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 in Determination of Metal Volume Thermal Expansion Measurement Using Hydrostatic Weighing System (HWS)

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ARTICLE INFO

Article history:
Received 9 July 2018
Received in revised form 29 September 2018
Accepted 3 January 2019
Available online 6 June 2019

ABSTRACT

Volume thermal expansion measurement of solid material is one of the most challenging issue in material industry especially when the size of the sample is large. The existing instruments such as dilatometer has a limitation to determine the volume thermal expansion due to various of samples sizes and shapes. In this study, a new and precise hydrostatic weighing system (HWS) has been proposed to fulfil various samples shapes and sizes in the volume thermal expansion determination. The performance of the developed HWS was tested and evaluated using several samples such as gold and tungsten. The volume thermal expansion of gold and tungsten rod measured using the HWS are 1.5×10^{-4} °C^{-1} and 7.7×10^{-5} °C^{-1} respectively with expanded uncertainty of 0.0003 °C^{-1}. The results of the HWS measurement was verified and compared with dilatometer. The comparison results show $E_n \leq 1$ indicated that the performance of the HWS is acceptable. Furthermore, it is cheaper than dilatometer with reasonable accuracy and traceable to SI unit.

Keywords:
Hydrostatic weighing system; Volume thermal expansion; Dilatometer

1. Introduction

Gold is one of the world's most precious commodity and the value or price of gold is subjected to its purity. In general, the destructive method such as fire assay and Inductively Couple Plasma (ICP) is not a preferred method for gold purity testing by pawn industry due to it will destroy customer gold samples [1-5], therefore a non-destructive method has been introduced [6-8]. The gold business trading nowadays suffered million losses from fake or counterfeit gold and therefore a reliable method for gold purity testing is extremely important [9].

According to the report by Asiah Alkharib Shah in 2018, preventing fake gold was the major challenge faced by Koperasi Yayasan Pembangunan Ekonomi Islam Malaysia (YaPEIM), Koperasi Pos Malaysia, Ar-Rahnu Express Habib Jewels Sdn Bhd and Angkatan Koperasi Kebangsaan Malaysia Berhad (ANGKASA) [10]. Malaysia had suffered RM75 million losses in 2012 due to unimplemented

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destructive method on customer gold samples to detect counterfeit gold [11]. Ay Maryani also reported that Indonesian pawn broking industries have been facing similar problems regarding the fake gold. Bank Negara Indonesia (BNI) sharia suffered more than 9 Million Rupiah or USD 6.5 Million losses due to fake gold [12].

Jaafar Abdullah and Mohamad Pauzi Ismail claimed that gold market was flooded with tungsten due to density of tungsten almost similar to gold [13]. Tungsten is the only metal that has a density close to gold where the values are 19.30 g/ml and 19.25 g/ml respectively [14, 15]. XRF and electronic gold pen which were usually used to determine gold purity had limitations. XRF can only penetrate the gold sample within 10 to 50 micron depth [16], while the electronic gold pen can only measure the gold surface [16].

Temperature effect such as expansion, conductivity and heat capacity also play an important role in metal properties measurement for gold and tungsten [17, 18]. Expansion of Gold and tungsten in same temperature is different [19] and the amount of expansion or contraction varies based on material properties. There are two types of thermal expansion: Linear and volume thermal expansion [20]. Linear thermal expansion of metal is the change of length Δ*l* with the change of temperature Δ°C. Currently, dilatometer is used to measure the metal linear thermal expansion [21]. However, dilatometer is unable to measure the metal thermal expansion if the size of sample is not suitable with the sample container such as gold bar. The limitation of using dilatometer is the shape of sample to be measured should be in rod shape with maximum size of diameter and length of 12 mm and 50 mm respectively.

Volume thermal expansion of metal is the change of volume Δ*V* with the change of temperature Δ°C. Currently, there are a lot of studies regarding volume thermal expansion only focusing on fluid and gaseous [22-25]. In this paper, the focus is to determine the volume thermal expansion of gold and tungsten with the new developed hydrostatic weighing system (HWS).

A few improvements to the HWS was achieved and able to determine the volume thermal expansion coefficient of the sample in any size and shape. Furthermore, distilled water was used as a standard liquid placed in the cylinder bath under controlled temperature condition. This standard liquid used was also traceable to National Metrology Institute (NMI) [26].

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 was weighed using an analytical balance in air as B_1. Then, the sample was 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

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

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

$$V_t = \frac{B_1 - B_2}{\rho_l - \rho_a} \tag{2}$$

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 will increase when the temperature of the chiller increase to T_2 where the temperature difference between T_1 and T_2 is stated as ΔT. Therefore, the equation for volume thermal expansion coefficient, γ can be derived as below.

$$\gamma = \frac{V_2 - V_1}{V_1 \Delta T} \tag{3}$$

E_n value is a method to evaluate performance of HWS where it can be stated as below [27].

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

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.

Sample was weighed by placing the sample into the sample holder where the hook fastened with the sample holder was attached to analytical balance (Mettler Toledo; Model XP504; capacity 500g). A calibrated digital thermometer (Model F250; accuracy 0.01°C) was used to measure the temperature of the distilled water in the sample bath and 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 in order 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.

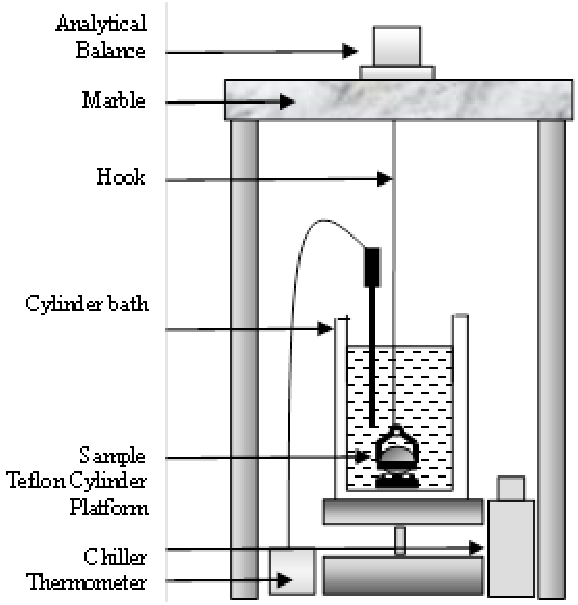

Fig. 1. Measurement setup for hydrostatic weighing system

First step, the sample has to be cleaned prior to the volume measurement in order to prevent contamination. Then, the sample is placed onto the holder where the holder is hanged 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 will only show the mass of the holder and then the analytical balance need to be reset to zero. The object will return to the holder when the platform moves downwards along with the teflon cylinder. At this stage, the analytical balance shows the mass of the sample where the reading will be obtained and taken directly from it. Then, the distilled water temperature will be increased until its reached stable state. Finally, the HWS platform is moved up and down to obtain the mass of the sample at new distilled water temperature.

3. Results

Table 1 shows the volume thermal expansion coefficient of metals 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 of 0.0003 °C-1 at k=2. The volume thermal expansion coefficient of gold was found to be higher than tungsten and this was aligned with measurements done from other researchers [28, 29].

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 it was difficult 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.

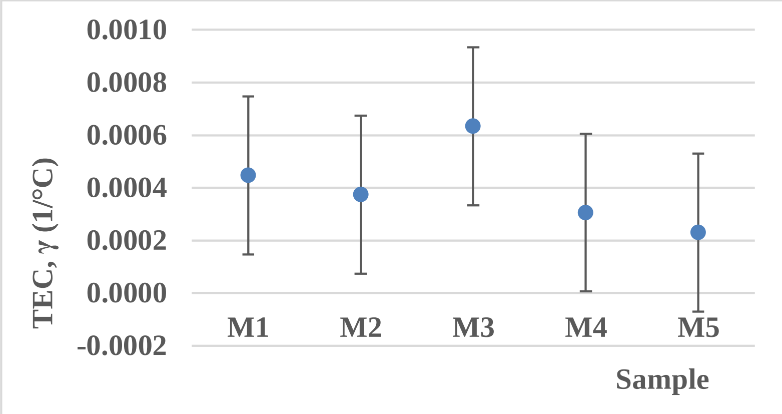

Fig. 2. Volume thermal expansion coefficient of gold and tungsten are quite similar

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) [30]. 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 indicated that the performance of HWS is in satisfactory.

Table 2
Verification of the HWS with dilatometer

Sample	Dilatometer		HWS		En
	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 also traceable to NMI. Furthermore, HWS was inexpensive to develop compared to dilatometer.

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