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Research paper

Fake Gold: Gold Purity Measurement Using Non Destructive Method

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Abstract

Determination of the gold bar purity by non-destructive method remains one of the most challenging in gold industry especially when the tungsten is inside the gold bar. The existing instruments have a limitation to determine the fineness of gold bar and it was difficult to detect the tungsten inside the gold bar due to the density of tungsten is almost similar to the density of gold. This report presents the limitation of the non-destructive method instruments such as densimeter, weighing balance, x-ray fluorescence (XRF) and ultrasonic. Furthermore, the research on the non-destructive method by other researchers also will be discussed in this report.

Keywords: *Fake gold, Density, Non-destructive method, Tungsten*

1. Introduction

Gold, silver, platinum and palladium are types of the precious metal [1]. However, gold is one of the world's most precious commodities and gold remains to be a secure investment. It is important to determine its purity because the value of gold depends on its purity. There are different grades of gold in market such as 24 carat, 22 carat, 18 carat, 14 carat, 12 carat and 10 carat [2-5]. The unit of gold alloys purity is stated as carat (symbol: K or kt). It shows the percentage of the gold in gold bar, jewellery or coins [6, 7].

Recently there are a lot of people who purchase gold for trade and investment. Gold can be classified into three types or designs such as gold bar, coin and jewellery. Usually gold bar has a certificate to show its purity, serial number, gold weight and it is certified by assayer and the manufacturer. The gold bar certificate is very important for trading purpose. Gold bar for trading in the market can be obtained in 1 kg, 500 g, 100 g, 50 g, 30 g, 20 g and 5 g. The world's largest gold bar is weighing at 250 kg where it was manufactured by Mitsubishi Materials Corporation[8].

Gold purity measurement is to measure the gold purity of the gold sample such as gold bar, jewellery and coins. The analysis of gold purity must be determined precisely and accurately[9]. The gold content verification is important and significant due to gold bar price depend on gold purity[10].

There are two groups method for gold purity measurement: Destructive method and non-destructive method. Destructive method is a gold purity measurement method and it will destruct the gold sample such as fire assay and Inductively Couple Plasma (ICP) [3, 11-16]. There are several International Standards that describe on purity gold using destructive method [17-19]. Non-destructive method is a gold purity measurement method and it will not destruct the gold sample. Furthermore, non-destructive method is able to measure the gold purity on the surface and whole sample. Densimeter, weighing balance and ultrasound are instruments that are able to measure the gold purity of whole sample[20-22]. X-ray Fluorescence (XRF), touch stone, electronic pen and needle are instruments that are able to measure the gold purity on the surface only [23-27]. It's difficult for instruments in non-destructive method to detect the presence of other metal in gold.

Usually pawn shop, jewelry shop and bank agencies in Malaysia will use densimeter, weighing balance, XRF, needle, chemical solution, tri-electronic, magnet and stone to determine gold purity due to legal requirement, economical, easy and non-destructive method [2]. Pawnbroker Act 1972 was introduced and has been gazette in Malaysia stated that, the pawnbroker cannot damage the gold that wants to be leased [28]. Pawnbroker Guideline for Islamic pawn also stated that the pawnbroker must take care the gold [29].

Nowadays there is no single non-destructive method that can determine the gold purity precisely and accurately. Hence, many cases of fake golds in the market arise due to this problem and pawnshops in Malaysia had suffered a loss of RM72 million in 2012 because of they cannot cut the gold [30].

Gold also can be easily bought and sold around the world[13]. The fake gold problem was also discovered in other country such as South Africa. The British Broadcasting Corporation (BBC) reported in 2008 that the central bank of Ethiopia has loss millions of dollars' due to fake gold bar. The bank tried to sell the gold to South Africa and it has been returned when the South Africa noticed this problem [31].

Archimedes was assigned to check purity of King Hieron II new crown[32]. King Hieron II wants to assure that his new crown made from pure gold. During that time, there were many alloy of gold and silver in the market[33] and it's show that the fake gold issue has long existed.

In modern era, tungsten was found plated with thin layers of gold[34, 35]. Jaafar Abdullah and Mohamad Pauzi Ismail [34] claimed that gold market is flooded with tungsten due to density of tungsten is almost the same as gold. Figure 1 show that the 100 g gold bar plated with tungsten. Tungsten is the only metal that has a density close to gold. Density of gold and tungsten are 19.30 g/ml and 19.25 g/ml respectively [20, 22, 34, 36, 37].

Fig.1: 100 g gold bar plated with tungsten

Table 1 shows the research project about gold purity measurement using non-destructive method. The main purpose of these research projects is to prevent fake gold in the gold trading. XRF and ultrasonic used to determine gold purity has limitation. XRF can penetrate the gold sample within 10 to 50 microns [38]. The limitation of the ultrasonic is the measurement can only be done starting from 1 mm depth. JC Kraut and W B Stern [39] claimed that the gold density measurement is easy for binary alloys such as gold-silver or gold-copper. Hence, the binary alloys for gold-tungsten are also easy to measure.

Table 1: Gold purity measurement using non-destructive method

Year	Sample	Non-destructive method	Reference
2000	Gold	Density	[39]
2015	Gold	XRF	[34]
2018	Gold	Ultrasonic	[40]

2. Archimedes Principle

Gold density measurement is based on the hydrostatic weighing method. It is direct application of the Archimedes' principle [36, 41, 42]. This hydrostatic weighing method is to measure the mass of the sample in air and displaces its own volume of liquid[43]. Usually this method used for the calibration of hydrometer, solid and liquid density measurement, underwater weighing and purity precious metal measurement [44-47].

Density of a material is defined by its mass per unit volume of the material [48-50]. It can be stated in grams per milliliter (g/ml) or in the SI unit system as kilograms per cubic meter (kg/m^3)[51]. The purposes of measuring the material density are for material quality control, concentration determination and also to identify purity of precious metal [8, 51-54]. Weighing balance and densimeter are among of the reliable instrument to determine the purity of gold using hydrostatic weighing method [34, 38, 55]. Figure 2 and Figure 3 show the measurement of material using the densimeter and weighing balance respectively.

Table 2: Technical papers on density gold measurement using hydrostatic weighing method

Year	Sample	Accuracy	Reference
1992	Gold	0.1 g/ml	[55]
1997	Gold	0.1 g/ml	[38]

Table 2 shows that the technical papers on gold density measurement using hydrostatic weighing method. E.Mercer [55] was used Mettler Toledo balance with hydrostatic weighing accessories in this project where gold samples used were from 8 carat to 24 carat. They discover that this hydrostatic weighing cannot detect gold plated especially if the material has a density similar with gold.

Christopher W.Corti [38] claimed that the gold density can be measured accurately due to modern accurate analytical balances used. However, practically there were several problems arise when this hydrostatic weighing method applied. He concluded that the hydrostatic weighing is a simple, cheap and non-destructive method but it cannot produce an accurate assay.

Fig.2: Densimeter used to measure the purity of gold

Fig.3: Weighing balance used in testing and analytical laboratory

2.1 Densimeter

Pawn shop, jewelry shop and bank agencies in Malaysia are using densimeter to examine the gold purity due to its economical, simple and non-destructive method. Densimeter will determine the sample gold mass in air and in distilled water. The mass readability of the densimeter is 0.01 g. Then, the liquid in glass will be used to measure the distilled water temperature.
Usually the distilled water temperature is similar to environment temperature. Density of distilled water will be obtained from Kell 's equation [56]. Lastly the densimeter software allows for density determination and the sample gold purity to be calculated. The sample gold density determination from the densimeter is inaccurate due to accuracy of the densimeter is 0.1 g/ml. Figure 2 and Figure 4 show the densimeter that is commonly used in Malaysia market and the flowchart of procedure to determine the gold purity respectively.

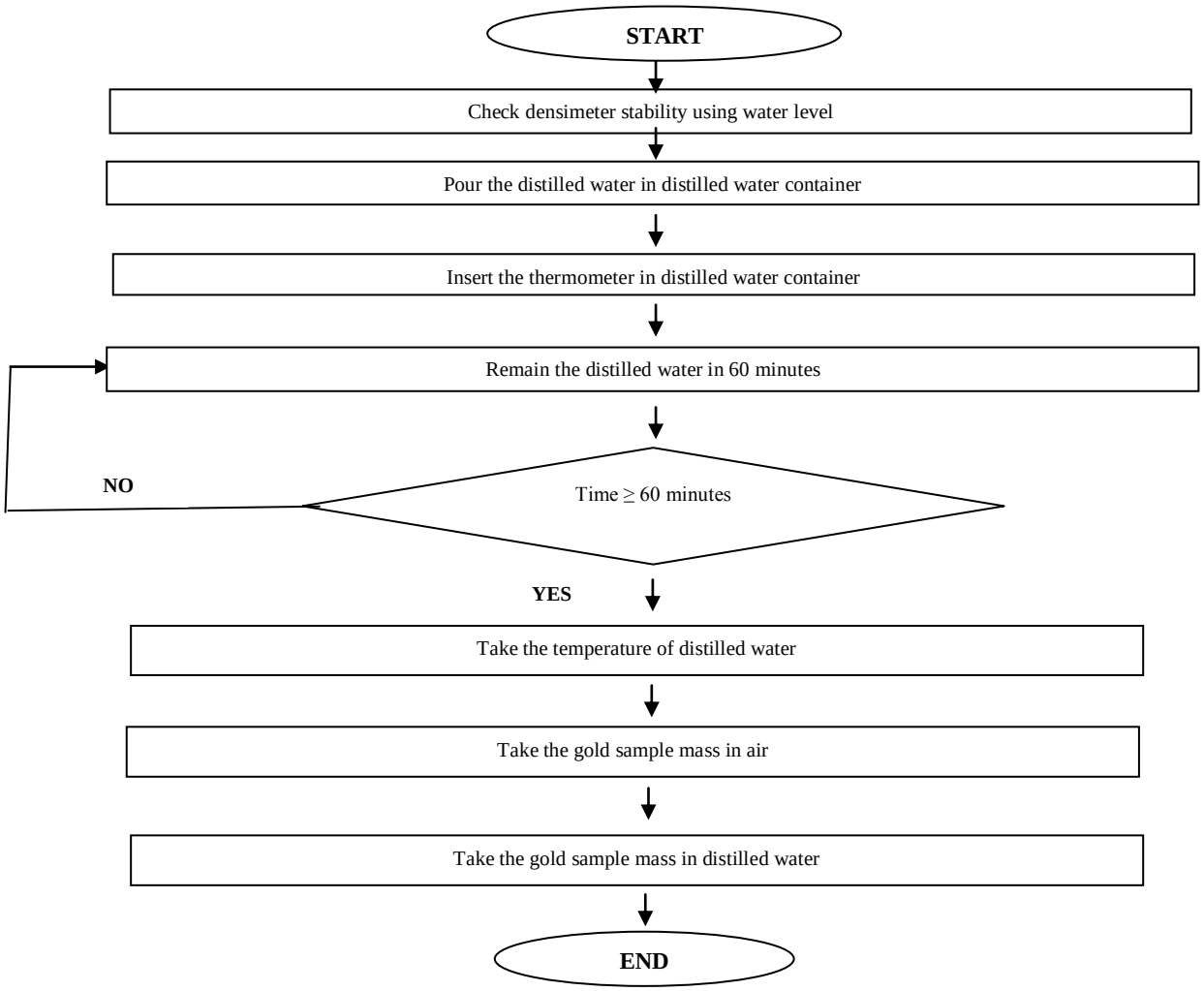

Fig.4: Flowchart of the gold purity procedure using densimeter

2.2 Weighing Balance

Testing and analytical laboratory used weighing balance to check the purity of gold. This instrument also can determine the density of gold sample. Gold sample mass in air and the distilled water will be measured to calculate the density of gold sample. Usually, the mass

readability of the weighing balance is 0.0001 g. Then, the liquid in glass will be used to measure the distilled water temperature and Kell's equation will be applied to obtain the density of gold sample[56].

Finally, the density of gold sample will be calculated using the weighing balance software. The density readability of the weighing balance is 0.00001 g/ml but the density accuracy is 0.1 g/ml [38]. Figure 3 and Figure 5 show the weighing balance used in the laboratory and flowchart for gold sample purity checking using weighing balance respectively.

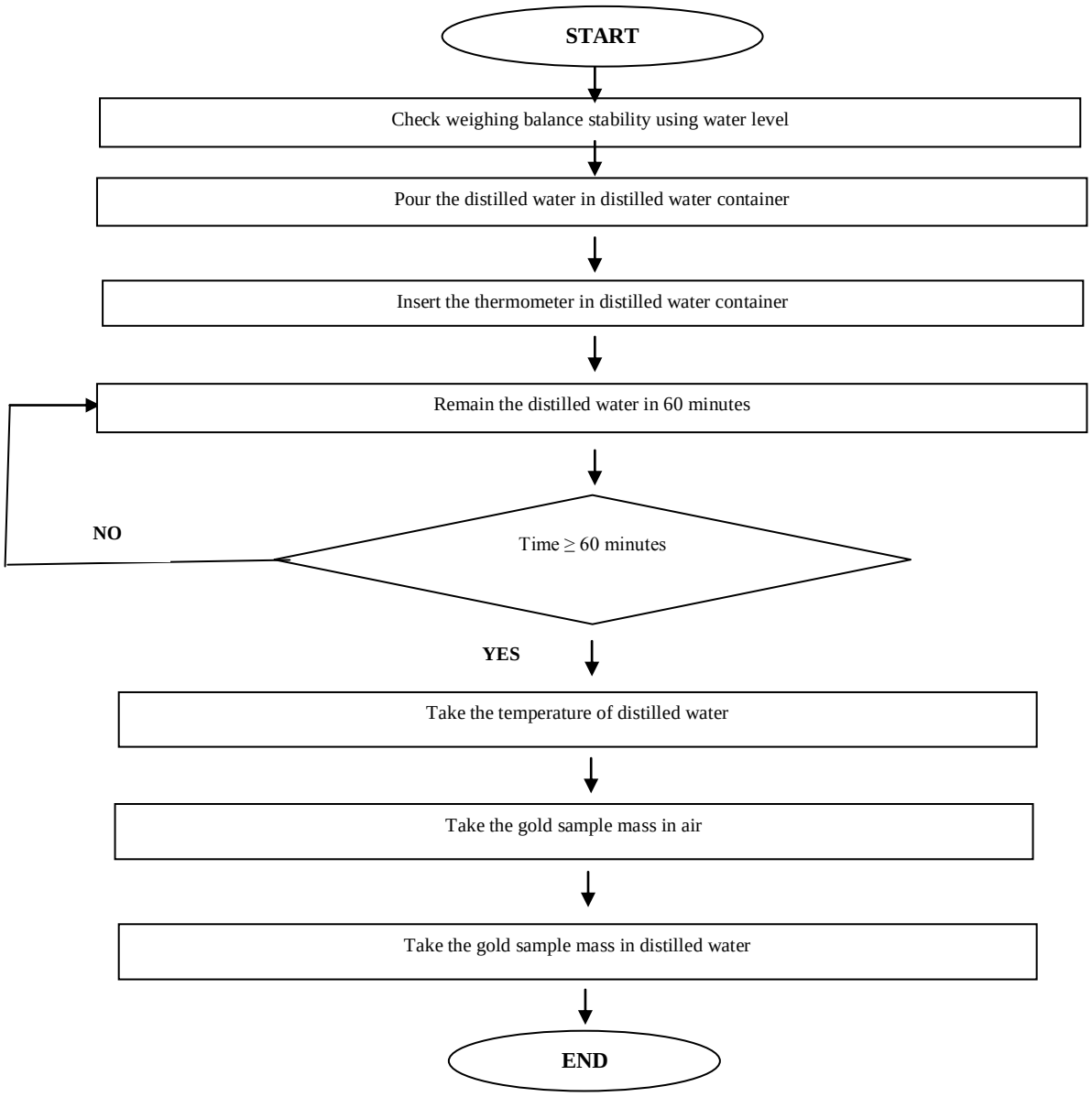

Fig.5: Flowchart of the gold sample purity checking using weighing balance

2.3 Traceability

Traceability is the ability to demonstrate the accuracy of a measurement result in terms of appropriate national or international standards [57-60]. It is important for instruments to have a traceability to the SI unit or national standards in order for the user to realize their measurement are align with others around the world [61-63].

Figure 6 summarizes the traceability of the gold density, starting from the primary density standard to the gold sample. The primary density standard is based on the physical artifact determined by its standard mass and length and it must comply with the definition of the SI base unit.

National Metrology Institute of Japan (NMIJ) use optical interferometer and hydrostatic weighing system for material density measurement [64]. NMIJ use optical interferometer to measure the density of silicon sphere where a laser (He-Ne) is used to measure the diameter, D of the silicon sphere [65-67]. The asphericities silicon sphere is 70 nm, hence the volume sphere can be calculated accurately [68, 69].

Korea Research Institute of Standards and Science (KRISS) and NMIM uses hydrostatic weighing system to measure the density of Zeradur and Crystal sphere [44, 45]. Figure 7 shows the NMIM's crystal sphere as a density standard. KRISS's hydrostatic weighing system apparatus consists of a silicon sphere, tridecane, electronic balance and standard weights. KRISS's silicon sphere is calibrated at NMIJ and tridecane is used as a transfer liquid where it will determine a density value of the Zeradur. Conversely, there are many research institutes using distilled water as a standard liquid [70-72].

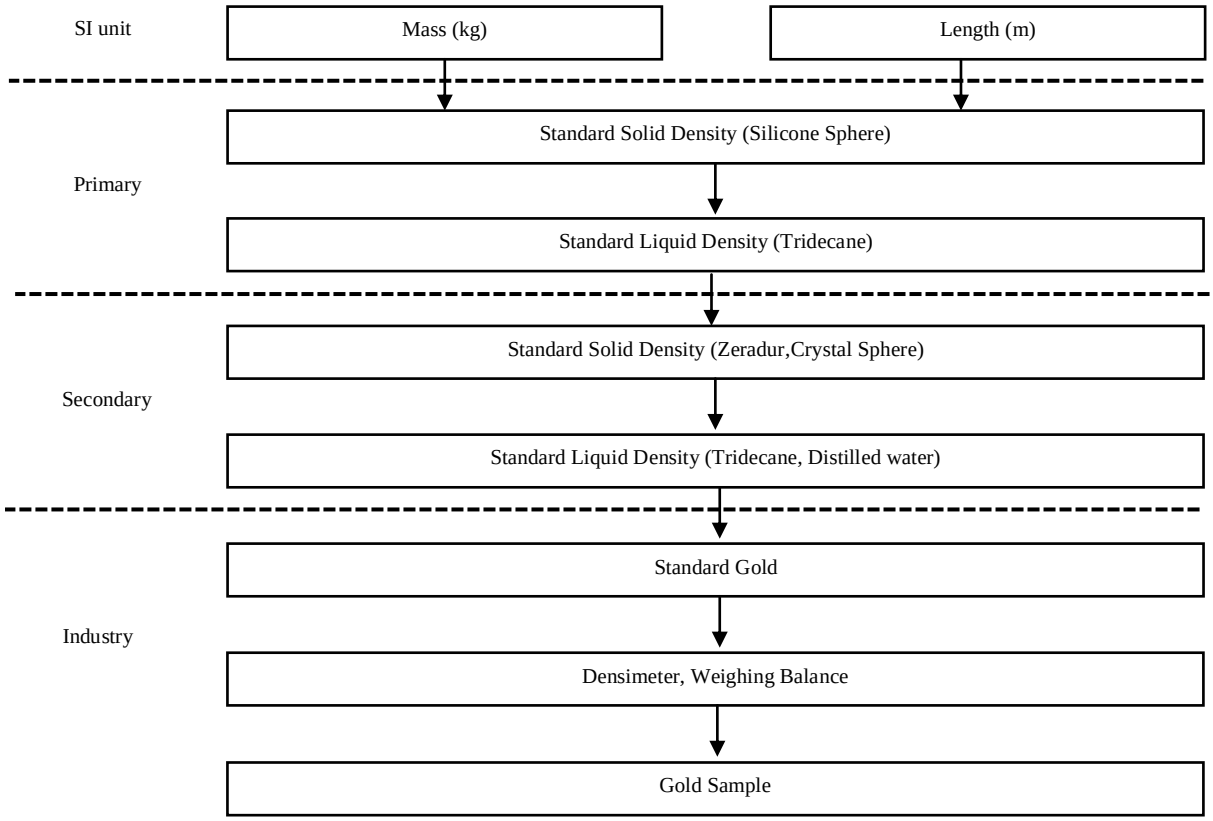

Fig.6: Traceability of the gold density

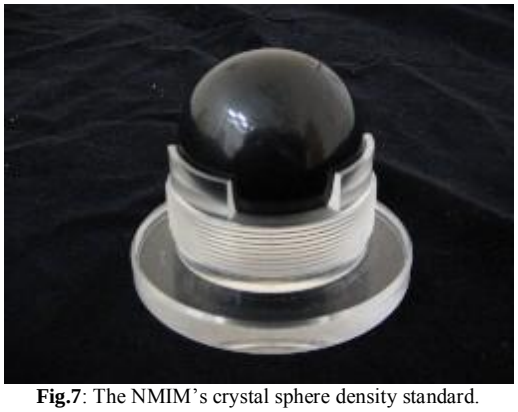

Fig.7: The NMIM's crystal sphere density standard.

The hydrostatic weighing method will be used to measure a standard liquid such as tridecane or distilled water whenever measuring the density of standard solid density. Then the value of the standard liquid density will be used to measure standard gold using hydrostatic weighing method.

Standard gold will be the reference standard to calibrate the gold purity measurement instruments such as densimeter and weighing balance. These instruments will measure the gold sample such as gold bar and jewellery to check their purity.

NMIM has developed standard gold to provide the traceability for densimeter and weighing balance as shown in Figure 8 [73-75]. Table 3 shows the NMIM's standard gold specification. Hydrostatic weighing system and XRF were used to measure the density and purity of the standard gold.

Table 3: NMIM's standard gold specification

No	Serial Number	Density (g/ml)	Purity (%)	Dimension (mm)
1	24 K	19.222	99.8	30 x 18 x 2
2	22 K	17.260	91.6	30 x 18 x 2
3	18 K	15.231	75.0	30 x 18 x 2

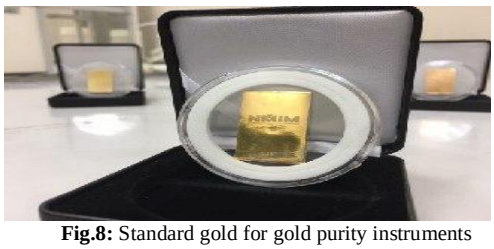

Fig.8: Standard gold for gold purity instruments

Standard gold was used as a reference standard to calibrate the densimeter and weighing balance [76]. Hence, all the gold purity measurement instruments were traceable to SI unit and their measurement values were more accurate and uniform moreover to avoid error during measurement. Furthermore, the trade will be increased and consumer confidence will be improved. Figure 9 shows the calibration of the client's densimeter using standard gold.

Fig.9: Calibration of the densimeter using NMIM's standard gold

3. Analysis of the Current Situation

Currently there is no single non-destructive method that can determined the gold purity precisely and accurately. Therefore, a lot of fake gold cases existed in the market [30, 77-80]. All non-destructive methods can only determine the gold purity at surface level. It's difficult for instruments of non-destructive method to detect the presence of other metal in gold. Normally the pawn shop, jewelry shop, bank agencies and testing laboratory use densimeter, weighing balance, XRF, needle, chemical solution, tri-electronic, magnet and stone due to economical, easy and all mentioned equipment above are using non-destructive method.

Although most commonly used instruments previously discussed have several advantages, still there are some major limitations and weaknesses such inaccurate measurement, poor repeatability and limited parameter in measurement. Tungsten is the only metal that has a density close to gold. Density of the gold and tungsten are 19.30 g/ml and 19.25 g/ml respectively[34]. The Densimeter and weighing balance are unable to detect the presence of tungsten in gold because of the tungsten density is extremely close to gold. Therefore, it is difficult for these instruments to trace the tungsten in gold.

There are several difficulties using both of these instruments. Inaccuracy of determining the density of gold is one of the difficulties. The accuracy of these instruments is 0.1 g/ml[55]. It will give a bad impact to gold industry due to the density of tungsten is almost similar to the density of gold [38]. Hence, it is difficult for these two instruments to identify the sample whether it is gold or tungsten whenever there is inaccuracy in the measurement.

4. Summary

Research study on gold density measurement was conducted in 1992 and 1997. Fake gold related to tungsten was discovered in 2012 after pawnshop in Malaysia had suffered a loss of RM 72 million. Hence, the study on fake gold focusing on jewelry was done by Malaysian researcher which was started in 2015 and their interest were on non-destructive method such as XRF and ultrasonic.

The most commonly used instruments previously discussed have several advantages, still there are some major limitations and weaknesses such inaccurate measurement, poor repeatability and limited parameter in measurement. Table 4 shows the limitation for non-destructive method instruments.

Table 4: Limitations for non-destructive method instruments

Instrument	Method	Unit	Limitation
XRF	Surface	%	Penetrate 10 to 50 microns
Weighing balance	Whole	g/ml	Similar with tungsten density
Densimeter	Whole	g/ml	Similar with tungsten density
Ultrasonic	Whole	m/s	Below 1 mm

5. Conclusion

This review has shown that the difficulties to identify the fake gold using non-destructive method instruments such as ultrasonic and XRF due to some major limitations. Research study on fake gold was started in 2015 focusing on jewelry. There is no research study on fake gold bar due to costly. Fake gold bar issues can be solved if the accuracy of density instrument can be improved to 0.01 g/ml where the main reason of this solution is the different between gold and tungsten density is 0.05 g/ml. Other instrument such as XRF will be used to verify the gold surface. Therefore, this fake gold bar problem can be solved using these two combination method

References

[1] Description and Marking of Articles of, or containing Precious Metal - Code of Practice. Malaysian Standard, 2005. MS 1247:2005.
[2] Stankiewicz, W., B. Bolibrzuch, and M. Marczak, Gold and gold alloy reference materials for XRF analysis. Gold Bulletin, 1998. 31(4): p. 119-125.
[3] Singh, N., A rugged, precise and accurate new gravimetry method for the determination of gold: an alternative to fire assay method. SpringerPlus. 1(1): p. 1-6.

[4] Corti, C.W., Metallurgy of microalloyed 24 carat golds. Gold Bulletin, 1999. 32(2): p. 39-47.
[5] Ning, Y., Properties and applications of some gold alloys modified by rare earth additions. Gold Bulletin, 2005. 38(1): p. 3-8.
[6] Bache JJ. World gold deposits: A geological classification. Elsevier Publishing Company; 1987 Jul 1.
[7] Dutton, J., Gold. By Kettell Brian. Cambridge, Massachusetts: Ballinger Publishing Company, 1982, Pp. xv, 283. $22.50. The Journal of Economic History, 1982. 42(4): p. 985-986.
[8] Mitsubishi makes record-size gold bar. Japan Times, June 17, 2005.
[9] Jotanović A, Memić M, Suljagić Š, Huremović J. Comparison of x-ray fluorescent analysis and cupellation method for determination of gold in gold jewellery alloy. Glasnik hemičara i tehnologa Bosne i Hercegovine. 2012;38:13-8.
[10] Bardi U, Niccolai F, Tosti M, Tolstogouzov A. Gold assay with Knudsen effusion mass spectrometry. International Journal of Mass Spectrometry. 2008 Jun 15;273(3):138-44.
[11] Battaini, P., E. Bemporad, and D. De Felicis, The fire assay reloaded. Gold Bulletin, 2014. 47(1-2): p. 9-20.
[12] Karadjova, I., S. Arpadjan, and L. Jordanova, Determination of trace metals in high purity gold. Fresenius' journal of analytical chemistry, 2000. 367(2): p. 146-150.
[13] Kinneberg, D.J., S.R. Williams, and D.P. Agarwal, Origin and effects of impurities in high purity gold. Gold Bulletin, 1998. 31(2): p. 58-67.
[14] Brill, M., Analysis of carat gold. Gold technology, 1997. 22: p. 10.
[15] Brill, M. and K.H. Wiedemann, Determination of gold in gold jewellery alloys by ICP spectrometry. Gold Bulletin, 1992. 25(1): p. 13-26.
[16] Hanrahan, J.F., The fire assay method as applied to high purity gold at the Rand Refinery, Limited. Journal of the Southern African Institute of Mining and Metallurgy, 1962. 62(12): p. 712-727.
[17] Determination of gold in gold jewellery alloys - Cupellation method (fire assay). International Standard, 1997. ISO 11426(2nd Edition:1997(E)).
[18] Jewellery - Determination of precious metals in 999% gold, platinum and palladium jewellery alloys - Difference method using ICP-OES. International Standard, 2015. ISO 15093:2015 (E)(2nd Edition).
[19] Copper, lead and zinc sulfide concentrates - Determination of gold and silver - Fire assay gravimetric and flame atomic absorption spectrometric method. International Standard, 2016. ISO 10378:2016 (E)(3rd Edition).
[20] Raw, P., The assaying and refining of gold, a guide for the gold jewellery producer. World Gold Council, 1997.
[21] Smrcka, L., K. Misek, and J. Bednar, The density of quenched gold. Cechoslovackij fiziceskij zurnal B, 1965. 15(6): p. 418-424.
[22] Eames DA, Eames GA, Eames MA, inventors. Device to test and authenticate precious metal objects. United States patent application US 14/661,466. 2015 Oct 29.
[23] Majcen N, Majer M, Svegl IG, De Bievre P. Traceability of results of measurements of gold in precious metal alloys by XRF. Acta chimica slovenica. 2002 Jan 1;49(1):187-94.
[24] Rastrelli, A., et al., Modern and ancient gold jewellery attributed to the Etruscans: a science-based study. ArcheoSciences. Revue d'archéométrie. 2009(33): p. 357-364.
[25] Piorek S, Shefsky SI, Dugas ME, inventors; Thermo Scientific Portable Analytical Instruments Inc, assignee. System and method for identification of counterfeit gold jewelry using xrf. United States patent application US 13/365,713. 2013 Aug 8.
[26] Schaffer, S., Golden means: Assay instruments and the geography of precision in the Guinea trade, in Instruments, Travel and Science. 2003, Routledge. p. 32-62.
[27] Jalas, P., J.P. Ruottinen, and S. Hemminki, XRF analysis of jewelry using fully standardless fundamental parameter approach. Gold technology, 2002. 35: p. 28.
[28] AKTA PEMEGANG PAJAK GADAI 1972. Pesuruhjaya Penyemak Undang-Undang, Malaysia, 1972.
[29] GARIS PANDUAN AKTIVITI PAJAK GADAI ISLAM (AR-RAHNU). Suruhanjaya Koperasi Malaysia, 2013.
[30] Shamsuddin, N., PENIPUAN EMAS: LUAR BETUL DALAM TIPU. Harian Metro, 2016: p. 6.
[31] Blunt, E., Fake fears over Ethiopia's gold. BBC News, 2008.
[32] Reese, R.L., University physics. 2000: Brooks/Cole., pp: 501-504
[33] Hughes, S.W., Archimedes revisited: a faster, better, cheaper method of accurately measuring the volume of small objects. Physics Education, 2005. 40(5): p. 468.
[34] Abdullah J, Samsudin A, Omar NL, Manan HA. Non-Destructive Assaying Gold Jewellery Using Dual-Energy MicroComputed Tomography. JURNAL TEKNOLOGI. 2015 Jan 1;73(3).
[35] Arbutine, A., Pawnbroker's Guide to Metals Testing. Today's Pawnbroker, 2008.
[36] Oddy, A., Assaying in antiquity. Gold Bulletin, 1983. 16(2): p. 52-59.
[37] Nekrasov, I.Y., Geochemistry, mineralogy and genesis of gold deposits. 1996: CRC Press.
[38] Corti, C.W., Assaying of gold jewellery-Choice of technique. Gold technology, 2001. 32: p. 20-30.
[39] Kraut, J.C. and W.B. Stern, The density of gold-silver-copper alloys and its calculation from the chemical composition. Gold Bulletin, 2000. 33(2): p. 52-55.
[40] Ismail MP, Sani S, bin Mohd Shofri FS, Harun M, Omar NB. Ultrasonic inspection of fake gold jewelry. InIOP Conference Series: Materials Science and Engineering 2018 Jan (Vol. 298, No. 1, p. 012025). IOP Publishing.
[41] Lorefice S, Malengo A, Vámossy C, Bettin H, Toth H, do Céu Ferreira M, Gosset A, Madec T, Heinonen M, Buchner C, Lenard E. EUROMET. MD-K4/EUROMET Project 702: Comparison of the calibrations of high-resolution hydrometers for liquid density determinations. Metrologia. 2008 Jan 1;45(1A):07008.
[42] Wilson, R.M., Archimedes's principle gets updated. Physics Today. **65**(9): p. 15.
[43] Reid, F.H. and W. Goldie, Gold plating technology. 1974.
[44] KH Chang, Y.L., Hydrostatic Weighing at KRISS. Metrologia, 2004(41): p. 95-955.
[45] Nor MF, Othman H, Abidin AR. Density Measurement of Tridecane by using Hydrostatic Weighing System at Density Laboratory, NML-SIRIM. InAIP Conference Proceedings 2009 Jul 7 (Vol. 1150, No. 1, pp. 196-200). AIP.
[46] Nor, F.M., Ring Method for Hydrometer Calibration. International Measurement Confederation, IMEKO, 2012.
[47] Nor FM, Ismail AK, Clarkson M, Othman H. An improved ring method for calibration of hydrometers. Measurement. 2014 Feb 1;48:1-5.
[48] Walker, J., R. Resnick, and D. Halliday, Fundamentals of physics. 2008: Wiley.
[49] Breithaupt, J., Physics Extension File:(For International Schools). 1998: Nelson Thornes.
[50] Johnson, K., Physics for you. 2001: Nelson Thornes.
[51] Gupta, S.V., Practical density measurement and hydrometry: Taylor & Francis.
[52] Paradisa, P.F., T. Ishikawaa, and N. Koikeb, Density of liquid gold measured by a non-contact technique. Gold Bulletin, 2008. 41(3): p. 242-245.
[53] Suzuki T, Kitsutaka R, Muto T, Morisaki S. Determination of the Purity of Gold Alloys Using Gamma-Ray Transmisson Techniques. Japanese journal of applied physics. 1998 Nov;37(11R):6242.
[54] Mansouri SS, Farsi A, Shadravan V, Ghader S. Density calculation of liquid organic compounds using a simple equation of state up to high pressures. Journal of Molecular Liquids. 2011 May 1;160(2):94-102.
[55] E.Mercer, M., METHODS FOR DETERMINING THE GOLD CONTENT OF JEWELRY METALS. Gems and Gemology, 1992. 28(4): p. 222-233.
[56] Specification for Density hydrometers. British Standard 1991. BS718:1991.
[57] Nicholas, J.V. and D.R. White, Traceable temperatures: an introduction to temperature measurement and calibration. 2002, IOP Publishing.

[58] Nicholas, J.V. and D.R. White, Traceable temperatures: an introductory guide to temperature measurement and calibration. Vol. 234. 1982: Science Information Division, DSIR.
[59] Rahim, R.A., Pengukuran dan transduser. 1999: Penerbit UTM.
[60] Nicholas, J.V. and D.R. White, Traceable Temperatures: an introduction to temperature measurement and calibration. 1994: Wiley New York.
[61] Kochsiek M, Gläser M, editors. Handbook of Metrology. John Wiley & Sons; 2010 Jun 15. pp:9-11
[62] Morris, A.S. and R. Langari, Measurement and instrumentation: theory and application: Academic Press. pp:1-10
[63] Jenkins, S., Measurement and Instrumentation: Theory and Application. Chemical Engineering. 118(12): p. 9-10.
[64] Fujii, K., A. Waseda, and N. Kuramoto, Development of a silicon density standard and precision density measurements of solid materials by hydrostatic weighing. Measurement Science and Technology, 2001. 12(12): p. 2031.
[65] Saunders, J.B., Ball and cylinder interferometer. Res. Natl Bur. Stand. C, 1972. 76: p. 11-20.
[66] Nicolaus, R.A. and G. Bonsch, A novel interferometer for dimensional measurement of a silicon sphere. IEEE transactions on instrumentation and measurement, 1997. 46(2): p. 563-565.
[67] Gupta, S.V., Comprehensive Volume and Capacity Measurements. 2006: New Age International.
[68] Smith, G.T., Industrial metrology: surfaces and roundness. 2002: Springer.
[69] R.K.Rajput, Engineering Metrology And Instrumentation (Including Laboratory Practicals). S.K.Kataria & Sons, 2010(4th Edition). pp: 213-240
[70] Tanaka M, Girard G, Davis R, Peuto A, Bignell N. Recommended table for the density of water between 0 C and 40 C based on recent experimental reports. Metrologia. 2001 Aug;38(4):301.
[71] Patterson, J.B. and E.C. Morris, Measurement of absolute water density, 1 C to 40 C. Metrologia, 1994. 31(4): p. 277.
[72] Bigg, P.H., Density of water in SI units over the range 0-40 C. British Journal of Applied Physics, 1967. 18(4): p. 521.
[73] Alias, A.Y., SIRIM hasilkan MyRM GOLD tentukan ketulenan emas. Utusan Malaysia, 20 Disember 2017.
[74] Zain, R.M., SIRIM lancar khidmat rujuk ketulenan emas. Berita Harian, 20 Disember 2017.
[75] NMIM lancar myRM Gold. Harian Metro, 20 Disember 2017.
[76] Bahan K, Penentukuran K, Penentukuran F, Instrumen PP, untuk Menentukur P, Penentukuran I, Penentukuran P, Penentukuran PS, Instrumen R, Instrumen MK. BAB 1 METROLOGI Pengenalan Kemudahkesanan Definisi Interpretasi.
[77] Ahmad, Z.A., Law to require gold, silver contents verified. The Star, 4 October 2002.
[78] Alias, W.N.H.W., Bank tempatan rugi RM75 juta ditipu. Utusan Malaysia, 24 July 2012.
[79] Rahman, D.A.A., Rantai emas palsu pun nak digadai. Harian Metro, 25 Januari 2018.
[80] Shamsuddin, N., Penipuan Emas: Kaji Ketulenan. Harian Metro, 8 November 2011.