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Design of Analytical Balance for Calibration of Measuring Cup of Observatory Type Rain Gauge with Automatic Pump

[1,2] Muhammad Wildan Abdulmajid, [1*]Kerista Tarigan, [1] Syahrul Humaidi, [1]Marhaposan Situmorang, [1] Perdinan Sinuhaji, [3] Yahya Darmawan

[1] Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Sumatera Utara, Jl. Dr. T. Mansur No.9, Padang Bulan, Medan 20222, Indonesia.

[2] BMKG – Indonesia Meteorology, Climatology and Geophysics Agency Regional I, Jl. Ngumban Surbakti No. 15, Medan 20131, Indonesia.

[3] School of Meteorology, Climatology and Geophysics (STMKG), Jl. Perhubungan I No.5, Pd. Betung, Tangerang Selatan 15221, Indonesia.

*Corresponding Author e-mail: kerista@usu.ac.id

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Abstract

The Observation type rain gauge is a manual type rain gauge that requires a measuring cup to measure rainfall in millimeters (mm) of rain. Precise measurement requires calibration of the measuring cup so that the scale reading on the measuring cup can be trusted. Calibration of measuring cups using the mass method related to volume can use an analytical balance. Technological developments can make manual analytical balance calibration automatic by utilizing microcontrollers and pumps in filling the volume. The design of the analytical balance gets results where the average correction value for the 50 ml set point is 0.001ml, the 100 ml set point is -0.760 ml, the 150 ml set point is -0.024 ml, the 200 ml set point is -0.739 ml, and the 250 ml set point is 0.628 ml. The uncertainty value for all set points is ±0.58 ml. The correction value at each set point is different, this is influenced by the value of the measuring cup meniscus, water temperature, and Load Cell sensor. The data generated by the tool can be downloaded through the Arduino IDE application and produced files in Excel.

Keywords: Measuring Cup, Calibration, Analytical Balance, Uncertainty, Arduino IDE, Excel

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INTRODUCTION

Rain is one of the most important natural phenomena for the survival of humans and ecosystems. Rain brings much-needed water for plant growth, maintains the water balance on the earth's surface, and helps solve drought problems. However, increased pollution and irresponsible human activities can affect the quality of rainwater and cause environmental damage. The Meteorology Climatology and Geophysics Agency (BMKG) is a government agency responsible for monitoring and studying the science of weather, climate, and geophysics and providing information and advice on weather and climate change to the public, one of which is about rainfall.

Rainfall is the amount of rainwater that falls on an area in a certain period of time, measurements can be made using a rain gauge. Rainfall data is very critical for BMKG, especially in providing early warning of potential natural disasters such as floods, landslides, and droughts. Information on high rainfall over a short period of time can indicate the potential for floods and landslides, while information on low rainfall over a long period of time can indicate the potential for drought. Rainfall information can also be used to predict future weather and climate.

To obtain rainfall data, BMKG uses several tools to measure rainfall, including automatic and manual rain gauges in various parts of Indonesia. The automatic type of rain gauge can read rainfall automatically and the read data is sent directly to the server. Manual rain gauge types are Hellman type and Observatory type, this rain gauge data requires a rain gauge glass to read the rainfall which each has a different volume and scale. The reading of the rainfall scale in the calibration process on the rain gauge glass manually has several reading errors, occurring due to parallax factors, improperly calibrated scales, and environmental conditions.

The important thing that affects the error in reading on the measuring cup is the scale that is not properly calibrated. Rain gauge measuring cups can be calibrated using the gravimetric method, but data collection is still handwritten and filling in water manually which takes a lot of time, errors in filling in the volume of water, and must be input data into the software to get calibration results. Based on these problems, a tool design was developed that can reduce several error factors and can be used in carrying out measuring cup calibration.

According to KAN (2019) on Guidelines Regarding Calibration of Volumetric Equipment, the calibration requirements are: calibration of volumetric equipment requires a single pan balance (mechanical or electronic) or an equal-arm balance, which has sufficient capacity to weigh a filled container, sensitivity, and sizes that can accept the container to be considered. As a guide, sufficient measurement uncertainty to verify volumetric equipment with sure accuracy, a scale with discrimination of no more than 1/10 the maximum error limit of the volumetric equipment to be calibrated is required.

METHOD

Design Flowchart

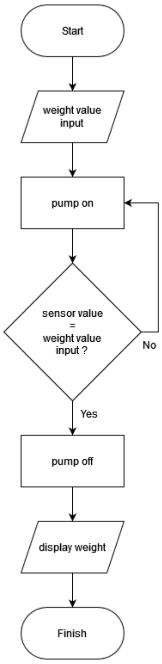

Figure 1. Design flowchart system

The system flow diagram on the tool to be made can be seen in Figure 1, the system starts can display the weight obtained by the sensor, then input the weight value to be measured. The pump will turn on when the value has been given, when the sensor has reached the weight value given, the pump will stop and the weight read by the sensor will be displayed on the LCD.

Tool Design Schematic

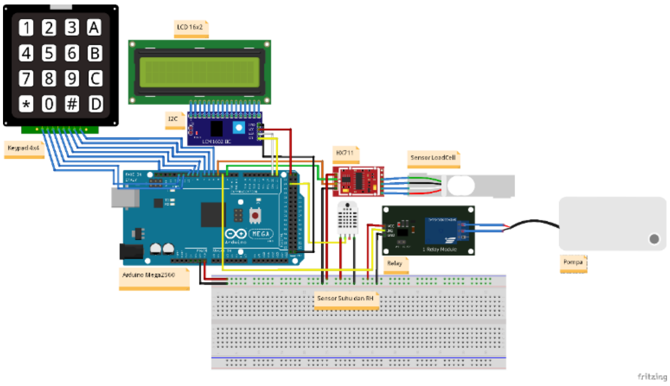

Figure 2. Tool Design Schematic

Schematic design to make an automatic observatory-type measuring cup calibration tool using a pump. Some sensors and other components will be set by the ATMega 2560 microcontroller. Connection of the Load Cell sensor connected to the HX711 module as a Load Cell sensor signal conditioner to make it easier to read by the ATMega 2560 microcontroller. DHT22 sensor that can detect changes in temperature and humidity for the condition of the measuring cup calibration test research room. design of a pump connected to a relay as a controller for on or off conditions on the pump. The pump requires a battery that can be recharged. 16x2 LCD connected to the I2C module so that the ATMega 2560 microcontroller can read the response from the LCD. The LCD is used as a display or displays the value of the Load Cell and DHT22 sensors that are read. 4x4 keypad which is used to set the amount of water flowing by the pump, as well as a button to run the command so that the relay can turn on the pump.

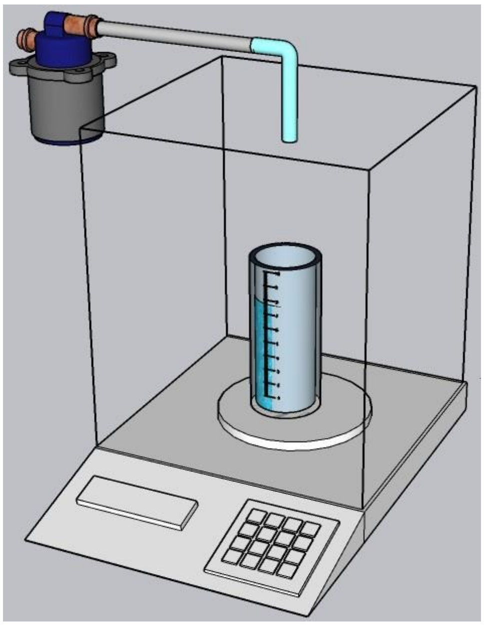

Figure 3. Tool Design

Calibration of Measuring Cups

Calibration Preparation

In carrying out calibration, there are several things that must be prepared, namely:

First, prepare a raw data form to record the readings in the calibration process. Second, prepare stationery. Third, prepare a flat table or place. Fourth, prepare an analytical balance that has been made. Fifth, prepare Fluke 1502A to measure water temperature. Sixth, prepare a barometer to measure room air pressure. Seventh, prepare clean water / distilled water. Eighth, prepare a clean cloth or tissue. Ninth, prepare a thermometer to measure the temperature of the distilled water. Tenth, make sure the table is placed in the right position, to be more accurate you can use a water pass or inclinometer. The scale of the measuring cup of the observatory rain gauge is 0-25 mm, so the set points to be tested are 5 mm, 10 mm, 15 mm, and 20 mm.

Calibration Procedure

The steps for calibrating the measuring cup using a pump are as follows: First, fill the measuring cup with water to clean the dirt, then wipe it with a tissue until it is completely dry. Second, place the measuring cup in empty condition on the balance sheet. Third, the analytical balance that has been designed has a tare feature, the empty glass that is weighed will be converted to 0 grams. Fourth, set the keypad for the first set point of 50 mL, press the 50 buttons on the keypad, then press the "D" button to run the pump program. The pump will automatically stop when the weight of the water in the measuring cup has reached 50 grams. Fifth, for the first set point of 50 mL, the observatory type measuring cup (obs) is calculated, namely, the area of the obs rain gauge funnel is 100 cm2, on the measuring cup scale is considered as the height to determine the volume, then the amount of distilled water poured is 50 cm3 (50mL) /100 cm2 = 0.5 cm or on the measuring cup scale is 5 mm. Record the results on the form that has been determined. Sixth, place a thermometer in the measuring cup to measure the temperature of the distilled water. Read and record the water temperature. Seventh, read and record the temperature, humidity, and pressure of the air in the environmental conditions. Eighth, transfer the water from the measuring cup to the distilled water reservoir, then clean the measuring cup until dry. Ninth, repeat 4 (four) times in the same set of points. Tenth, do the procedure from lift 1 to 8 until all set points have been calibrated.

Measurement Uncertainty Calculation

According to the book "Guidelines on Calibration of Volumetric Equipment" published by KAN with KAN number Pd-02.08, the estimation of measurement uncertainty based on solving general equations using tables in ASTM E 542, AS 2162.1 and ISO 4787 can be done referring to the possible volumetric errors caused by weighing, water temperature, air temperature, air pressure, air relative humidity and density of reference calibration scales, based on a simplified mathematical model as follows:

$$V_{20} = f(m_{air}, t_{air}, t_{udara}, p_{udara}, rH_{udara}, \rho_{AT})$$

where the estimated contribution of the standardized uncertainty of each quantity
input to the combined standard uncertainty of the measured volume at 20ºC can be evaluated as follows:

a. Standardized uncertainty contribution of the weighted water mass

$$u_{\Delta R} = \sqrt{(\sigma_{timb}/\sqrt{2})^2 + (LOP_{timb}/2\sqrt{3})^2}$$

b. Standardized uncertainty contribution from water temperature

$$u_{t_{air}} = \sqrt{(U_{95\_t_{air}}/k)^2 + (|t_{awal\_air} - t_{akhir\_air}|/2\sqrt{3})^2} \;;$$

$$c_{t_{air}} = 10^{-4} \cdot V_{nom}/0.5\,;$$

c. Standardized uncertainty contribution from air temperature

$$u_{t_{air}} = \sqrt{(U_{95\_t_{udara}}/k)^2 + (|t_{awal\_udara} - t_{akhir\_udara}|/2\sqrt{3})^2}$$

$$c_{t_{air}} = 10^{-5} \cdot V_{nom}/2.5\,;$$

d. Standardized uncertainty contribution from air pressure

$$u_{t_{air}} = \sqrt{(U_{95\_P_{udara}} / k)^2 + (|p_{awal\_udara} - p_{akhir\_udara}| / 2\sqrt{3})^2};$$

$$c_{t_{air}} = 10^{-4} \cdot V_{nom} / 0.8;$$

e. Kontribusi ketidakpastian baku dari kelembaban relatif udara

$$u_{t_{air}} = \sqrt{(U_{95\_rH} / k)^2 + (|rH_{awal} - rH_{akhir}| / 2\sqrt{3})^2}$$

$$c_{t_{air}} = 10^{-4} \cdot V_{nom} / 0.5;$$

f. Standardized uncertainty contribution from air relative humidity

$$u_{t_{air}} = 0{,}1\rho_m$$

$$c_{t_{air}} = 10^{-5} \cdot V_{nom} / 600$$

g. Standardized uncertainty contribution from meniscus setting (calibration system repeatability)

$$u_{meniskus} = \sigma_{control\_chart} / \sqrt{n}$$

h. Combined standard uncertainty

$$u_{V_{20}} = \sqrt{c_{m_{air}}^2 u_{m_{air}}^2 + c_{t_{air}}^2 u_{t_{air}}^2 + c_{t_{udara}}^2 u_{t_{udara}}^2 + c_{P_{udara}}^2 u_{P_{udara}}^2 + c_{rH_{udara}}^2 u_{rH_{udara}}^2 + c_{\rho_{AT}}^2 u_{\rho_{AT}}^2 + u_{meniskus}^2}$$

i. Expanded uncertainty

$$U_{95} = k \cdot u_{V_{20}}$$

j. Air Density (ρ_a)

To determine the density of air using CIPM Formula refers to OIML R111-1: 2004 which has air pressure requirements of 900 < p < 1100 mbar, temperature 10ºC < t < 30ºC and humidity less than 80% with a relative uncertainty of 2 x 10-4.

$$\rho_a = \frac{0{,}34848 \times p - 0{,}009(hr) \times \exp(0{,}061 \times t)}{273{,}15 + t} \quad g/mL$$

Dimana:

ρ_a = density of air (kg/m^3)

t = temperature (ºC)

p = air pressure (mbar)

h = relative humidity (%)

k. Water Density (ρ_w)

$$\rho_w = 999{,}8395639 + 0{,}06798299989 \times T - 0{,}009106025564 \times T^2 + 0{,}0001005272999 \times T^3 - 0{,}000001126713526 \times T^4 + 0{,}000000006591795606 \times T^5$$

Where:

ρ_w = density of water (kg/m^3)

T = water temperature (ºC)

The density value of water can be determined using the following table:

Table 1. Water density according to the Decree of the Director General of Consumer Protection and Trade Order No.124 of 2020

Temp	Density of water (kg/m^3)									
	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
15	999.0977	999.0826	999.0673	999.0519	999.0364	999.0208	999.0051	998.9892	998.9733	998.9572
16	998.9410	998.9247	998.9083	998.8917	998.8751	998.8583	998.8414	998.8244	998.8073	998.7901
17	998.7728	998.7553	998.7378	998.7201	998.7023	998.6845	998.6665	998.6483	998.6301	998.6118
18	998.5934	998.5748	998.5562	998.5374	998.5185	998.4995	998.4804	998.4612	998.4419	998.4225
19	998.4030	998.3833	998.3636	998.3438	998.3238	998.3037	998.2836	998.2633	998.2429	998.2224
20	998.2019	998.1812	998.1604	998.1395	998.1185	998.0973	998.0761	998.0548	998.0334	998.0119
21	997.9902	997.9685	997.9467	997.9247	997.9027	997.8805	997.8583	997.8360	997.8135	997.7910

Temp	Density of water (kg/m^3)									
	0.0	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**
22	997.7683	997.7456	997.7227	997.6998	997.6767	997.6536	997.6303	997.6070	997.5835	997.5600
23	997.5363	997.5126	997.4887	997.4648	997.4408	997.4166	997.3924	997.3680	997.3436	997.3191
24	997.2944	997.2697	997.2449	997.2200	997.1950	997.1699	997.1446	996.1193	997.0903	997.0685
25	997.0429	997.0172	997.9914	997.9655	997.9396	997.9135	997.8873	996.8611	997.8347	997.8033
26	996.7818	996.7551	996.7284	996.7016	996.6747	996.6477	996.6206	996.5934	996.5661	996.5388
27	996.5113	996.4837	996.4561	996.4284	996.4005	996.3726	996.3446	997.0305	996.2883	996.2600
28	996.2316	996.2032	996.1746	996.1460	996.1172	996.0884	996.0595	997.7356	996.0014	996.9722
29	996.9430	996.9136	996.8842	996.8546	996.8250	996.7953	996.7655	996.4319	996.7056	995.6765

Conversion : 1000 kg/m^3 = 1 g/mL

RESULTS AND DISCUSSION

Calibration Result

Table 2. Calibration results of measuring cup with pump

Set Point (ml)	Mass (g)	Water Temp (ºC)	Room Condition		
			Temperature (ºC)	Relative Humidity (%)	Air Pressure (mbar)
50	50.22	24.1	23.4	44.5	1001.2
	50.24	24.1	23.4	44.5	1001.2
	50.24	24.1	23.4	44.5	1001.2
	50.26	24.1	23.4	44.5	1001.2
100	104.34	24.1	23.4	43.0	1001.2
	104.35	24.1	23.4	43.0	1001.2
	104.31	24.1	23.4	43.0	1001.2
	104.41	24.1	23.4	43.0	1001.2
150	149.94	24.5	23.5	43.0	1001.9
	149.91	24.5	23.5	43.0	1001.9
	149.94	24.5	23.5	43.0	1001.9
	149.92	24.5	23.5	43.0	1001.9
200	199.03	25.0	23.5	45.0	1001.9
	199.04	25.0	23.5	45.0	1001.9
	199.02	25.0	23.5	45.0	1001.9
	199.03	25.0	23.5	45.0	1001.9
250	250.20	25.1	23.5	45.0	1001.9
	250.21	25.1	23.5	45.0	1001.9
	250.21	25.1	23.5	45.0	1001.9
	250.20	25.1	23.5	45.0	1001.9

Table 2 is the result of the calibration test using a pump, this data is then processed using the Excel application to facilitate the calculation. After processing the data, the results of the calibration will produce a correction value and calculation uncertainty value. The calculation of the correction value can be seen in the table below.

Table 3. Correction calculation result

Set Point (ml)	Mass (g)	ρ air / ρW (g/ml)	ρ udara / ρA (g/ml)	V actual (ml)	Correction (ml)
50	49.800	0.9973	0.0011703	49.981	-0.019
	49.820	0.9973	0.0011703	50.001	0.001
	49.820	0.9973	0.0011703	50.001	0.001
	49.840	0.9973	0.0011703	50.021	0.021
Average	49.820	0.9973	0.0011703	50.001	0.001

105	103.870	0.9973	0.0011705	104.247	-0.753
	103.880	0.9973	0.0011705	104.257	-0.743
	103.840	0.9973	0.0011705	104.216	-0.784
	103.940	0.9973	0.0011705	104.240	-0.760
Average	103.883	0.9973	0.0011705	104.240	-0.760
150	149.440	0.9973	0.0011714	149.989	-0.011
	149.410	0.9973	0.0011705	149.958	-0.042
	149.440	0.9973	0.0011705	149.989	-0.011
	149.420	0.9973	0.0011708	149.969	-0.031
Average	149.428	0.9973	0.0011708	149.976	-0.024
200	198.500	0.9971	0.0011703	199.261	-0.739
	198.510	0.9971	0.0011703	199.271	-0.729
	198.490	0.9971	0.0011703	199.251	-0.749
	198.500	0.9971	0.0011703	199.261	-0.739
Average	198.500	0.9971	0.0011703	199.261	-0.739
250	249.660	0.9970	0.0011703	250.623	0.623
	249.670	0.9970	0.0011703	250.633	0.633
	249.670	0.9970	0.0011703	250.633	0.633
	249.660	0.9970	0.0011703	250.623	0.623
Average	249.665	0.9970	0.0011703	250.628	0.628

Table 3 is the result of calibrating the measuring cup using an analytical balance with a pump, it can be seen that the average correction value of the measuring cup at set point 50 ml is 0.001 ml, and at set point 105 ml the average correction value of the measuring cup is -0.760 ml, at set point 150 ml the average correction value of the measuring cup is -0.024 ml, at set point 200 ml the average correction value of the measuring cup is -0.739 ml and at set point 250 ml the average correction value of the measuring cup is 0.628 ml. There is no measuring cup correction value above 1 ml, which means that the measuring cup observatory is operational. The 105 ml set point should be a 100 ml set point, but after repeated experiments, the measuring cup does not show a 100 ml scale, but 10.5 mm or 105 ml.

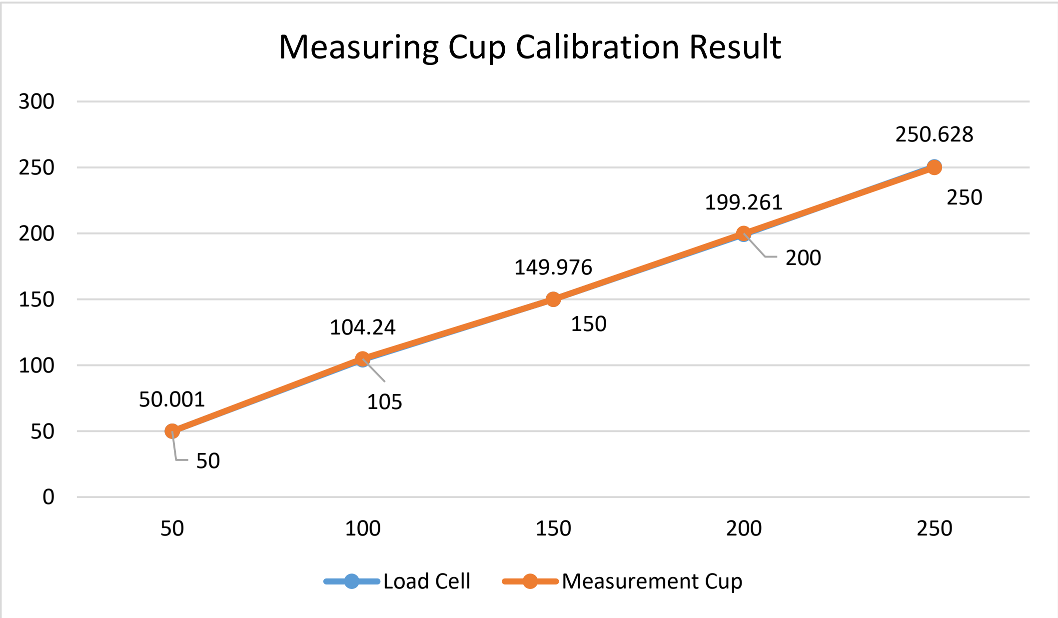

Figure 4. Graph of average results of measuring cup correction values

The figure above is the average calibration result using a pump, the graph illustrates a linear line, where the calibration results have reliable precision and accuracy. The red line shows the scale value read on the measuring cup and the blue line that is close to the red line is the result of calibration using an analytical balance.

Table 4. Calculation of measuring cup measurement uncertainty

Uncertainty Measurement

Component	Type	Ui	Vi	Ci	UiCi	(UiCi)2	(UiCi)4/Vi
1. Repeatability Meniscus	B	5.79E-03	60	1	5.79E-03	3.36E-05	1.88E-11
2. Mass	B	1.83E-02	60	1.004	1.84E-02	3.39E-04	1.91E-09
3. Water Temperature	B	7.65E-02	60	-0.001	-1.03E-04	1.07E-08	1.90E-18
4. Water Density	B	5.20E-07	1.00E+07	-50.215	-2.61E-05	6.81E-10	4.64E-26
5. Air Density	B	2.89E-07	1.00E+07	43.961	1.27E-05	1.61E-10	2.59E-27
6. Density Scales	B	8.08E-02	60	0.0009	7.39E-05	5.47E-09	4.98E-19
7. Coefficient of Expansion of Space	B	1.56E-06	60	-198.728	-3.10E-04	9.60E-08	1.53E-16
8. Meniscus Reading	B	2.89E-01	60	1	2.89E-01	8.33E-02	1.16E-04
Summary					3.13E-01	8.37E-02	1.16E-04
Combined standard uncertainty (Uc)					**0.2893**		
Effective Degrees of Freedom					**60.5**		
Coverage Factor K=student for Veff and CL 95%					**2.00**		
Uncertainty of expanse, U= k*Uc					**± 0.579**		

Table 4 is the result of the calculation of the uncertainty of the calibration of the measuring cup using the tool that has been built, the measurement uncertainty component is a factor that affects the measurement of the measuring cup using calibration. The final result obtained is on the Uncertainty of expanse which is ± 0.579 grams. This means that when taking measurements on a measuring cup using a tool designed to get expanded measurement uncertainty.

The working system on the tool that has been designed is to enter the desired weight or set point value with the keypad, then the microcontroller processes the command and turns on the pump, when the pump is on then the water will flow into the measuring cup on the scale. The pump will turn off when the Load Cell sensor reads the same value as the value inputted from the keypad. The calibration results for the measuring cup get a correction value. The correction value obtained on the measuring cup varies which can be seen in Table 3, these values include at set point 50ml the average correction is 0.001 ml, at set point 105ml there is an average correction of -0.760 ml, at set point 150 ml there is an average correction of -0.031 ml, at set point 200 ml there is an average correction of -0.739 ml, and at set point 250 ml there is an average correction of 0.628 ml. For the measurement uncertainty value can be seen in table 4.

CONCLUSION

The design of a measuring cup calibration tool using a pump has produced a correction value on the measuring cup. The pump successfully turns on when the weight input value is given to the ATMega 2560 microcontroller via the keypad. The obstacle on the keypad is that there is a delay that causes the keypad when pressed does not immediately appear numbers on the LCD display. The pump must be adjusted to the keypad value to match the desired value, this is because the system has a delay value that serves to stabilize the value of the Load Cell and DHT22 sensors used. The observatory type measuring cup correction value at the 50 ml set point is 0.001 ml, at the 105 ml set point the average measuring cup correction value is -0.760 ml, at the 150 ml set point the average measuring cup correction value is -0.024 ml, at the 200 ml set point the average measuring cup correction value is -0.739 ml and at the 250 ml set point the average measuring cup correction value is 0.628 ml. There is no measuring cup correction value above 1 ml, which means that the measuring cup observatory is operational. The 105 ml set point should be a 100 ml set point, but after repeated experiments, the measuring cup does not show a 100 ml scale, but 10.5 mm or 105 ml.

RECOMMENDATION

To develop a system that has been used it is recommended to improve the quality of the Load Cell sensor and the addition of a microcontroller so that the performance of the system can work without any obstacles that cause losses. The addition of an interface application is needed to make it easier to calculate the correction value and uncertainty that will be given.

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