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Bulk Density Measurement of Small Solid Fragments

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1. Abstract

We report on the direct buoyant force measurements using a high precision electronic balance on small solid fragments ($0.05\,\mathrm{gm} < m < 0.15\,\mathrm{gm}$) of $(\mathrm{Cd,Zn})_{0.5}\mathrm{Ni}_{0.5}\mathrm{Fe}_2\mathrm{O}_4$ ferrites in a vegetable cooking oil. The bulk density deduced via the Archimedes principle is shown to be reliable. Its variation as a function of the sample pre-sintering green density is also presented.

1. Introduction

The bulk density of a substance is defined as the mass per unit volume of the substance. Its accurate determination depends on how well both mass and volume are obtained. The measurement of mass tends to be easy and straightforward. It can be measured with high precision using electronic balances some of which are readily available in a standard Chemistry or Physics Laboratory. Some of the best balances have a precision of at least 0.00001 grams.

Apart from relatively large objects and those having regular geometry, volume determination tends to be more complicated. Basic commercial instruments to measure density have specification of sample size from 0.1 to 135 cm^3 [1]. Direct measurement of volume tends to be impractical and hence the reason to resort to indirect methods. In this context, there is a simpler and readily available solution to the problem of density measurement based on the actual determination of the buoyant force on an object that is completely submerged in a liquid. This relies on mass measurement, which can be achieved with high precision even on small fragments. The buoyant force, F_B is equivalent to the weight of the displaced fluid,

$$F_B = V_o \rho_f g \tag{1}$$

V_o : volume of the object; ρ_f : density of the fluid; g : acceleration due to gravity.

The left hand side of equation (1) depends on how F_B is being measured. If the mass is being weighed in air and then in the liquid [2], the apparent mass loss is

$$\Delta m = V_o \rho_f \,. \tag{2}$$

The density of the object of mass m can easily be deduced to be

$$\rho_o = \frac{m\rho_f}{\Delta m} \,. \tag{3}$$

Unfortunately, this is usually easier said than done especially if you want high precision in your measurements.

Equation (3) can also be obtained if we measure the buoyant force directly. This is a good illustration of Newton's third law. Since the buoyant force is the force exerted by the liquid on the object, we measure the force exerted by the object on the liquid while it is suspended in the liquid by a supporting string secured to a stand. One can therefore take advantage of a modern high precision balance with re-zeroing capability to monitor the apparent change in mass of the liquid and container when the object is lowered into the liquid. This procedure is usually not well known but it is conceptually straightforward. In the next section we present the experimental details and justification for adopting this procedure to determine the bulk densities of our samples.

2. Experiment

Two systems of $(Cd,Zn)_{0.5}Ni_{0.5}Fe_2O_4$ compounds were prepared by the combustion process from nitrate solutions using urea as a fuel [3,4]. The resulting material was well homogenized before being pressed into pellets at different pressure. The pellets were sintered in air in a tube furnace for two hours at 1210 °C. A Mettler AT261 Delta Range electronic balance with precision of 0.00001 grams determined the masses of the pellets. A micrometer was used to determine the dimensions of the pellets. The mass of each pellet was about 0.4 grams and its typical dimensions were about 7.4 mm in diameter and 2.0 mm in thickness. This gives a bulk density of 4.65 g cm^{-3} and a sample volume of 0.086 cm^3. Clearly the sample size is below the minimum demand of the present commercial available instruments. Also small, but nevertheless visible, pellets imperfections on their edges led to the present method of density determination where small fragments of material -masses ranging from about 0.05 to about 0.15 grams- were measured.

Figure 1 shows a schematic diagram of the apparatus and experimental arrangement for density determination based on Archimedes principle. The plastic container with liquid is mounted on weighing platform of the balance. A small wire basket suspended by a nylon string was used to catch the solid fragments. A small copper plate was placed inside the basket. This helped the basket to sink easily and also to act as a base for solid pieces to settle. The selection of the liquid was very critical in this experiment. Distilled water turned out to be unsuitable because the balance used was sensitive enough to detect the rate of evaporation of water. Similarly glycerin alcohol was unsuitable as it showed continuous mass adsorption from the atmosphere. For the third choice of liquid we used a vegetable cooking oil (Brazilian soya oil), which proved to be an excellent choice as it showed no detectable mass change when exposed to the atmosphere. The density of the oil was determined by direct mass and volume measurements.

Before mounting the container with oil on the balance, the masses of all the solid fragments were measured first. Once the container with the oil was on the balance, the basket was lowered into the oil until it was completely submerged. The balance reading was observed to increase in consistence with the effect of buoyancy. One by one the fragments were dropped into the basket and each value of Δm noted. Using equation (3), the density of each fragment was determined.

In order to check the reliability of our density values, we also measured the Δm values for fragments of pure metal pieces (Cr, Hf, Ni, Zn and Zr) of known density [4] and then used equation (3) to determine the density of the oil.

3. Results

The density of the vegetable cooking oil used in our measurements was found to be 0.922 ± 0.001 g.cm^{-3} by direct mass and volume measurements. The value of the density of oil based on buoyancy on pure metals was found to be 0.93 ± 0.01 g.cm^{-3}. The two values are in agreement. All subsequent density calculations of the solid fragments were based on a density of oil of 0.922 ± 0.001 g.cm^{-3}.

The variation of the bulk density of the $(Cd,Zn)_{0.5}Ni_{0.5}Fe_2O_4$ ferrites based on the geometrical method to determine the volume are shown in Figure 2. Figure 3 shows similar plots based on the Archimedes principle obtained by direct buoyant force measurements. The two sets of data have comparable values of densities and somewhat similar trends. However, the differences are also significant. The geometrical method for volume determination tends to over estimate the volume. This is consistent with sample pellets that have some imperfections. Reliable values of bulk density are those based on Archimedes principle in the present instance.

4. Conclusion

We have used a less used and discussed procedure to determine the bulk density of small solid fragments. The current procedure is based on Archimedes principle and utilizes the limit of high precision of mass determination of a modern electronic balance. This therefore allows for the density measurement of small solid fragments, which would be unlikely to measure using most commercial pycnometers. Our results show a significant influence of the green density on the final bulk density of $(Cd,Zn)_{0.5}Ni_{0.5}Fe_2O_4$ ferrites investigated. The bulk density measurements are important because they can provide information of the quality of the materials and how their properties are influenced by the sample preparation conditions such as the pre-sintering green density.

Acknowledgements

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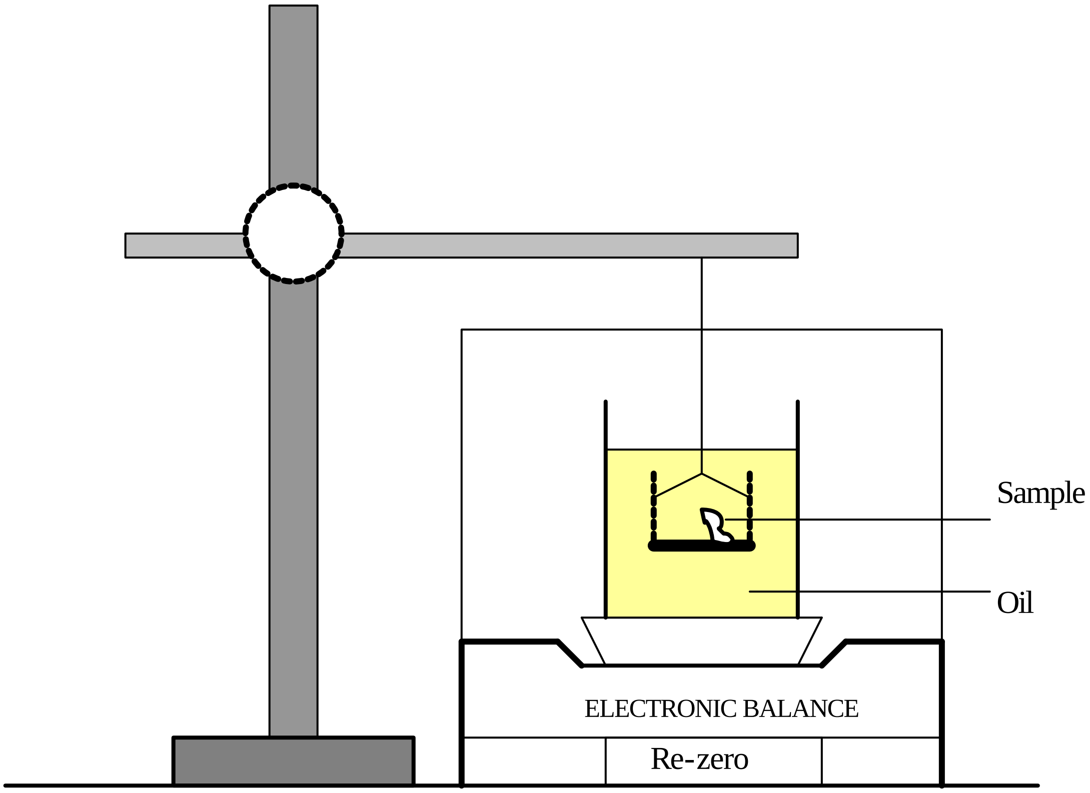

Figure 1 Bulk density determination base on Archimedes principle. A nylon string secured to a stand supports the basket with a copper metal sink. The plastic container of vegetable oil is mounted on an electronic balance.

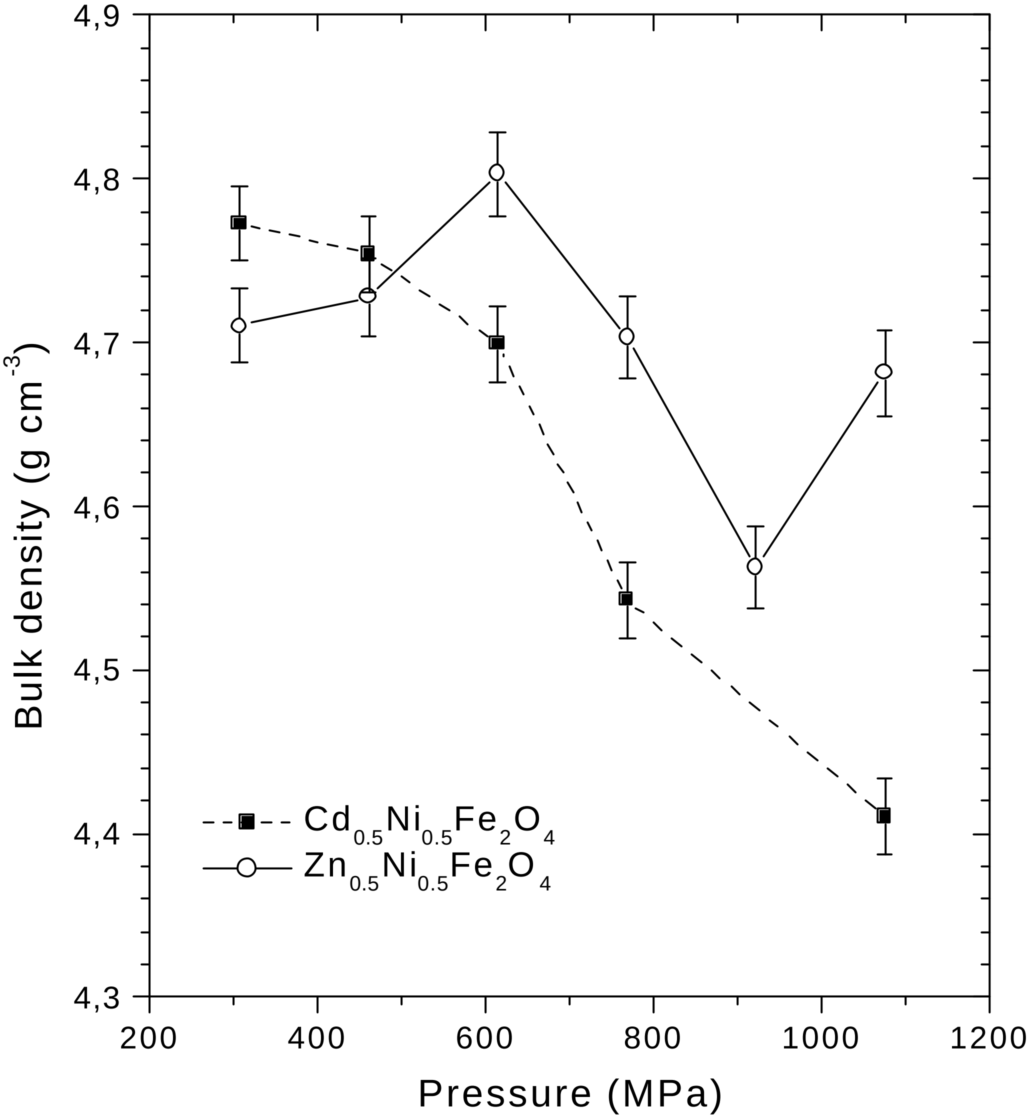

Figure 2 Variation of bulk densities of sintered (Cd, Zn)-Ni ferrites as a function pressure (or green density) of pre-sintered pellets. Volume determinations were based on the geometry of the pellets.

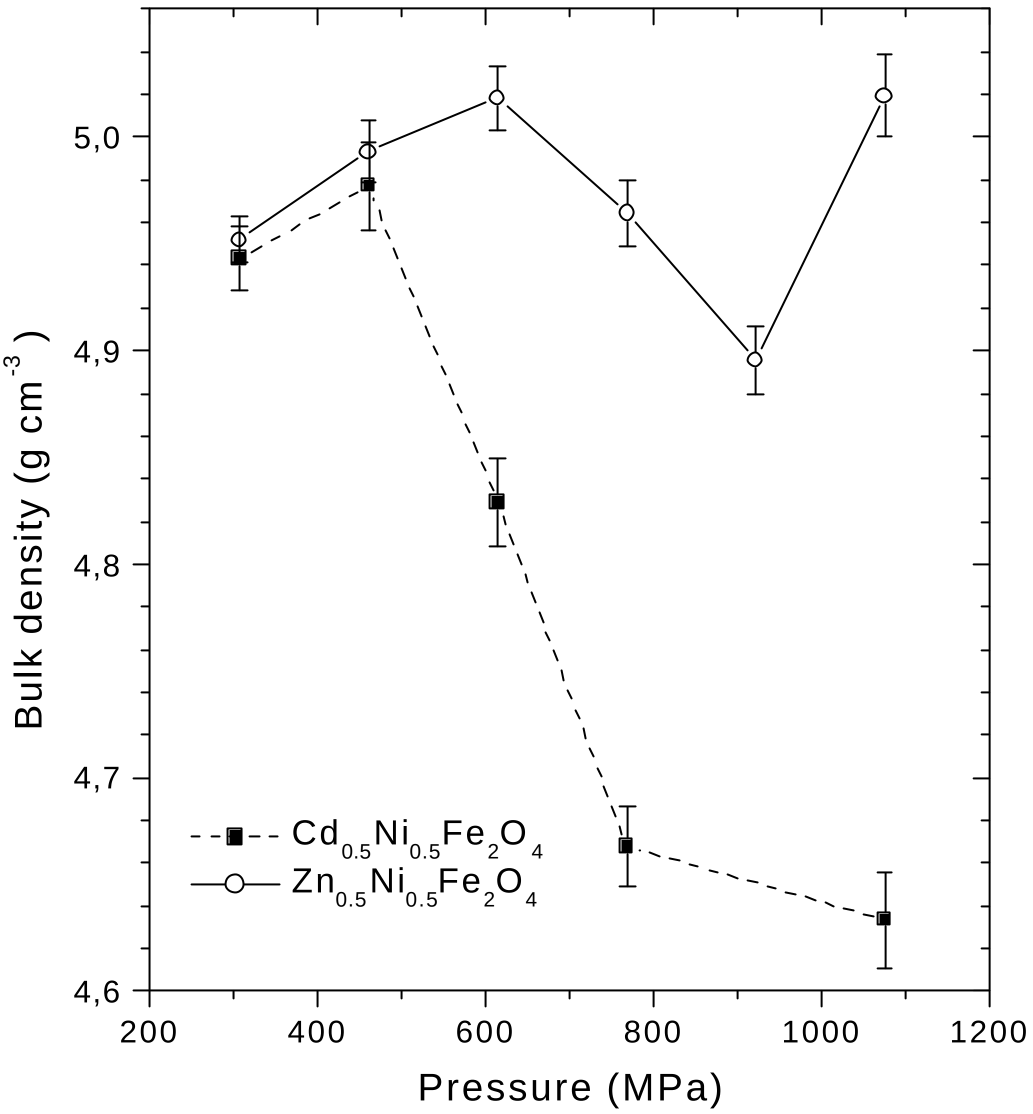

Figure 3 Variation of bulk densities of sintered (Cd, Zn)-Ni ferrites as a function pressure (or green density) of pre-sintered pellets. The densities were determined from the direct measurement of the buoyant force based on Archimedes principle.