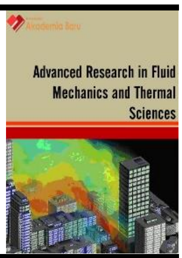
Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 53, Issue 1 (2019) 106-110

Penerbit Akademia Baru

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: www.akademiabaru.com/arfmts.html
ISSN: 2289-7879



New Development of the Metal Volume Thermal Expansion

Open Access

Fazrul Mohd Nor[1,*], Abd Rahman Tamuri[2], Abd Khamim Ismail[2]

[1] National Metrology Institute of Malaysia, 43900 Sepang, Malaysia
[2] Department of Physics, Faculty of Science, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia

ARTICLE INFO

Article history:
Received 30 October 2018
Received in revised form 1 December 2018
Accepted 5 December 2018
Available online 10 January 2019

Keywords:
Hydrostatic weighing system, Volume thermal expansion, Dilatometer

ABSTRACT

Volume thermal expansion measurement of the solid is one of the most challenging issue in material industry especially when the solid is in big size. The existing instruments such as dilatometer has a limitation to determine the volume thermal expansion of material. Therefore, a new and precise system has been proposed to determine the volume thermal expansion. In this study, several samples such as gold and tungsten were used to determine its volume thermal expansion by using custom made hydrostatic weighing system (HWS) where the experimental results show that the HWS can determine the volume thermal expansion. Volume thermal expansion value for gold rod and tungsten rod are 1.5×10^{-4} °C^{-1} and 7.7×10^{-5} °C^{-1} respectively. The expanded uncertainty obtained using HWS was 0.0003 °C^{-1}. To assure the quality of the HWS, inter-instrument comparison between HWS and dilatometer was performed. The results of the comparison show that the $E_n \leq 1$ indicates the performance of the HWS is acceptable. Thus, this study will demonstrate on how the volume thermal expansion of the material is precisely and accurately measured using HWS. Furthermore, it is cheaper than dilatometer with reasonable accuracy and it was traceable to SI unit.

1. Introduction

Most materials will expand in different temperature except rubber. However, metals will expand in different amounts at the same temperature changes [1]. The amount of expansion or contraction varies is depending on the material. There are two types of thermal expansion: Linear and volume thermal expansion [2]. Linear thermal expansion of metal is the change of length Δl when the temperature change Δ°C. Currently, dilatometer was used to measure the metal linear thermal expansion [3]. However, dilatometer was unable to measure the metal thermal expansion if the size of sample was not suitable with sample container such as gold bar.

Volume thermal expansion of metal is a volume change ΔV when the temperature change Δ°C. Currently, there are a lot of studies regarding volume thermal expansion but only focusing on fluid and gas [4-7]. In this paper, the focus will be to determine volume thermal expansion of gold and

* *Corresponding author.*
E-mail address: mfazrul@sirim.my (Fazrul Mohd Nor)

tungsten with HWS that has been developed. There are some issues of fake gold due to similar density of pure gold and tungsten [8, 9]. The density of pure gold and tungsten are 19.30 g/ml and 19.21 g/ml respectively with expanded uncertainty 0.01 g/ml at $k = 2$. Problem arises when tungsten was found plated with thin layers of gold to defraud buyers [10].

A few of improvement in HWS have been achieved where the HWS was able to determine the volume thermal expansion coefficient in any size and shape of the sample. The limitation of using dilatometer is the shape of sample to be measured has to be in rod shape with maximum size of diameter and length at 12 mm and 50 mm respectively. Furthermore, the distilled water was used as a standard liquid in HWS where the water temperature in the cylinder bath was controlled and stabled. This distilled water used also was traceable to National Metrology Institute (NMI) [11].

2. Materials and Methods

In this study, the volume thermal expansion of the gold and tungsten was determined by HWS based on Archimedes' principle. This method can determine the volume of gold and tungsten without destructing the samples. In this method, the sample will be weighed using an analytical balance in air noted as B_1. Then, the sample will be immersed in the distilled water which was a standard liquid and being weighed again as B_2. The difference between B_1 and B_2 can be derived as

$$B_1 - B_2 = \left[m\left(1 - \frac{\rho_a}{\rho}\right) \right] - \left[m\left(1 - \frac{\rho_l}{\rho}\right) \right] \quad (1)$$

The volume V_t of the sample at temperature t was calculated as

$$V_t = \frac{B_1 - B_2}{\rho_l - \rho_a} \quad (2)$$

where

B_1, B_2 : Balance reading (g)
m : Mass of the sample (g)
ρ_a : Air density (g/ml)
ρ_l : Density of liquid (g/ml)
ρ : Density of sample (g/ml)
V_t : Volume of the sample at temperature t

The distilled water temperature will increase or decrease depend on the chiller function. The volume of the sample, V_1 will change due to change in temperature, t. Volume, V_2 of the sample increase when the chiller increased the temperature to T_2 where the temperature difference between T_1 and T_2 stated as Δt. Therefore, the equation for volume thermal expansion coefficient, γ can be derived as below

$$\gamma = \frac{V_2 - V_1}{V_1 \Delta t} \quad (3)$$

E_n value is a method to evaluate performance of HWS where it can be stated as below [12]

$$E_n = \frac{\gamma_{HWS} - \gamma_D}{\sqrt{U_{HWS}^2} + \sqrt{U_D^2}} \tag{4}$$

where

γ_{HWS}	: Volume thermal expansion value determined by HWS
γ_D	: Volume thermal expansion value determined by Dilatometer
U_{HWS}	: expanded uncertainties of HWS
U_L	: expanded uncertainties of Dilatometer
$\|E_n\| \leq 1$	: indicates satisfaction in HWS performance
$\|E_n\| > 1$	: indicates unsatisfaction in HWS performance

HWS consists of analytical balance, digital thermometer and chiller. The equation will be derived by considering all factors affecting the measurement of the volume thermal expansion such as density of distilled water, air density, mass in liquid and liquid temperature. All parameters will be determined in order to evaluate the expanded uncertainty of the measurement. Figure 1 shows the experimental setup for HWS.

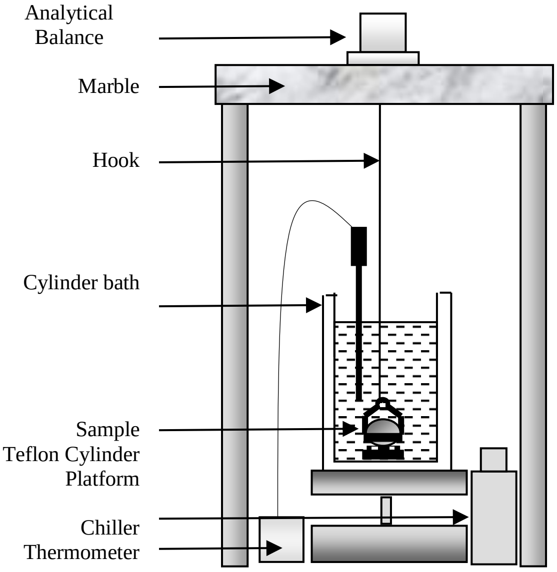


Fig. 1. Measurement setup for hydrostatic weighing system

Sample was hanged to analytical balance (Mettler Toledo; Model XP504; capacity 500g) by using sample holder and hooks. Analytical balance was used when weighing the sample. A calibrated digital thermometer (Model F250; accuracy 0.01°C) was used to measure the temperature of the distilled water in the sample bath. It was traceable to National Metrology Institute of Malaysia (NMIM). The sample bath was a glass cylinder containing the liquid used to control the thermal and stability of the bath and it was transparent to view the level of sample immersion. A chiller was used to stabilize the temperature of the distilled water. The air density was obtained from calculations by including air temperature, humidity and ambient pressure.

The sample has to be cleaned before the volume measurement can be started. A sample is placed on the holder where the holder is hang below the precision balance. When the platform of the HWS moves up, the teflon cylinder will push the sample upwards. At this moment, the analytical balance only shows the mass of the holder and the analytical balance is tare to zero. The objet will return back to the holder as the platform moves downwards along with the teflon cylinder. At this phase, the analytical balance will show the mass of the sample and the reading is taken directly from it. Then, the distilled water temperature will be increased until its reached stable state. Finally, the HWS platform will be moved up and down to obtain the mass of the sample at new distilled water temperature.

3. Results

Table 1 shows that the volume thermal expansion coefficient of metal with expanded uncertainty at k=2. Volume thermal expansion coefficient for M1, M2, M3, M4 and M5 are 0.00045 °C^{-1}, 0.00037 °C^{-1}, 0.00063 °C^{-1}, 0.00031 °C^{-1} and 0.00023 °C^{-1} respectively with expanded uncertainty 0.0003 °C^{-1} at k=2. The volume thermal expansion coefficient of gold was identified to be higher than tungsten and this statement is agreed with other research [13, 14].

Table 1
Volume thermal expansion coefficient of metal with expanded uncertainty at k=2

Material	Sample	β (°C^{-1})	U (k=2)
Gold Rod	M1	0.00045	0.0003
Gold Bar	M2	0.00037	0.0003
Gold Bar	M3	0.00063	0.0003
Gold Bar	M4	0.00031	0.0003
Tungsten Rod	M5	0.00023	0.0003

Figure 2 shows the volume thermal expansion coefficient of gold and tungsten where there were difficulties discovered to differentiate the volume thermal expansion coefficient of gold and tungsten. M1, M2, M3 and M4 are gold samples and M5 is tungsten sample. The expanded uncertainty of measurement has to be small and more accurate in order to differentiate the volume thermal expansion coefficient of the gold and tungsten.

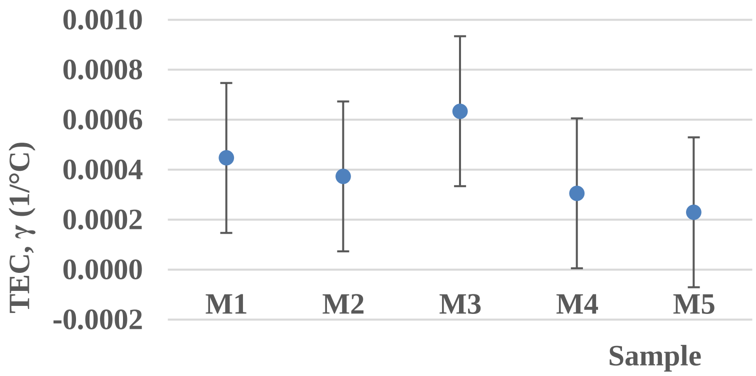


Fig. 2. Volume thermal expansion coefficient of gold and tungsten are quite similar

The HWS developed need to be verified by dilatometer in order to determine the performance of this developed system. Dilatometer was traceable to certified reference material from National Institute of Standards and Technology (NIST) [15]. M1 and M5 were used as a sample due to suitability of dilatometer sample container. Table 2 shows the volume thermal expansion coefficient of M1 and M5 determined using dilatometer and HWS. Dilatometer is more accurate compared to

HWS due to the expanded uncertainty of the dilatometer is smaller than HWS, but the E_n value obtained is below than 1 indicates that the performance of HWS is in satisfactory.

Table 2
Verification of the HWS with dilatometer

Sample	Dilatometer		HWS		E_n
	γ_D (°C^{-1})	Unc (°C^{-1})	γ_{HWS} (°C^{-1})	Unc (°C^{-1})	
M1	0.00016	0.00003	0.00045	0.00030	0.9
M5	0.00003	0.00003	0.00023	0.00030	0.7

4. Conclusions

An improved hydrostatic weighing method has been successfully developed, tested and verified. This newly developed HWS has some advantages such as able to measure any shape and size of sample and better temperature stability since it was equipped with temperature controller. A verification procedure has been performed with dilatometer and the evaluated expanded uncertainty was 0.00030 °C^{-1}. More importantly, the results also can be traceable to base unit of temperature through NMIM and the distilled water was used as a standard liquid which was traceable to NMI. Furthermore, it was much cheaper to develop HWS compared to dilatometer.

References

[1] Giancoli, D.C., *Physics for scientists and engineers*. Vol. 3. 2000: Prentice hall Upper Saddle River, NJ.
[2] Reese, Ronald Lane. *University physics*. Vol. 1. Thomson Brooks/Cole, 2000.
[3] Scabarozi, T. H., S. Amini, O. Leaffer, A. Ganguly, S. Gupta, W. Tambussi, S. Clipper *et al.,* "Thermal expansion of select M n+ 1 AX n (M= early transition metal, A= A group element, X= C or N) phases measured by high temperature x-ray diffraction and dilatometry." *Journal of Applied Physics* 105, no. 1 (2009): 013543.
[4] Espejo, F. and S. Armada, Determination of Volumetric Coefficients of Thermal Expansion in Alcoholic Beverages and Aqueous Ethanolâ€"Sucrose Mixtures by Differential Volume Measurements. *Food and Bioprocess Technology*. 5(7): p. 2805-2818.
[5] Nayak, A.K., R.K. Singh, and P.P. Kulkarni, *Measurement of volumetric thermal expansion coefficient of various nanofluids.* Technical Physics Letters. 36(8): p. 696-698.
[6] Brillo, J., I. Egry, H. S. Giffard, and A. Patti. "Density and thermal expansion of liquid Au-Cu alloys." *International journal of thermophysics* 25, no. 6 (2004): 1881-1888.
[7] Avdiaj, Sefer, Janez Setina, and Bojan Erjavec. "Volume Determination of Vacuum Vessels by Gas Expansion Method." *Mapan* 30, no. 3 (2015): 175-178.
[8] Abdullah, Jaafar, Abibullah Samsudin, Nor Laili Omar, and Hafizza Abdul Manan. "Non-Destructive Assaying Gold Jewellery Using Dual-Energy MicroComputed Tomography." *JURNAL TEKNOLOGI* 73, no. 3 (2015).
[9] Ismail, Mohamad Pauzi, Suhairy Sani, Faris Syazwan bin Mohd Shofri, Mohd Harun, and Norlaili Binti Omar. "Ultrasonic inspection of fake gold jewelry." In *IOP Conference Series: Materials Science and Engineering*, vol. 298, no. 1, p. 012025. IOP Publishing, 2018.
[10] Arbutine, A., *Pawnbroker's Guide to Metals Testing.* Today's Pawnbroker, 2008.
[11] Specification for Density hydrometers. British Standard 1991. BS718:1991.
[12] Van der Veen, Adriaan MH, and Nederlands Meetinstituut. "Measurement uncertainty in proficiency testing." *CD da Escola Avançada de Metrologia em Química, Inmetro* (2003).
[13] Bodryakov, V. Yu. "Correlation of temperature dependences of thermal expansion and heat capacity of refractory metal up to the melting point: Tungsten." *High Temperature* 53, no. 5 (2015): 643-648.
[14] White, White, G. K., and J. G. Collins. "Thermal expansion of copper, silver, and gold at low temperatures." J*ournal of Low Temperature Physics* 7, no. 1-2 (1972): 43-75.
[15] Yamada, Naofumi, Remi Abe, and Masahiro Okaji. "A calibration method for measuring thermal expansions with a push-rod dilatometer." *Measurement Science and Technology* 12, no. 12 (2001): 2121.