THE MEASUREMENT OF LIQUID DENSITY BY COMPARISON BETWEEN AIR PRESSURES IN CMS

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Abstract − We use the U-type height method to measure the liquid density. The system is like a U-type manometer, while the different liquid used in the tubes. One of the tube was set to the air pressure, another one was decreased the pressure below 1 atm. When a lower pressure was pumped into the tube from the top end, the heights of the level of liquid were measured. Then we got the density of the liquid.

During the experiment, the laser interferometer and proper floating reflectors were used. We utilized these instruments to measure the levels of the liquid. These results for measuring water and alcohol will be presented in the conference.

Keywords: U-type, Laser interferometer, Floating reflectors

1. INTRODUCTION

The density of liquids can be traced by the solid density standard occasionally when we use the hydrostatic weighing. And the unit of the solid density is followed the SI unit (the Internal System of Units) that is derived by the units of mass (kg) and the length (metre) [1]. When we measure the absolute value of solid density, it is necessary to trace the mass to the prototype of the kilogram and the length of the wavelength of laser locked at the recommended lines.

The National Physical Laboratory (NPL) in the United Kingdom firstly fulfilled the concept in 1957 by using a tungsten carbide cube as a sample to measure the volume and mass with the absolute method [2]. A Michelson laser interferometer with traced wavelength was used to measure the distance between the opposite faces of the cube. So the volume can be traced to the length of standard. The mass of tungsten carbide cube was then compared with that of calibrated and traced weights.

The Physikalisch-Technische Bundesanstalt (PTB) in Germany performed the similar work recently in 2004, weighing the cubic sample in liquid to determine the density of liquid. This article showed the method of mercury density measurement, using the mercury used in a manometer, great masses in gravitational constant measurement and a natural density standard for relative density estimation. The density of the mercury was obtained by weighing this tungsten carbide cube immersed in the mercury.

To overcome the damage effect caused by the mercury to the tungsten cubic, a silicon sphere is used instead to measure the length of its diameter. Because of the high purity of silicon, the property is a good reason for silicon solid to be as a density standard. Furthermore, the volume of a sphere with a high sphericity may be determined with a small uncertainty from the mean of diameters over many directions. The National Institute of Standards and Technology (NIST) in the U.S.A. realized the absolute measurement of the density by using a sphere in 1972. This measurement was performed both for the determination of the Avogadro constant and a solid density standard based on silicon crystal. The lattice constant of silicon crystal was obtained by the x-ray crystal density method, and the Avogadro constant N_A is determined by absolute value of the lattice constant a, molar mass M, and density ρ on an identical silicon crystal. Then the Avogadro's constant was obtained as $N_A = 8M\rho^{-1}a^{-3}$ and the silicon crystals solid density standard were also obtained [2]. The measurement was also tried to redefine the definition of the mass by counting the silicon atoms. Fig. 1 shows the connection.
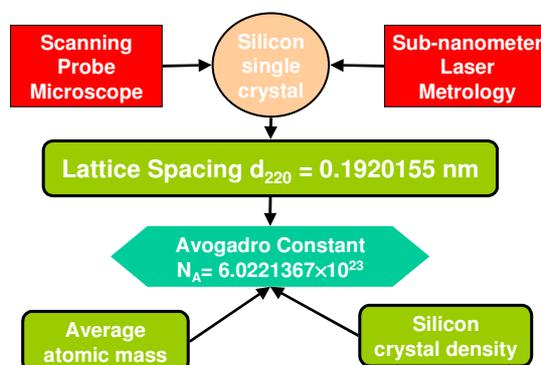

Fig. 1. The connection between the measurement of the Avogadro's constant and the definition of the mass.

Concerning the comparison type of the liquid density measurement, the hydrometer is a typical instrument. The operation of hydrometer is based on the Archimedes principle. The surface tension is negligible when it is in equilibrium. The mass of liquid displaced by the hydrometer is equal to the mass of the hydrometer. A reading of the hydrometer shows the density value measured. The effect of temperature will affect the uniformity of liquid measurement especially and the effect of non-uniform density was caused by vertical temperature gradient [4]. Because reading the level of hydrometer is important, the optical instrument CCD was used in the hydrometer measurement to improve the precision of liquid density measurement [5].

In this paper, we will introduce a comparison-type idea of the density instrument that is transferred from a U-tube manometer. The U-tube manometer contains mercury or water in a U-shape tube, and usually is used to measure gas pressure. One end of the tube is exposed to the unknown pressure field and another end is connected to a reference pressure source. In the recent years, the laser interferometer was used in the level measurement. The proper floaters were used to measure the levels of the manometer in both tubes as the beam reflector of the manometer systems [6, 7].

2. THE PRINCIPLE AND EQUIPMENT

The Fig.1 shows the diagram of the system with liquid in each tube. When the state is in equivalent condition, the pressures can be expressed as (1):

$$p_t + h_t \cdot \rho_t = p_r + h_r \cdot \rho_r \qquad (1)$$

$$\rho_t = \frac{p_r - p_t}{h_t} + (\frac{h_r}{h_t}) \cdot \rho_r \qquad (2)$$

$$\Delta\rho_t = \frac{\Delta p_r - \Delta p_t}{h_t} - (\frac{p_r - p_t}{h_t^2} + h_r \cdot \rho_r) \cdot \Delta h_t + \frac{\rho_r \cdot \Delta h_r + \Delta\rho_r \cdot h_r}{h_t} \qquad (3)$$

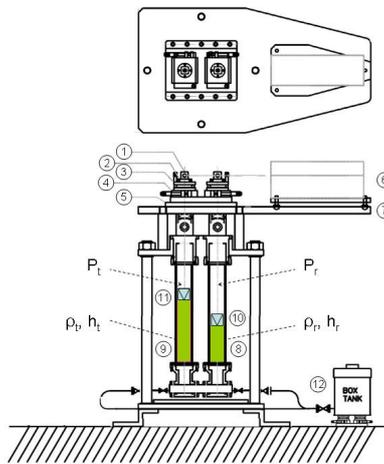Equation (3) shows the differential form of ρ_t.

Fig. 2. The diagram of the system.

The parts in the diagram of the system shown in Fig. 1 are: 1 is the interferometer; 2 is the holder of interferometer; 3 is the tilt stage; 4 is the translation stage; 5 is the connector holder; 6 is the laser head; 7 is the optical platform; 8 and 9 are the U-tubes with liquids inside; 10 and 11 are the reflector corner cubes; 12 is the liquid tank.

The U-tube system in the CMS contains two fused silica tubes. Each tube was sixty cm long and six cm diameter as shown in Fig. 3. There is a corner cube reflector floater in the bottom of each tube. The tubes were connected to the same container with the liquid to be measured. Each tube has one pumping-out channel at the top which can adjust the tube to the different air pressure condition. There is another channel at the top of each tube to be used to measure the residual pressure after the pumping schedule by connecting to the barometers. The two laser interferometers (HP10706) were set up at the top of the optical platform with the tilt stages and the translation stages. The laser beam came from the laser head was aligned by using two pins in the horizontal direction. The interferometer and the corner mirror reflector can be adjusted by screwing the tilt stages and the translation stage. As the alignment is well, the indication light of the receivers will be on.

In the system, the readings of the interferometer, pressure and the temperature were recorded by the industrial computer system [9]. During the measurement, the pressure in one of the tubes was pumped out through the pumping-out channel to set this tube under the pressure condition lower than the air pressure and another tube was set under the air pressure condition.
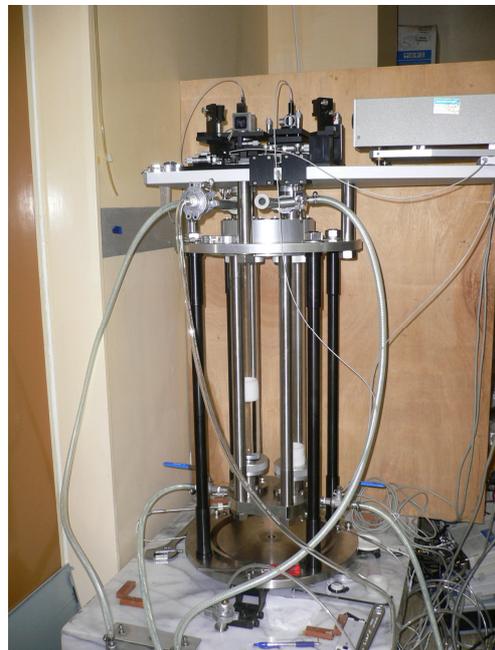

Fig. 3. Photo of the U-tube liquid measurement system.

3. RESULTS

The data of height were record per second. Sampling rate of temperature and pressure is 0.125 Hz. Every eight data of liquid height were averaged as the height of the position in

equilibrium. These results were listed in Table1 to Table3 and Fig.4 to Fig.9.

If the distilled and de-aerated water is used as the medium, its density ρ_l is a well-known function of temperature and can be calculated by [8]:

$$\rho_l = a_5 \left[1 - \frac{(t_l + a_1)^2 (t_l + a_2)}{a_3 (t_l + a_4)} \right] \qquad (4)$$

With:
$a_1 = -3.983035$ °C;
$a_2 = +301.797$ °C;
$a_3 = +522528.9$ °C^2;
$a_4 = +69.34881$ °C;
$a_5 = +999.974950$ kg m^{-3}.

In these tables, the subscript L represents the left tube and R represents the right side. The subscript the represents the theoretical value calculated by (4).

Table 1. Measurement results for distilled and de-aerated water after pumping.

	T_L °C	T_R °C	P_L mbar	P_R mbar	P_L-P_R mbar	ρ_{Lthe} kg m^{-3}	ρ_{Rthe} kg m^{-3}	H_R mm	H_L mm	H_L-H_R mm
Mean	21.051	20.777	983.843	1000.123	-16.280	997.984	998.043	7.499	-158.578	166.077
STD	0.0008	0.0202	0.0972	0.0175	0.1093	0.0002	0.0043	0.0017	0.0493	0.0499
Calculated result	999.596 kg m^{-3}		Deviation rate		0.16 %		TP$_{Index}$	51-68	H$_{Index}$	346-440

Table 2. Measurement results for distilled and de-aerated water after leakage.

	T_L °C	T_R °C	P_L mbar	P_R mbar	P_L-P_R mbar	ρ_{Lthe} kg m^{-3}	ρ_{Rthe} kg m^{-3}	H_R mm	H_L mm	H_L-H_R mm
Mean	21.054	20.819	982.479	1000.086	-17.607	997.983	998.034	8.118	-171.796	179.914
STD	0.0017	0.0190	0.0700	0.0221	0.0746	0.0004	0.0041	0.2023	0.0926	0.2201
Calculated result	997.901 kg m^{-3}		Deviation rate		0.01 %		TP$_{Index}$	70-89	H$_{Index}$	453-579

Table 3. Measurement results for alcohol after pumping.

	T_L °C	T_R °C	P_L mbar	P_R mbar	P_L-P_R mbar	H_R mm	H_L mm	H_L-H_R mm
Mean	20.816	20.829	982.827	1000.085	-17.258	6.431	-211.655	218.086
STD	0.0013	0.0045	0.0097	0.0051	0.0123	0.0011	0.1071	0.1074
Calculated result	806.953 kg m^{-3}			TP$_{Index}$	35-63	H$_{Index}$	225-413
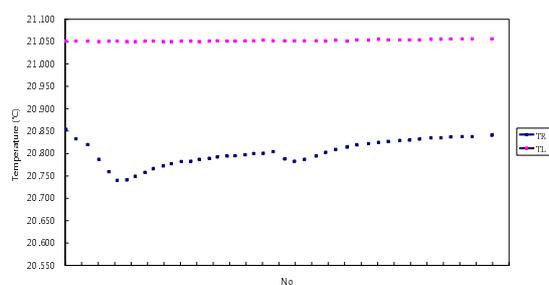
Fig. 4. Temperatures for distilled and de-aerated water.

Fig. 6. Heights for distilled and de-aerated water.

Fig. 5. Pressures for distilled and de-aerated water.
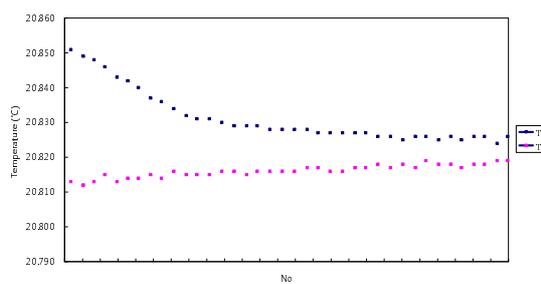
Fig. 7. Temperatures for alcohol.

Data of the pressures in the left and right side of the U-tube

Fig. 8. Pressures for alcohol.

Data of the heights in the left and right side of the U-tube
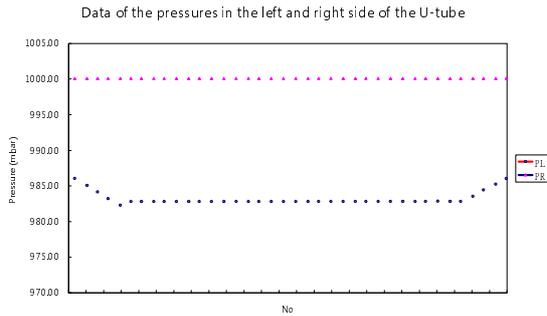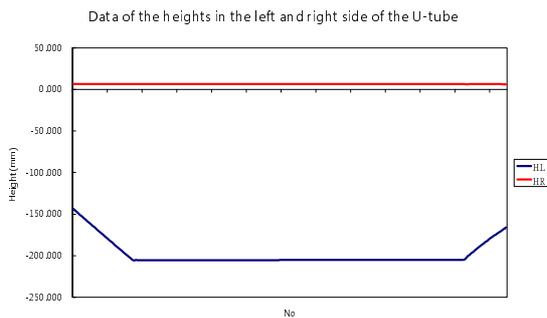
Fig. 9. Heights for alcohol.

Table1 and Table2 show the data for distilled and de-aerated water used as the liquid in the tubes. Table1 is the data after pumping and Table2 is the data after leakage. The densities of the liquids in the left tube and the right tube calculated by (4) are expressed as ρ_{Lthe} and ρ_{Rthe} in Table1 and Table2 respectively. Deviation rate from the calculated results by the experiment data to the calculation values by (4) are 0.16 % and 0.01 % respectively.

Table3 shows the data after pumping for alcohol (ethanol 99.5%) used as the liquid in the tubes. The value of density is 806.953 kg m^{-3} and is 1.5 % higher than the value provided by the manufacturer specification.

When we change the position of the tank 2 cm higher there come out a jump as shown in Fig.4 and Fig.5. The corresponding changes can be seen also in the height measurements as in Fig.6. It was a check in the experiment.

4. OUTLOOK

We tried to use the method of manometer measurement to measure the density and obtained the primary results as presented. In the future, we will modify the temperature control to improve the experiment.

REFERENCES

[1] The International System of Units (SI) 7th ed, 1998 (Sevre: Bureau International des Poids et Mesures)
[2] Kenichi Fujii, "Present state of the solid and liquid density standards", References therein. Metrologia 41, S1-S15, 2004
[3] H. Bettin and H. Fehlauer, "Density of mercury-measurements and reference values", Metrologia 41, S16-S23, 2004
[4] Martti Heinonen and Sampo Sillanpaa, "The effect of density gradients on hydrometers", Meas. Sci. Tech nol. 14 (2003) 625-628
[5] S Lorefice and A Malengo, "An image processing approach to calibration of hydrometers", Metrologia 41 (2004) L7-L10
[6] Ooiwa A., Ueki M., Kneda R., New Mercury interferometric Baromanometer as the Primary Pressure Standard of Japan, Metorlogia, 1993/1994, 30, 565-570.
[7] Alasia F., capelli A., Cignolo G., Sardi M., A New Generation of Mercury Manometer at the IMGC, Metrologia, 1993/1994, 30, 571-577.
[8] M. Tanaka, G. Girard, R. Davis, A. Peuto & N. Bignell, Recommended table for the density of water between 0 °C and 40 °C based on recent experimental reports, Metrologia, 2001, 38, pp. 301-309, 2001.