AN IMPROVED RING METHOD FOR CALIBRATION OF HYDROMETERS

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A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Science (Physics)

Faculty of Science
Universiti Teknologi Malaysia

AUGUST 2014

To my beloved parent

Mohd Nor bin Jaafar
Fatimah bte Ithnin

To my beloved wife and children
who always there for me

Noor Zarina bte Sulaiman
Ahmad Farhan bin Mohd FazrulHisyam
Ahmad Farihin bin Mohd FazrulHisyam
Khairun Naajihah bte Mohd FazrulHisyam

You are always in my mind...

ACKNOWLEDGEMENT

I wish to express my sincere gratitude to my supervisor, Dr. Abd Khamim bin Ismail for his encouragement, guidance, criticism and friendship. My special thanks to Dr. Mark Clarkson, Dr. Kunihiko Toda and Mr.Futoshi Inoue for their technical support.

My greatest appreciation goes to Mrs Hafidzah Othman for her supports in this project. My fellow colleagues should also be recognized for their support and assistance in various occasions. Their views and opinions are indeed useful.

I am also indebted to the Ministry of Science, Technology and Innovation of Malaysia and SIRIM for their financial support.

And last but not least, special thanks go to all my family members who have given me strength and moral support in completing this thesis.

ABSTRACT

This study describes an improved hydrometer calibration method using a ring type sinker as a reference standard mass. Ring method offers simple yet effective hydrometer calibration method with comparable performance to other hydrometer calibration methods. This work also reports a ring method experimental setup for calibrating hydrometers. The theoretical calculation was developed and tested with experimental data. This calibration method can be used for any surface tension and reference temperature design of hydrometer. A suitable dimension of standard ring was used to sink hydrometers into distilled water. The distilled water was used as standard liquid, traceable to a standard solid density determined by hydrostatic weighing method. A tensiometer consisting of balance and Wilhelmy plate was used to measure the surface tension of the distilled water. The calibration results showed an improvement in the calibration range between 0.600 g mL^{-1} and 1.000 g mL^{-1} with an uncertainty of 0.0002 g mL^{-1} for hydrometers with scale graduations of 0.0005 g mL^{-1}. The differences in measured scale corrections of this method compared to the comparison method and hydrostatic weighing method indicate a bias smaller than half of the hydrometer graduation. In comparison, this method offers simpler, cheaper calibration with accuracy comparable to other existing hydrometer calibration methods. Furthermore, no harmful chemicals were used as standard liquid especially mixtures of volatile hydrocarbons or aqueous solutions of acids.

ABSTRAK

Kajian ini menerangkan penambahbaikan tentukuran hidrometer dengan menggunakan cincin pemberat sebagai standard rujukan. Kaedah cincin ini menawarkan tentukuran hidrometer yang berkesan dan setanding dengan kaedah tentukuran hidrometer yang lain. Selain daripada itu, kajian ini juga melaporkan persediaan eksperimen untuk menentukur hidrometer dengan menggunakan kaedah cincin. Pengiraan teori telah dibangunkan dan diuji dengan data eksperimen. Kaedah penentukuran ini boleh digunakan untuk semua jenis ketegangan permukaan hidrometer dan suhu rujukan hidrometer. Cincin standard yang sesuai telah digunakan untuk menenggelamkan hidrometer ke dalam air suling. Air suling digunakan sebagai standard cecair yang bolehkesan kepada standard pepejal melalui kaedah hidrostatik. Tensiometer yang terdiri daripada alat penimbang dan plat Wilhelmy telah digunakan untuk mengukur ketegangan permukaan air suling. Keputusan tentukuran menunjukkan penambahbaikan dalam penentukuran antara 0.600 g mL^{-1} dan 1.000 g mL^{-1} dengan ketidakpastian sebanyak 0.0002 g mL^{-1} untuk hidrometer dengan sub-skala 0.0005 g mL^{-1}. Perbezaan dalam pembetulan skala digunakan bagi membandingkan kaedah cincin dengan kaedah perbandingan dan kaedah hidrostatik. Perbezaan dalam pembetulan skala menunjukkan perbezaannya sangat kecil. Sebagai perbandingan, kaedah ini menawarkan cara yang lebih mudah, penentukuran lebih murah dengan ketepatan setanding dengan lain-lain kaedah penentukuran hidrometer yang sedia ada. Seterusnya, tiada sebarang bahan kimia berbahaya digunakan sebagai standard cecair terutama campuran hidrokarbon yang mudah meruap atau asid.

TABLE OF CONTENTS

CHAPTER	TITLE		PAGE
	DECLARATION		i
	DEDICATION		ii
	ACKNOWLEDGEMENT		iii
	ABSTRACT		iv
	ABSTRAK		v
	TABLE OF CONTENTS		vi
	LIST OF TABLES		x
	LIST OF FIGURES		xi
	LIST OF SYMBOLS		xiv
	LIST OF ABBREVIATIONS		xvii
	LIST OF APPENDICES		xviii
1	**INTRODUCTION**		
	1.1	Background of Problem	1
	1.2	Problem Statement	3
	1.3	Objectives	3
	1.4	Research Significance	3
	1.5	Scope	4

2	**LITERATURE REVIEW**		
	2.1	Introduction	5
	2.2	Hydrometer	6
	2.3	Hydrometer Calibration	8
	2.4	Hydrometer Calibration Method	9
		2.4.1 Hydrostatic Weighing Method	10
		2.4.2 Comparison Method	13
		2.4.3 Ring Method	17
	2.5	Hydrometer Calibration Method used by NML-SIRIM	17
	2.6	Proposed Hydrometer Calibration Method	20
		2.6.1 Ring	24
		2.6.2 Distilled Water	27
		2.6.3 Air Density	29
3	**METHODOLOGY**		
	3.1	Introduction	31
	3.2	Sample Preparation	31
	3.3	Hydrostatic Weighing Method	32
		3.3.1 Experimental Setup	33
		3.3.1.1 Measurement of Tridecane Density	33
		3.3.1.2 Surface Tension Measurement of Tridecane using Wilhemy Plate	37
		3.3.1.3 Measurement of Stem Hydrometer Diameter	40
		3.3.1.4 Cleaning the Hydrometer	41
		3.3.1.5 Measurement of Tridecane Temperature	41

		3.3.1.6 Measurement of Air Density	42
		3.3.2 Calibration Procedure	43
	3.4	Comparison Method	47
		3.4.1 Experimental Setup	47
		3.4.1.1 Cleaning the Hydrometer	47
		3.4.1.2 Density Solution Preparation	47
		3.4.1.3 Density Solution Temperature Measurement	49
	3.4.2	Calibration Procedure	49
	3.5	Ring Method	56
		3.5.1 Experimental Setup	57
		3.5.1.1 Density of Distilled Water Measurement	57
		3.5.1.2 Surface Tension of Distilled Water Measurement	58
		3.5.1.3 Stem Hydrometer Diameter Measurement	58
		3.5.1.4 Cleaning the Hydrometer	59
		3.5.1.5 Distilled Water Temperature Measurement	59
		3.5.1.6 Air Density Measurement	59
	3.5.2	Calibration Procedure	60
4	**RESULT AND DISCUSSION**		
	4.1	Introduction	62
	4.2	Standard Liquid Density	63
		4.2.1 Tridecane	63
		4.2.2 Distilled Water	65
	4.3	Surface Tension of Liquid	66
		4.3.1 Tridecane	66
		4.3.2 Distilled Water	68
	4.4	Air Density Measurement	70
	4.5	Hydrometer Calibration Method Result	72
	4.6	Verification of Hydrometer Calibration Method	75

4.6.1 Comparison Result Between Ring Method and Other Well Established Method 75

4.7 Bilateral Comparison with Other NMI 79

4.7.1 Bilateral Comparison between NML-SIRIM and MSL-NZ 79

4.7.2 Bilateral Comparison between NML-SIRIM and NMIJ 80

4.8 Other benefits 82

5 CONCLUSION AND RECOMMENDATION

5.1 Conclusion 83

5.2 Recommendation 84

PUBLICATIONS 86

REFERENCES 87

Appendices 91

LIST OF TABLES

TABLE NO.	TITLE	PAGE
2.1	Surface tension correction	15
2.2	Number of hydrometer received for year 2008 to 2010	18
2.3	Cost involved in comparison method	19
2.4	Dimension of the standard sinkers	25
3.1	Stem diameters for hydrometers	32
3.2	List of density solution mixtures	48
3.3	Density solution list for hydrometer calibration by comparison method.	51
4.1	Analysis of expanded uncertainty at 95% confidence level	64
4.2	Density of distilled water	65
4.3	Sources of uncertainty estimated at 95% confidence level	67
4.4	Surface tension of the tridecane measurement data	67
4.5	Distilled water surface tension	69
4.6	Analysis of expanded uncertainty hydrostatic weighing method at an estimated 95% confidence level	78
4.7	Analysis of expanded uncertainty comparison method at an estimated 95% confidence level	78
4.8	Analysis of expanded uncertainty ring method at an estimated 95% confidence level	79
4.9	Time of hydrometer calibration	82

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
2.1	A freely floating hydrometer with representation of the force acting on it	8
2.2	Density Traceability	9
2.3	Crystal Sphere at NML-SIRIM, Malaysia	11
2.4	Hydrometer and sinker	12
2.5	Comparison method apparatus	14
2.6	Type of liquids	16
2.6 (a)	Clear liquid	16
2.6 (b)	Opaque liquid	16
2.7	Calibration of hydrometer (Serial Number:3108/F) by comparison method	18
2.8	A freely floating hydrometer and sinker with representation of the forces acting on it.	22
2.9	A ring type standard sinker design	24
2.10	Length comparator	26
2.11	Length comparator and standard sinker	26
2.12	Digital micrometer	27
2.13	Digital Thermohygrometer	30
3.1	Hydrostatic weighing experimental setup	34
3.1 (a)	Schematic diagram	34
3.1 (b)	Experiment setup	34
3.2	Crystal sphere holder	35
3.2 (a)	Crystal sphere holder schematic	35
3.2 (b)	Crystal sphere holder setup	35
3.3	Standard Weight (METTLER, E2)	36
3.4	Crystal sphere weighing scale	37
3.5	Surface tension liquid system	38

3.5 (a)	Schematic of surface tension liquid system	38
3.5 (b)	Surface tension liquid setup	38
3.6	Wilhelmy Plate	39
3.7	Measurement of stem hydrometer diameter by micrometer	40
3.8	Scrub the hydrometer stem by using 5% Decon 90	41
3.9	Digital thermometer (ASL, F250) with high accuracy for distilled water temperature measurement	42
3.10	Digital barometer (DRUCK, DPI705) in the Density Laboratory	43
3.11	Hydrostatic weighing system in the Density Laboratory	44
3.12	Flowchart for hydrostatic weighing method	46
3.13	Chemical solution cabinet	48
3.14	Liquid in glass thermometer	49
3.15	Density solution was kept in fume hood for 2 hours.	50
3.16	Hydrometer calibration by comparison method facilities	53
3.17	Comparison method flowchart	54-55
3.18	Setup of hydrometer calibration by ring method	56
3.19	Schematic of ring method	56
3.20	Reading the scale hydrometer	57
3.21	Flowchart of hydrometer calibration by ring method	60
4.1	Density of tridecane	61
4.2	Density of distilled water	63
4.3	Graph of distilled water density	65
4.4	Surface tension of the tridecane at 20°C	66
4.5	Distilled water surface tension versus Temperature	68
4.6	Distilled water surface tension measurement obtained by NML-SIRIM and MSL-NZ	69
4.7	Ambient temperature in the Density Laboratory, NML-SIRIM	70
4.8	Ambient humidity in the Density Laboratory, NML-SIRIM	71
4.9	Density hydrometer (Serial Number: 3108/F)	71
4.10	Density hydrometer (Serial Number: 778)	72
4.11	Density hydrometer (Serial Number: 3355/L)	73

4.12	Density hydrometer (Serial Number: 3213L)	73
4.13	Specific Gravity hydrometer (Serial Number: 08/259237)	74
4.14	Density hydrometer (Serial Number: 3355/L)	74
4.15	Density hydrometer (Serial Number: 3108F)	76
4.16	Density hydrometer (Serial Number: 01105)	76
4.17	Density hydrometer (Serial Number: 3213L)	77
4.18	Hydrometer errors determined by MSL and NML-SIRIM	77
4.19	Hydrometer errors determined by NMIJ and NML-SIRIM	80
		81

LIST OF SYMBOLS

ρ_c	-	Calculated Density
$\rho_{a1,3}$	-	Air density when weighing the standard weight, S1
ρ_a	-	Air density
ρ	-	Hydrometer reading
ρ_{at}	-	Density of air at the time of the measurement at temperature t
ρ_{st}	-	Density of the sinker at temperature t
ρ_{wt}	-	Density of distilled water at temperature t
γ	-	Surface tension of the distilled water
σ	-	Surface Tension liquid
β_{cry}	-	Thermal expansion coefficient of crystal sphere
Δs	-	Balance sensitivity
A_o	-	Contact angle
A_f	-	Contact angle of the liquid at the hydrometer stem
C_T	-	Temperature Corrections
C_{ST}	-	Surface Tension Corrections
C_M	-	Meniscus Corrections
C_{CAL}	-	Hydrometer Calibration Corrections
d	-	Stem diameter hydrometer
D	-	Diameter of hydrometer stem
F_M	-	Mass Force
F_{ST}	-	Surface Tension Force
F_i	-	Water Force
F_a	-	Air Force
F	-	Force
Fg_{sinker}	-	Standard sinker gravitational force
Fg_{hyd}	-	Hydrometer gravitational force

F_{ST}	-	Surface tension force
Fa_{hyd}	-	Hydrometer buoyancy force in air
Fi_{hyd}	-	Hydrometer buoyancy force in liquid
Fi_{sinker}	-	Sinker buoyancy force
g	-	Gravity
g_{RS}	-	Gravity ratios
g_l	-	Local gravity
i	-	Nominal scale range
L	-	Length
m	-	Mass
M_{S1}	-	True masses of the standard weight S1
M_{S2}	-	True masses of the standard weight S2
M_{cry}	-	True mass of the crystal sphere
M	-	Mass of the hydrometer
m_s	-	Mass of sinker(s) on the hydrometer
M_{wet}	-	Mass of the Wilhelmy plate wetted
M_{dry}	-	Mass of the Wilhelmy plate dry
m_H	-	Mass of the hydrometer
P	-	Ambient pressure
R	-	Hydrometer reading
s	-	Scale length
S_f	-	Surface tension of the liquid
S	-	Surface Tension Liquid
S_o	-	Surface tension
So	-	Design Surface Tension of hydrometer
T	-	Ambient temperature
t	-	Liquid temperature
t_S	-	Reference temperature of hydrometer
t_{plate}	-	Thickness of the Wilhelmy plate
v	-	Volume
V_{S1}	-	Volume of standard weight S1

V_{S2}	-	Volume of standard weight S2
$V^{20}{}_{cry}$	-	Volume of crystal sphere
V_i	-	Immersed volume of hydrometer
V_t	-	Volume of the hydrometer at temperature t
w	-	Width of the Wilhelmy plate

LIST OF ABBREVIATIONS

API	-	American Petroleum Institute
BS	-	British Standard
DCWU	-	Department of Chemistry, Wayne University
KRISS	-	Korea Research Institute of Standard and Science
MSL-NZ	-	Measurement Standard Laboratory, New Zealand
NMI	-	National Metrology Institute
NML-SIRIM	-	National Metrology Laboratory, SIRIM Berhad
NMIJ	-	National Metrology Institute of Japan
SI	-	International System
UUT	-	Unit Under Test

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Calibration reports of instruments	89
B	Table of temperature correction applicable to BS	108

CHAPTER 1

INTRODUCTION

1.1 Background of Problem

The earliest hydrometer ever invented was by Hypatia [1, 2]. She lived in Alexandria, Egypt and was born around 370AD. There were also inventors other than Hypatia including Leonardo Da Vinci [3], Antoine Baume [4], William Nicholson [5] and James Watt [6]

Hydrometer is an instrument used to measure a wide range of density of various liquid [7]. It will freely float with the stem partially immersed in liquid to an extent depending on the density of the liquid. The lower the density of the liquid the deeper the stem sink. There are many types of hydrometers namely: Density hydrometer, Specific Gravity hydrometer, Percentage hydrometer and Arbitrary scale hydrometer [8].

Hydrometers have found many practical applications particularly for measuring liquid density in many research areas and industries such as food and beverage, chemical, petroleum and gases [9, 10].

Before hydrometers can be used for measurement, they must go through calibration process. Calibration is a relationship between known value of a measurement and measuring instrument. The device with the known value is the standard. The second device or the measuring instrument is the unit under test or device being calibrated. The calibration objectives are to ensure readings from an instrument are consistent with other measurements and to determine the accuracy of the instrument readings.

Hydrometer calibration methods such as hydrostatic weighing method, comparison method, and ring method are the most popular methods commonly used by many national standards laboratories around the world [11-14]. There are many National Metrology Institutes such as Korea, New Zealand, Japan, Australia, Italy, Brazil and China using hydrostatic weighing method to calibrate the hydrometer [15-18]. They are using hydrostatic weighing method because of high accuracy compared with other method but high costly to develop. So there are many secondary laboratories using comparison method to calibrate the client hydrometer because it is cheaper than hydrostatic weighing method. National Metrology Institute, India is using ring method to calibrate the hydrometer [7, 12]. Ring method is more accurate compared to comparison method [19].

In the hydrostatic weighing method, the hydrometer is suspended from a weighing balance in order to determine the hydrometer mass in air and in standard liquid [20]. Both density of liquid and solid can be determined by using this method [21, 22]. It offers a high degree of accuracy but a high cost to develop. On the other hand, a comparison method offers simpler step where a hydrometer is compared to a standard hydrometer in chemical solution [13]. However it is time consuming since the chemical temperatures need to be stabilized before reading can be taken. The chemicals used as medium such as methanol, petroleum ether, sulphuric acid, mercury II iodide and potassium iodide are harmful and this is also a costly method to develop. The third method was so-called a ring method because a suitable dimension of metallic ring is used to sink the hydrometer into the liquid when inserted into its stem [12]. Harmful petroleum liquid such as diethyl ether and petroleum ether will be used as a standard medium. An expensive and fragile standard hydrometer was used to measure the density of the standard petroleum liquid. However, the calibration range of this method is very limited compared to other methods, which is only between 0.600g/ml to 0.650g/ml. Expanded range of calibration is very important and is currently on demands since typical hydrometer samples from industries are in the range between 0.600g/ml to 1.000g/ml.

1.2 Problem Statement

The most commonly used hydrometer calibration methods previously discussed have several advantages but also have some major limitations and drawbacks such as the used of harmful chemicals as standard solution, complicated calibration steps, limited range of calibration in the order of 0.600g/ml – 0.650g/ml, time consuming and expensive. This research project proposed a modified ring method which could solve some of those limitations.

1.3 Objectives

The objectives of this study are;

i. to design and construct a hydrometer calibration procedure based on ring method,
ii. to calibrate various samples of hydrometer using the proposed ring method and
iii. to verify and compare the performance of the proposed ring method with the existing hydrometer calibration method commonly used in Density Laboratory, National Metrology Laboratory, SIRIM Berhad (NML-SIRIM) and other National Metrology Institutes from other countries.

1.4 Research Significance

This work proposed an improved ring method for hydrometer calibration by using a ring type sinker as a traceable reference mass and later called as standard sinker. This standard sinker was added into the hydrometer stem and both were immersed into standard distilled water. The density of the standard distilled water will be measured using crystal sphere or solid artifact. This is much cheaper compared to an expensive and fragile standard hydrometer commonly used in hydrometer calibration. This method is predicted to be more accurate for up to five decimal places compared to the most popular methods mentioned above. The hydrometer calibration range could be further improved from 0.600 g/ml to 1.00 g/ml.

Furthermore, time spent for hydrometer calibration and monthly labor cost could be reduced since it offers much simpler calibration steps. The used of expensive and fragile standard hydrometer and standard harmful chemicals solution also can be avoided.

1.5 Scope

To meet the objectives, the following studies must be carried out:

i. Preparation and construction of the experimental setup for the ring hydrometer calibration method.
ii. Characterization and optimization of the parameters involved for verification purpose between the proposed method and the existing hydrometer calibration method.
iii. Construction of a computerized data acquisition system for the ring hydrometer calibration method.

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