium at 77 K. The sample density results in

$$\rho_s = \frac{m_s \rho_f}{m_b 10^5} \quad (2)$$

In some cases the contribution of adsorbed layers to the density of the sample has to be taken into account. A monolayer is built up in a statistical way: there are free places, but molecules at a distance up to three diameters are bound and contribute to the adsorbed mass (Fig. 5). This region of low density causes a noticeable buoyancy effect and may be calculated by introducing virial coefficients, only the second, B_2 , being of importance. Introducing B_2 in the equation of state yields

$$m_b = - (m_s - V_s m_s \rho_0) + m B_2 (p/(k T))^2 \quad (3)$$

This coefficient is positive, zero or negative depending on temperature and, thus, contributes differently to the regular buoyancy. A higher density, and, hence, a lower buoyancy is to be expected at low temperatures, while at high temperatures the opposite effect may occur. Pierotti (ref. 5) calculated a correction of + 100 μg at 78 K, 0 μg at 300 K, and of - 3 μg at 1000 K, 10^5 Pa and a surface area of 100 m^2 for the system helium/carbon.

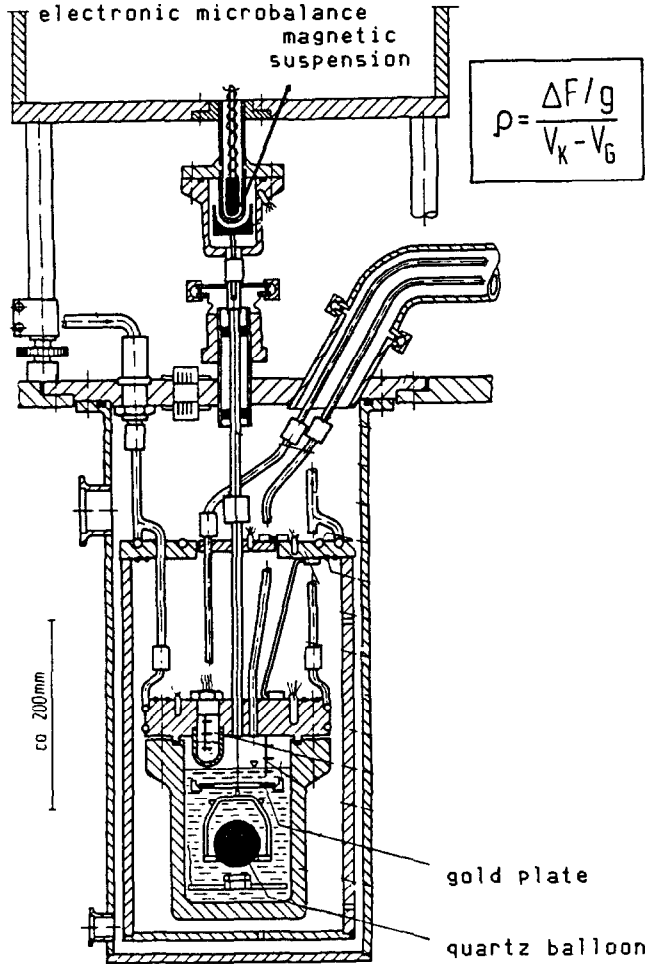


Fig. 4: Magnetic suspension balance used as hydrostatic balance for the measurement of the density of liquids according to Kleinrahm and Wagner (ref. 4).

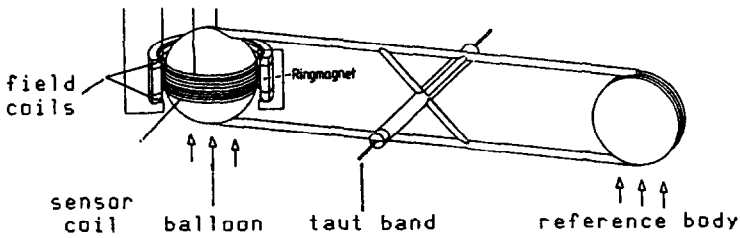


Fig. 6: Gas density balance according to Gast and Talebi-Daryani

It may be mentioned that an effect of the same cause and magnitude also disturbs volumetric gas-pykometry (ref. 6).

Closed pores may give a false value of density far below that of the compact material. On the other hand, if the density of the compact material is known the volume of closed pores can be determined by buoyancy measurements in a gas or using a liquid like xylene.

For example, corrosion of reactor graphite in CO_2 resulted in a considerable increase of the specific surface area and microporosity (ref. 7). Density determinations by buoyancy measurements in nitrogen versus vacuum and xylene versus air exhibited an increase in density during corrosion and, thus, revealed that the increase of surface and porosity was due to the fact that previously closed micropores became accessible.

Unfortunately, density determinations of microporous samples like activated carbon often fail because the samples adsorb surprisingly large amounts of the measuring gas at room temperature. At room temperature a gas may have access to micropores which are blocked at low temperatures.

Of course, it is possible to utilize the observation of density changes for process control. Gast (ref. 8,9) used a glass balloon connected to a microbalance (Fig. 6) to measure density variations of gases with high accuracy.

PRESSURE MEASUREMENT

If the type of gas is not changed the buoyancy of a glass balloon can be used to measure and control the pressure. Robens and Sandstede (ref. 10) described an instrument covering the range from 1 to 10^6 Pa. Massen et al. (ref. 11) extended the range down 10^{-3} Pa using in addition Knudsen forces generated by thermal gas flow (Fig. 7).

WEIGHING

In special cases, buoyancy was used to compensate balance deflections and, hence, using it as mass indicator variations (ref. 12,13). Czanderna and Honig (ref. 14) demonstrated the buoyancy effect as a useful means for very accurate calibration of microbalances. Probst (ref. 15) used a hydrostatic balance as a very sensitive mass comparator balance (Fig. 8), the relative sensitivity being 1×10^{-9} .

GRAIN SIZE DISTRIBUTION MEASUREMENT

Grain size distributions of particles bigger than 10 mm in diameter are usually performed by measuring the size of each particle using a perforated plate. Instead, Leschonski and Hermes (ref. 16,17) suggest individual buoyancy measurements of each particle as described above. This method is more accurate and much faster. Using

$$V_s = \frac{m_s - m_i}{\rho_f} \quad (4)$$

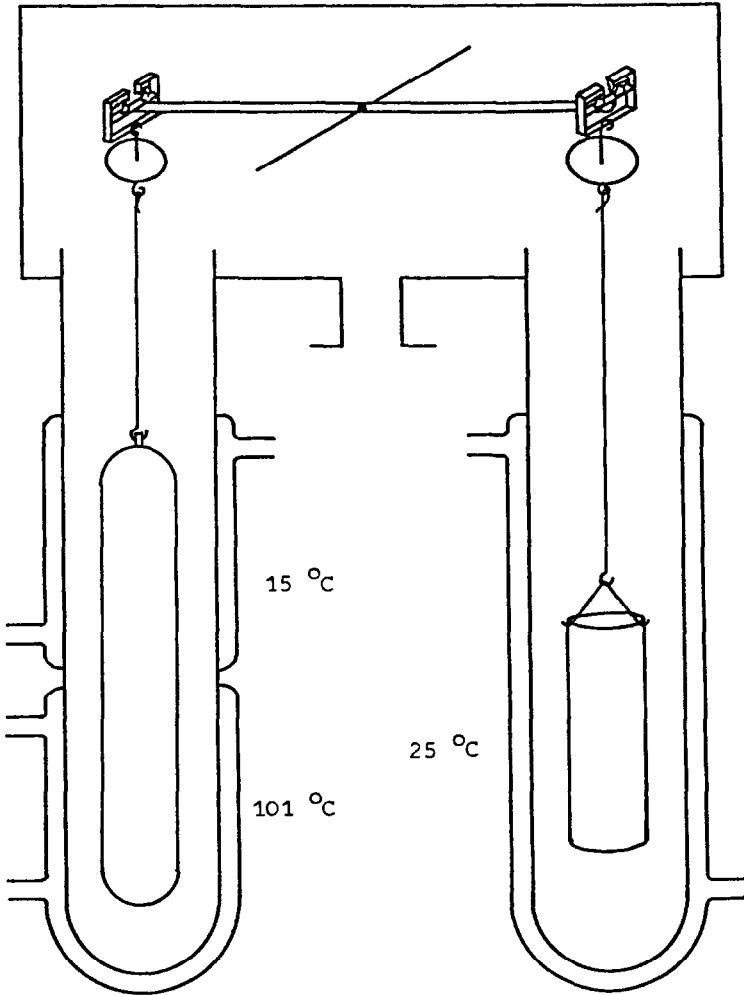


Fig. 7: Gas pressure balance according to Massen et al. (ref. 11).

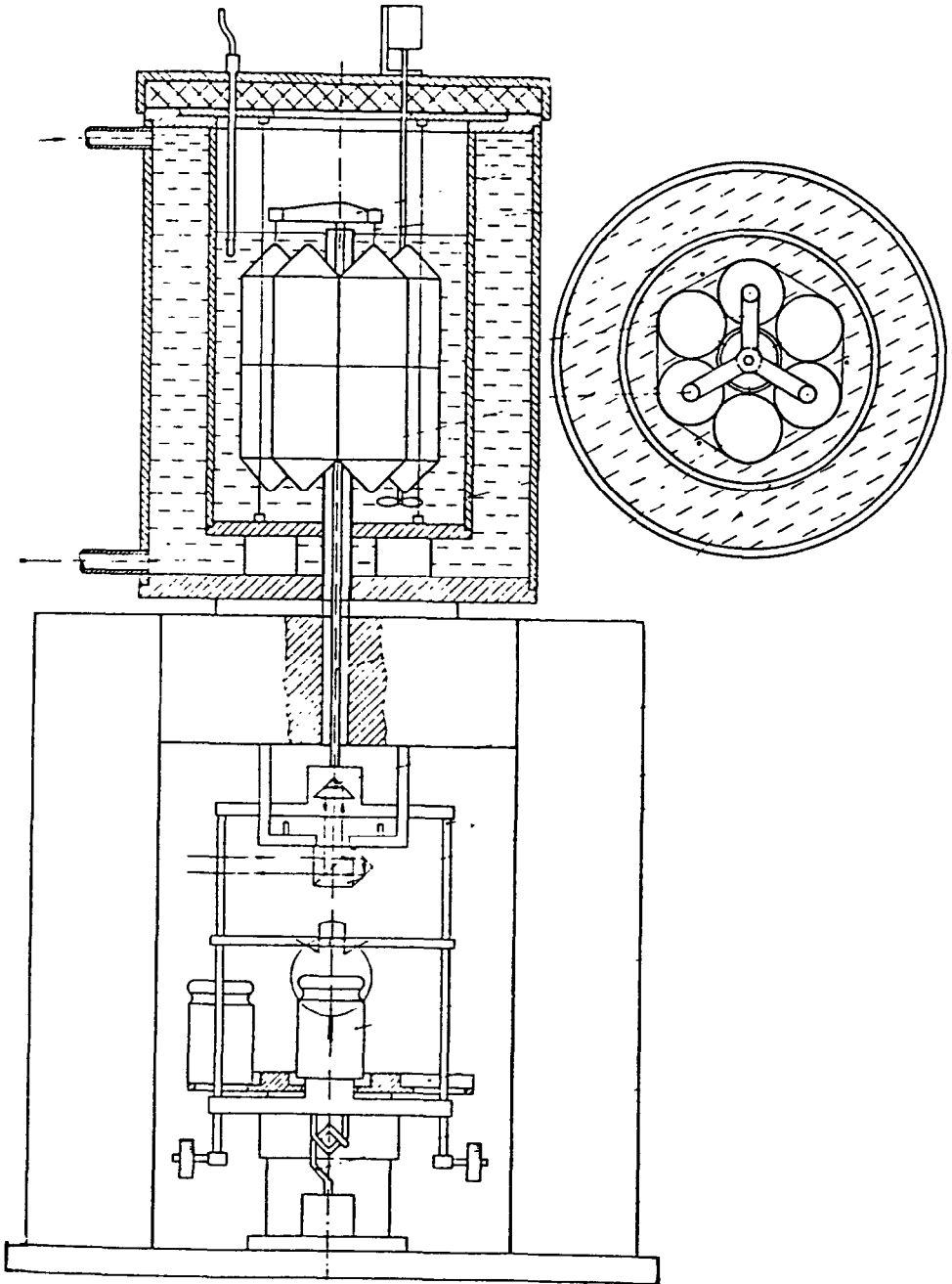


Fig. 8: Hydrostatic comparator balance according to Probst.

the volume of the sample can be calculated. Assuming a spherical shape the equivalent diameter is derived from

$$x_v = \sqrt[3]{\frac{6}{\pi} \frac{m_s - m_i}{\rho_f}} \quad (5)$$

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