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PROJECT COMPLETION REPORT OF

A NOVEL DESIGN AND DEVELOPMENT OF AN AFFORDABLE THERMOGRAVIMETRIC ANALYZER

by

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I. OBJECTIVE

Thermogravimetric analysis (TGA) is an analytical technique to determine thermal stability of a material. In this process, a test material is heated at a known rate such as 5ºC/min to a peak temperature of about 1200ºC. This provides useful information about second order phase transitions such as sublimation, evaporation, adsorption, absorption, desorption, dehydration and decomposition of a material. TGA analysis is useful in industries to quickly know the purity of polymers. It is routinely used to determine the purity of Carbon Nanotube.

TGA is a destructive analysis method but it requires only a few milligrams of a material. Each analysis takes about 2-8hours; making it is easy for industries to continuously monitor production quality.

Commercially available TGA are very expensive. They start at a price of Rs.15-20Lakh. Analysis of a single sample for industrial clients costs between Rs. 2000-10000/-. This severely limits the analytical capabilities of small industries which cannot afford such high costs.

Thus, we develop a low cost, reliable TGA using off-the-shelf components and open source software. Thermogravimetric analyzer comprises of an accurate micro-balance, heater, variable temperature controller, a light weight pan and software to analyze the data.

II. DEVIATION

It had been proposed to use a platinum pan to analyze the given sample. Due to different constraints on designing a small pan-like structure with less than 100mg, we have made use of an aluminium pan in place of the platinum pan.

Abstract

The phenomenon of exothermic reaction, endothermic reaction, weight loss on heating and cooling of any material can be determined by Thermogravimetric analysis. The following kinds of materials can be analyzed namely polymers, plastics, laminates, adhesives, food, pharmaceuticals, petroleum, explosives, biological samples etc.

The thermal stability of a material can be determined by monitoring the deviation in weight when compared to the actual weight when the component is being heated. In the case of Carbon Nanotube, the weight change in aerial environment is superposition of weight loss due to oxidation of carbon dioxide into carbon molecules and the weight gain due to oxidation of residual catalyst.

A TGA consists of a sample pan that is supported by a precision balance. That pan resides in a furnace and is heated or cooled during the experiment. The mass of the sample is monitored during the experiment. A sample purge gas controls the sample environment. This gas may be inert or a reactive gas that flows over the sample and exits through an exhaust. Temperature of the furnace ranges from 25ºC to 1000ºC. The samples can be weighed from 1mg to 150mg which could be in powder or crystal forms.

A high resolution PWM generator can provide very good resolution and precision while measuring mass. By using 8-bit PWM we could resolve a weight of 200mg in steps of 256 that is a resolution of 0.8mg per step. To get better precision we used 16-bit PWM interfaced which improved resolution to 65536 steps or 3µg per step. This helped us accurately monitor weight changes in Carbon Nanotube, which is better than commercial instruments.

INTRODUCTION

Chapter 1

Introduction

Thermogravimetric analysis is an analytical technique to determine the thermal stability of a material. In this process, a tiny mass is measured as it is heated at a specified ramp rate. This can reveal information about purity, chemical structure and thermal properties of the material.

A TGA is used to analyze materials in the laboratories conducting chemical experiments which can spare a very small amount of material for destructive analysis. It provides a record of second order parameters like sublimation, evaporation, absorption, adsorption, desorption, dehydration, decomposition etc. [1]. One round of TGA analysis runs up to 2 to 8 hours.

The use of TGA has applications in thermal stability, material characterization, compositional analysis, simulation of industrial processes, kinetic and corrosion studies explained briefly as follows. Due to the thermal stability, two similar materials can be compared at elevated temperatures in a desired atmosphere. Material characterization is the signature of a material where each material's TG curve is its unique "fingerprint". Optimum temperature and atmosphere is chosen to analyze complex materials. The thermo-balance and the furnace acts as a mini-reactor to perform reactions like in industrial reactors. The kinetic features of loss or gain in weight can be analyzed using vivid methods by understanding the controlling chemistry [2].

TGA plays an essential and vital role in estimating the filled materials in food items. It can determine the purity of minerals, organic and inorganic compounds. It is also used to analyze the evaporation rate to measure the volatile emissions of liquid mixtures. The reaction of a material with different gases can be analyzed very precisely [3].

1. 1 Need for TGA

Materials are tested to check for purity, physical properties and chemical properties before it is used in any application. These properties are different for different materials. The TGA instrument can be used to control the quality of a material.

To build a TGA, a manufacturer has to purchase expensive software tools to implement the instrument which increases the selling price of the instrument. But, to build this TGA a few open source softwares are used which significantly brings down the cost of the instrument. It is noted that in thermogravimetric analysis, it is essential to know the relative change in weight of the material being analysed but it's not necessary to know the weight of the material. Thus, the thermogravimetric analyser which is built is an inexpensive one.

The price a TGA instrument is the market is given in the table below:

Manufacturer of the instrument	Model	Price (USD)
TA Instruments	TGAQ500	$15,500 [4]
Jinan Quinggiang Technology Co.,	TGA	$20,000 [4]
CI Precision	CI Thermogravimetric Kit , LTG-01	$23,323 [5]
Linseis Inc.	STA PT 1000 with TG/DSC	$35,271 [6]
Xi'an Yima Opto-Electrical Technology Co.,	HTG-1 TGA	$25,000 [7]

1.2 Existing TGA

There are several manufacturers of Thermo gravimetric analysers. A few of them are as mentioned in the above table.

The features of the following TGAs are discussed in the further ahead.

1. TGAQ500
2. TGAQ50
3. TGAQ600
4. Discovery TGA

Figure 1: TGAQ500produced by TA Instruments [8]

Features of Q500 [9]**:**

- Vertical balance and furnace
- Temperature Range: Room temperature -1000°C
- Sample Weight: 10mg to 1g.
- Weight Precision: +/-0.01%
- Sensitivity: 0.1µg
- Furnace Heating: Resistance wound
- Controlled Heating Rate: 0.01-100°C/min.

Figure 2: TGAQ50 produced by TA Instruments [8]

Features of Q50 [9]**:**

- Vertical balance and furnace
- Temperature Range: Room temperature -1000°C
- Sample Weight: 10mg to 1g.
- Weight Precision: +/-0.01%
- Sensitivity: 0.1µg
- Furnace Heating: Resistance wound
- Controlled Heating Rate: 0.1-100°C/min.

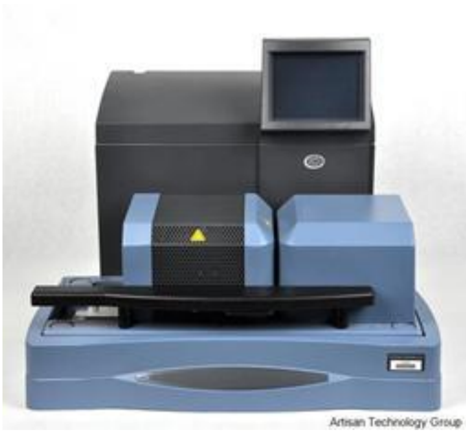

Figure 3: TGAQ600 produced by TA Instruments [8]

Features of Q600 [10]:

- Horizontal balance and furnace
- Temperature Range: Room temperature - 1500°C
- Sample Weight: up to 200mg
- Weight Precision: +/-0.01%
- Sensitivity: 0.1μg
- Furnace Heating: Bifilar wound
- Controlled Heating Rate: 0.1-100°C/min. (room temperature-1000°C)

Features of Discovery TGA [11]**:**

- Vertical balance and furnace
- Temperature Range: -180 -725°C
- Sample Weight: up to 750mg
- Dynamic Weighing Range: +/- 100mg
- Weight Precision: +/-0.01%
- Sensitivity: <0.1μg
- Signal Resolution: 0.001μg

Figure 4: Discovery TGA produced by TA Instruments [8]

METHODOLOGY AND CONSTRUCTION

Chapter 2

Methodology and Construction

The following are the main components of our microbalance

1. Balance pan (aluminium)
2. Opto-isolator
3. Aluminium Foil
4. Microcontroller board (Arduino Uno)
5. Galvanometer
6. Raspberry Pi B+
7. osPID Controller
8. Heater
9. Power Supply
10. Thermocouple

2.1 Working of Different Components

2.1.1 Opto-Isolator

Omron opto-isolator: EE-SX1108 is used to give isolation between two electrical circuits as shown in figure 7. The use of this instrument is to provide protection to the circuit from high voltages and also provides interface between different voltage levels. The output circuitry of the opto-isolator may consist of phototransistor, LDR or photodiode. When the input is given, then the LED emits light which activates the photosensitive device. The voltage of the opto-isolator is almost the same as that of the input voltage [12].

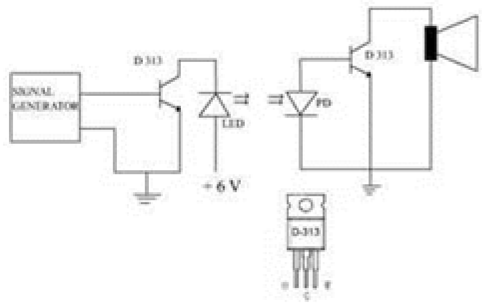

Figure 5: Basic circuit of opto-isolator [12]

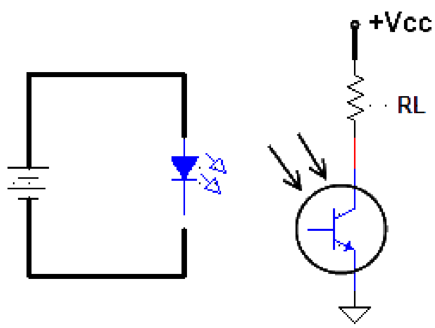

Figure 6: Working principle of opto-isolator[12]

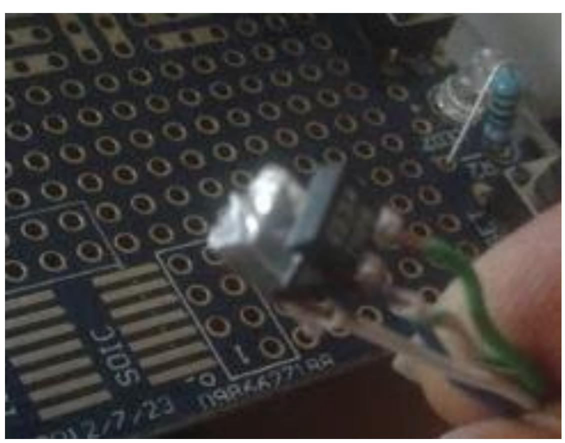

Figure 7: Omron opto-isolator EE-SX1108 [13]

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2.1.2 Arduino Uno

Arduino Uno is an Atmel microcontroller based on Atmega328 with an operating voltage of 5V. It consists of 14 digital I/O pins of which 6 produces PWM output, analog inputs- 6 in number, clock frequency of 16Mhz, with flash memory of 32 KB, SRAM of 2KB and EEPROM of 1KB. It also has USB connectivity along with power jack, ICSP header and a reset button. The board is started up by the conventional method of using batteries. The Arduino Uno board acts as the main controller for the TGA [14].

Figure 8: Arduino Uno Board [14]

2.1.3 Raspberry pi B+

The raspberry pi B model has HDMI out, RCA video out, 2 USB ports, an SD card slot, a headphone jack and an Ethernet port with an onboard ARM processor. It can behave like a normal computer with extremely low power consumption of about 3 watts. In this project, Raspberry pi B+ model plays the role of a main computer. It is connected to both the Arduino Uno microcontroller board and the osPID. The data from the Arduino Uno microcontroller board is displayed on the monitor of the Raspberry Pi [15].

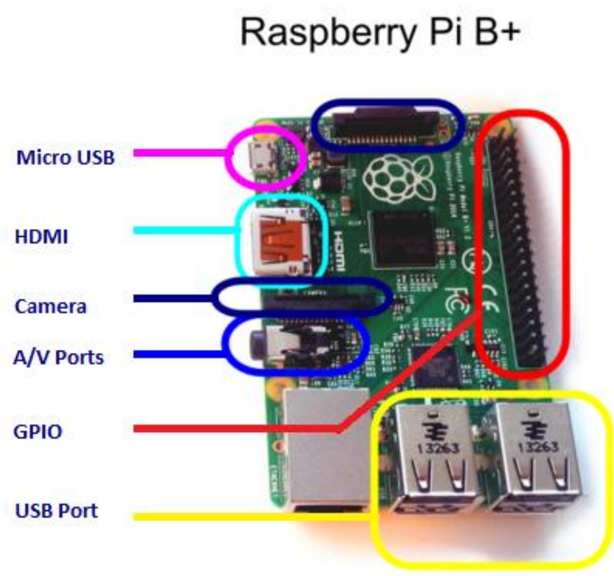

Figure 9: Raspberry pi B+ model [15]

2.1.4 osPID Controller

“osPID” stands for Optimal Self-adjusting Proportional Integral Derivative Regulator. It is an open source PID controller. It is a temperature controller which uses open source software called “Processing” to provide a plot of the data interpreted and observed. The osPID has 3 main components namely, main board, input card and output card. The main board provides a user interface. The input and the output cards can be swapped depending on the result desired. The features of this device are as follows:

1. Arduino compatible board with ATMega328P-AU
2. 8x2 LCD display
3. USB port
4. 4 Push buttons
5. 1 Red LED to indicate power
6. 1 Buzzer
7. Reset Button

8. 7-38 DC input range and many more [16].

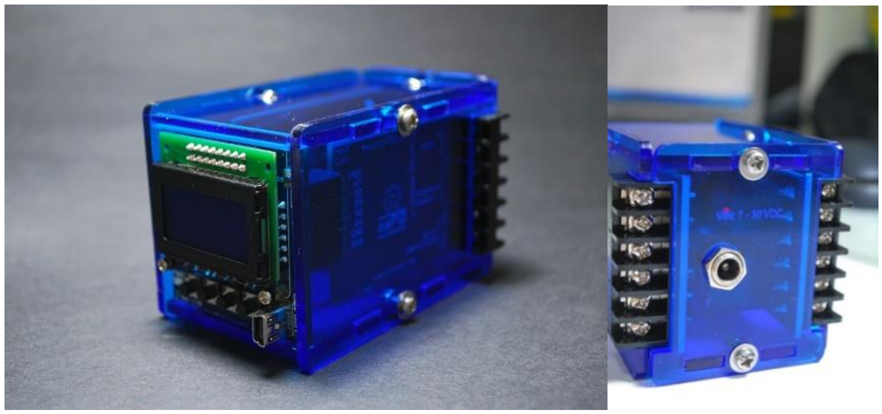

Figure 10: osPID Controller[17]

2.1.5 Heater

A quartz tube is wound with a conducting wire as shown in the figure 11.It is then coated with ceramic to keep the wire intact with the quartz tube. The quartz tube behaves like a furnace to heat the material up to different temperatures for the chemical reaction to take place. The heater is surrounded by an insulator to withstand high temperatures. The heater is height adjustable as shown in the figure 12.

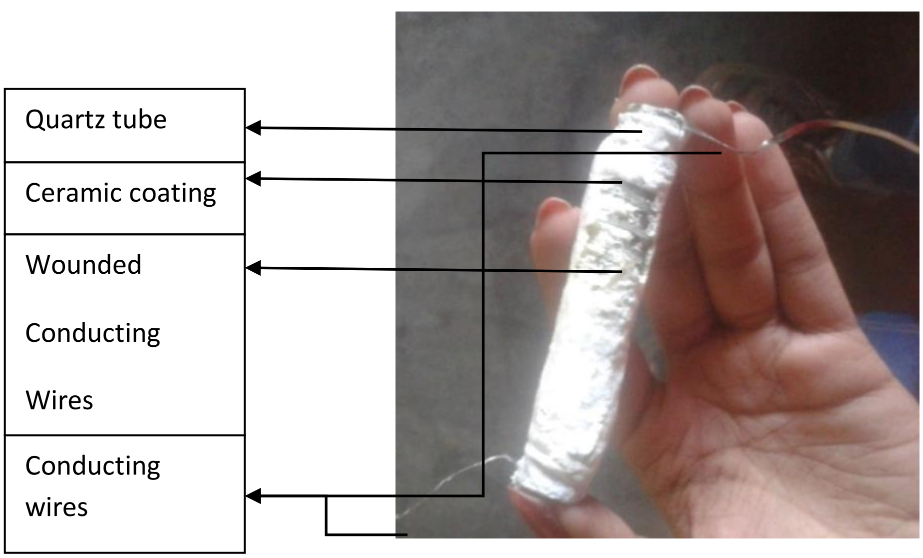

Figure 11: Cross-section of the furnace [13]

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Figure 12: Height Adjustable Heater [13]
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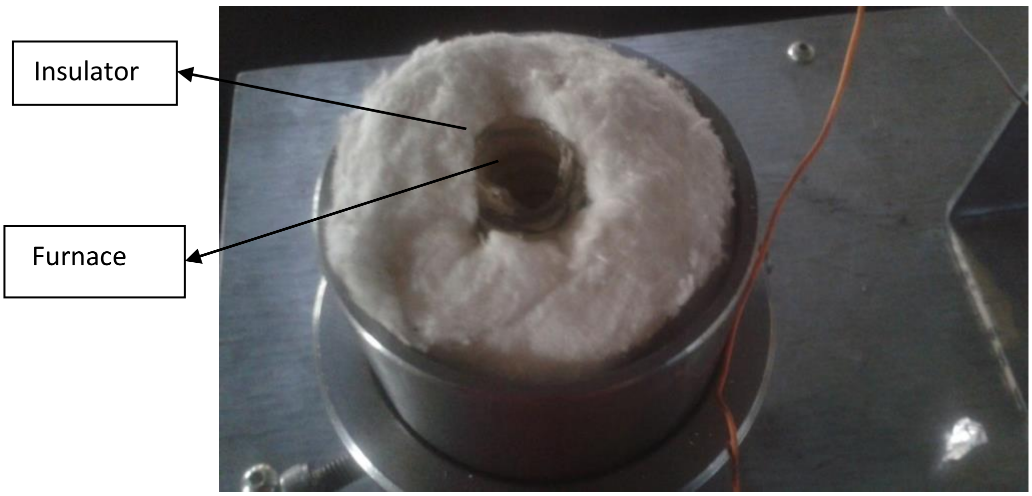

Figure 13: Heater
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2.1.6 Power Supply

A power supply is used to bring down the voltage in the main to a lower value to make it usable. The voltage at the main is 220V AC which is brought down to 12V DC to be supplied to different electronic devices [18]. The block diagram of the power supply is as shown in figure

12. A power supply which converts 230V AC to 24V DC is used and it has a maximum current of 4Amps.

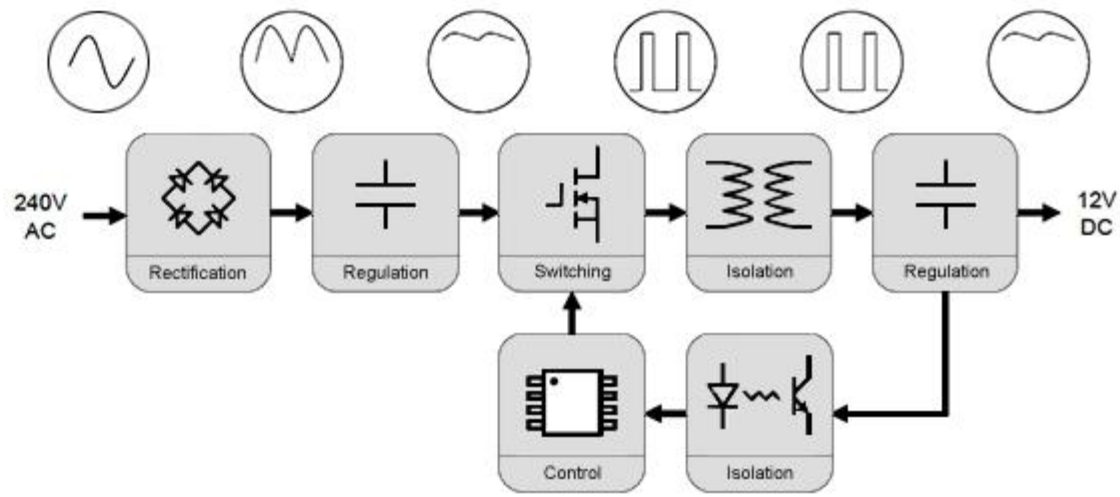

Figure 14: Block diagram of a switch mode power supply [18]

High DC voltage is produced by rectifying the AC signal which is switched on and off rapidly by a FET. The mark space ratio of switching is controlled by the feedback from the output. The transformer used in the switch mode power supply is very small; however it has to handle higher switching frequencies [18].

2.1.7 Thermocouple

A thermocouple is used to measure the temperature in different environments. It is a widely used device to measure temperature. Two metal wires form a junction one end of the wire is connected to the body whose temperature is being measured and the other one is kept at a known temperature for reference as shown in figure 15. Thus, the thermocouple measures the temperature of the unknown body keeping the temperature of the known body as a reference. The working if a thermocouple is based on the following three effects:

1. Seebeck Effect
2. Peltier Effect
3. Thomson Effect[19]

Thermocouples are used in many applications due to high accuracy and its ability to operate over a wide range of temperatures. They are inexpensive and are used to make an automated device as they are electrically controlled [20].

A K-Type thermocouple is used in this TGA instrument.

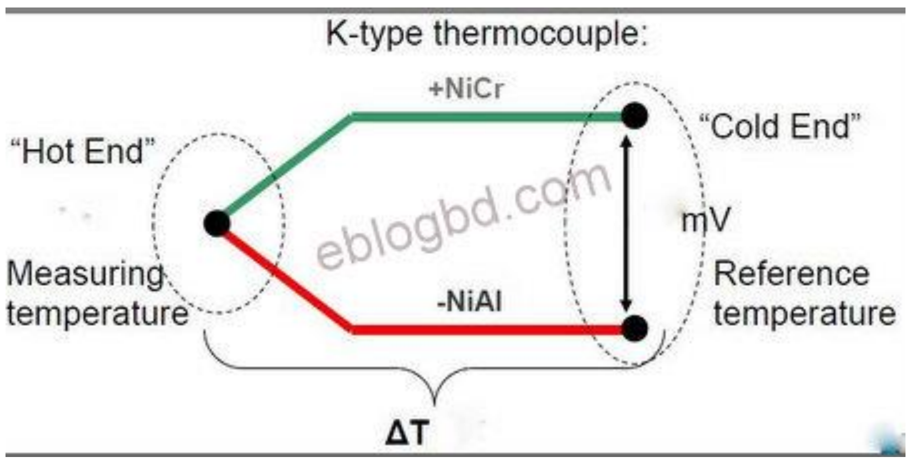

Figure 15: Working of a thermocouple [21]

Figure 16: Thermocouple with a flying lead [21]

2.2 Software Development

The software tools used to develop the TGA instrument is as follows:

1. Arduino

2. Processing
3. Python

Arduino software is used to control the Arduino Uno microcontroller board which sets up the microbalance part of the instrument. “Processing” software runs on Raspberry Pi. It is used to plot all the required graphs. Python software is run on the Raspberry Pi B+ model which controls both the Arduino Uno microcontroller board and the osPID to provide additional Graphical User Interface.

2.3 Evolution in Experiment

A tiny balance made of aluminium foil is connected to a magnetic coil to convert movement of the needle into electrical signals as mentioned in the Scientific American Column, The Amateur Scientist in the year 2000[22].

The galvanometer uses PWM generated by the microcontroller to keep the needle of the galvanometer at arm level. The Arduino Uno microcontroller is programmed to send different numbers of pulses (for 4bits, 8bits and 16bits) per second to the coil. When the substance is weighed, the arm of the galvanometer tends to point down. This is prevented by increasing the number of pulses in the coil. The inertia due to the needle of the galvanometer and the balance pan resists the response to each short pulse. The pulses control the average current flowing through the coil attached to the micro-balance. The pulse width of the pulses remains same with changing duty cycle. If the duty cycle is small, then the balance measures smaller weights. If the duty cycle is more, then the balance measures relatively heavier loads. The range of measurement can be determined by the number of values the duty cycles takes. The microbalance circuitry is as shown in figure 17.

A photo interrupter (an opto-isolator) is used to hold the galvanometer arm straight as shown in the figures 18. A galvanometer which can detect very small amounts of current and good calibration can suffice the construction. The position of the needle is determined by the electro-balance using a phototransistor and LED. The galvanometer is a very fragile instrument. About four galvanometers have been replaced to obtain proper results as it is very sensitive. An aluminium foil is placed at the LED-phototransistor unit as in figure 18. A small hole is made in the aluminium foil which centres at phototransistor. Due to the movement in the needle, there are changes in the signal of the photo transistor. If the current flowing through the coil is less, then the needle is at the least reading and blocks all the light emitted from the LED. If the current through the coil is high, it moves away from the path of LED and phototransistor, leading to changes in the signal received from the phototransistor. By counting the number of pulses sent by the microcontroller, and by having a proportionality constant, we can measure the unknown weight of the known substance. Equivalent conversion of the received data gives the value of mass in standard units.

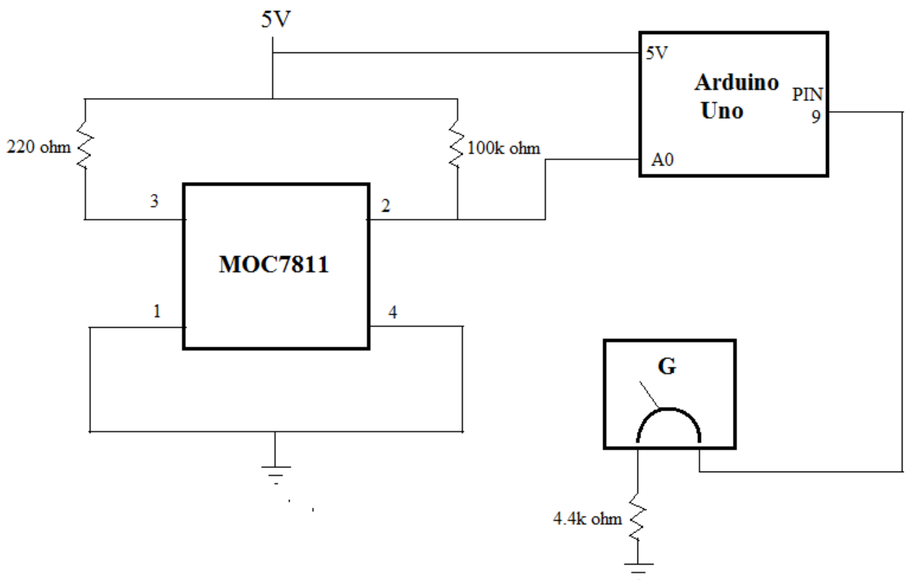

Figure 17: Circuit Diagram of the microbalance

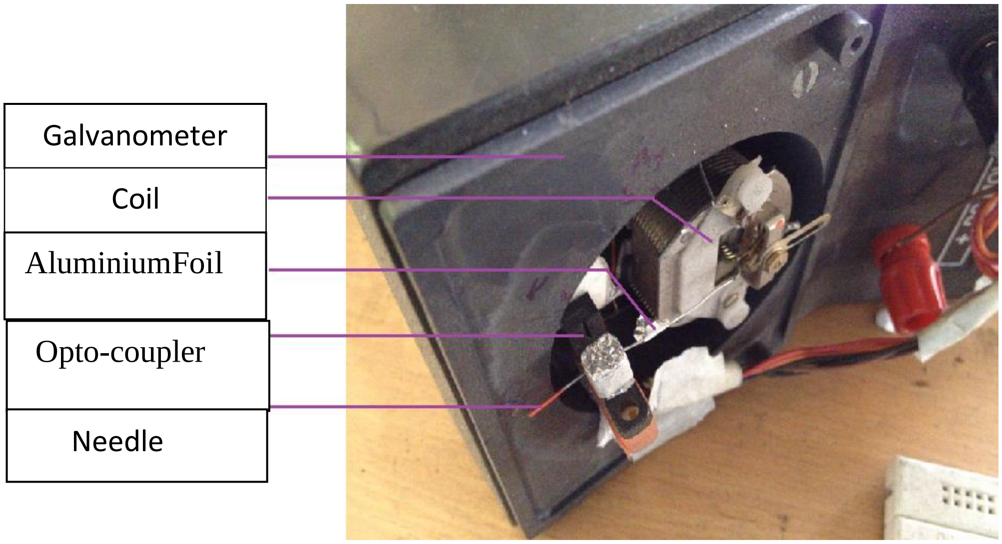

Figure 18: interfacing the galvanometer and the opto-isolator [13]

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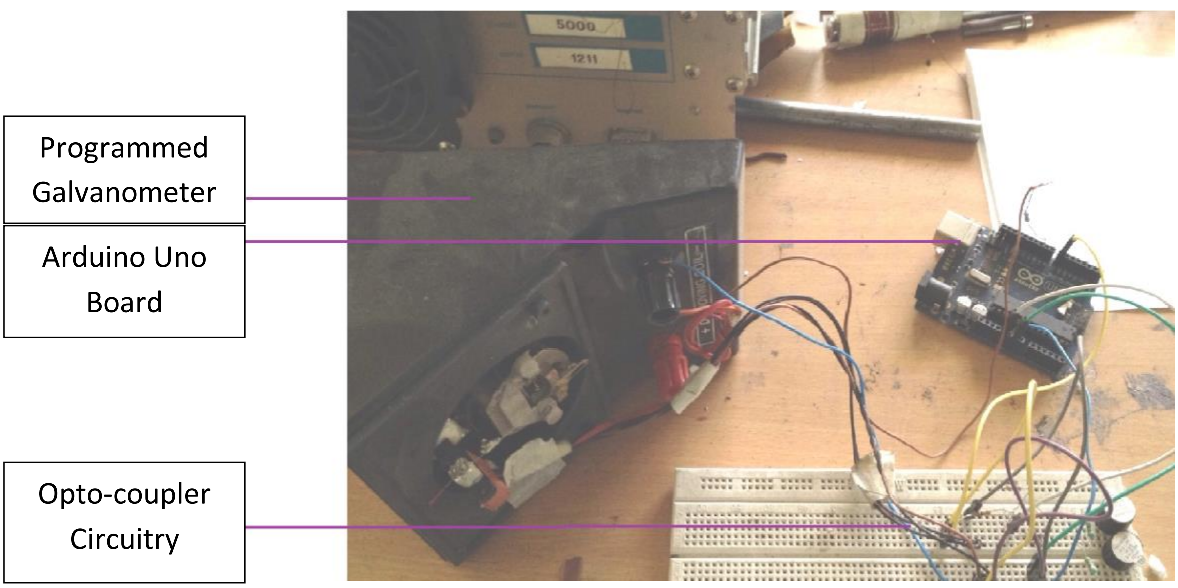

Figure 19: Complete Circuit of the interface [13]

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The opto-isolator in figure 18 was replaced by a smaller version of it as shown in figure 20. The new opto-isolator is small, thus it is not possible to make a cap out of aluminium. A flag like structure is made using aluminium to make the opto-isolator detect the needle.

Figure 20: Opto-isolator MOC7811 [13]
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The next component of the instrument is an accurate heater and controller. We plan on using a thermo isolator amplifier that provides 0.25degree Celsius resolution and can be easily interfaced with the Arduino board. The data from the microcontroller will be fed to the Raspberry Pi Model B+ computer. The raspberry can send data over wifi and the results can be accessed. The instrument can be calibrated prior to each experiment using standard weights. This will ensure reliability and repeatability of the instrument.

The heater used is a quartz tube which is wound with a conducting wire, connected to a 24V DC supply. The power supply acts as the main source for the heater to start heating. The heating is controlled by osPID which is programmed to vary the temperature with respect to the time as and how desired. The block diagram of the osPID is as shown in figure 21.

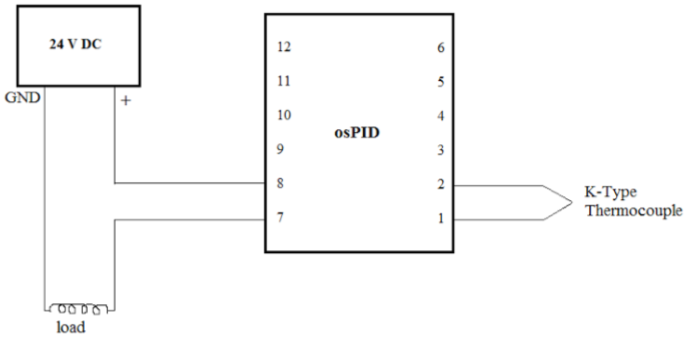

Figure 21: Block Diagram of osPID circuitry

Many layers of insulator are stuffed around the heater to ensure that the surface remains as cool as possible while having a small form factor as the heater is heated over 1000 degree Celsius. This whole setup is mounted on a mechanical structure which is made height adjustable as shown in figures 12.

A thermocouple is placed inside the furnace from underneath it to measure and return back the temperature inside the furnace. The readings from the thermocouple are sent to the osPID controller which is programmed to control the temperature. The reading from the thermocouple is compared with that of the temperature desired and the necessary changes are made automatically.

A miniature version of a balance is made using copper strings and aluminium foil so that it fits into the furnace as shown in figure vv. The idea was to use a pan made of platinum but it is here replaced by aluminium as it tedious to make a platinum pan to weigh less than 100 mg along with the strings. It is found that aluminium also exhibits properties where it can be heated upto 600C without causing it to melt having aluminium pan replace the platinum pan in the experiment. Thin copper wires are used to hang the pan onto the needle. The ridges in the inner surface of the furnace are removed to ensure smooth movement of the pan in the furnace. Many trials are made to ensure that the pan is suspended in the air and that it is not resting on the surface of the furnace.

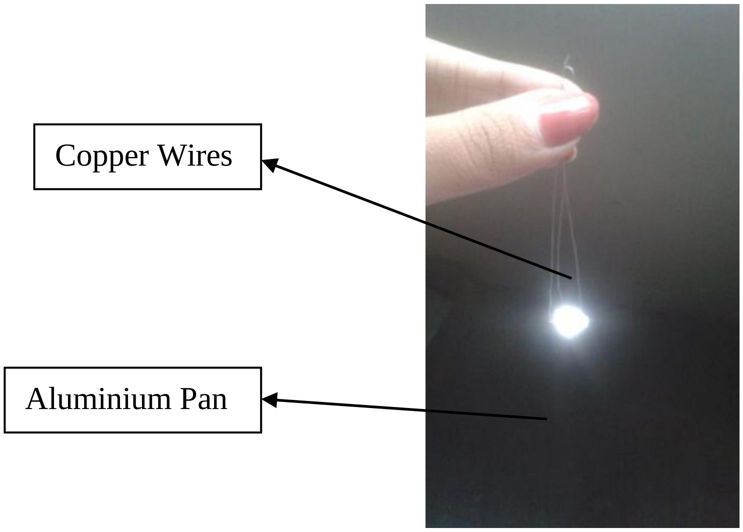

Figure 22: Aluminium pan with copper threads [13]

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After it is ensured that the pan is suspended in the air, a small amount of the sample is poured into the pan and the heater is turned on. The values from the opto-isolator are noted down as it indicates the number of pulses being sent to hold the needle of the galvanometer at the reference point. If the mass of the sample is unknown, then the number of pulses being sent is directly proportional to the unknown mass.

One the analysis is completed, a graph of time vs. temperature is plotted along with a graph of pulse vs. temperature. Taking a differential of the curve indicates the material present in it. Each material has a unique differential graph from which it can be identified. The plotted graph can be compared to the ideal graph to recognize the unknown material. This can also be used to check the purity of a known material.

2.4 Calibration

The instrument is calibrated by repeatedly pouring a few calculated amount of water into the pan and increasing the PWM to make the needle lift the weight. A micropipette is used to draw out microliters of water. The calculation of it is as given below.

Density of water = 1.0mg/ml

1mg/ml = 1µg/µl

Thus, water of 1mg = 1µl

The needle is then calibrated to zero. Firstly, the empty pan is calibrated to zero. Then 10mg of water sample is poured into the pan and is set to zero by increasing or decreasing the pulses. Similarly, it is done up to 25mg of the water sample

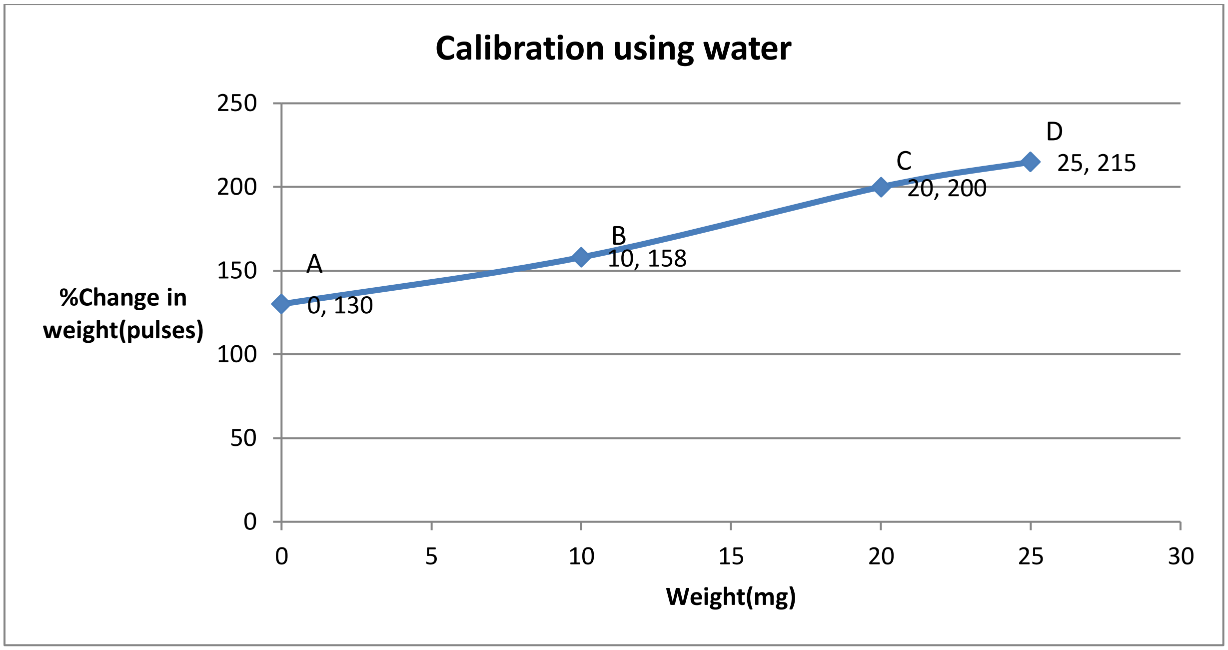

Figure 23: Calibration with water, %change in weight vs. weight of sample(mg).

The curve is a straight line which follows the straight line equation, **y=mx+c**, here y is the pulse, m is the slope, x is the mass of sample, and c is constant.

The slope of

1. AB= 2.8
2. BC=4.2
3. CD=3

The average slopes is 4.33 i.e. **m=4.33**.

From the straight line equation, **c=y-mx**.

For,

1. y=158, x=10 we get c=114.7
2. y=200, x=20 we get c=113.4
3. y=215, x=25 we get c=106.75

The average of the last two value gives 111.61 i.e. **c=111.61**.

Different values of mass can be found out when vaporization occurs which controlled temperature changes by generalizing the formula as

x=(y-m)/c.

When substituting for m and c in the above equation, we get

x=(y - 4.33)/111.61

ANALYSIS

Chapter 3

Analysis

2.5 Experiment Conducted

Polyurethane material was used for an analysis using the TGA built. Polyurethane is a polymer which is a chain of organic units joined by carbamate links. It is an extremely durable and flexible synthetic material which is used in most of all items from airplanes to toys. A polyurethane stick is shown in figure 24.

Figure 24: Polyurethane stick [13]

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Two trials were conducted for two different weights of the sample and the following are the resultant graphs. Trial 1 had a sample of 50mg with a heating rate of 6.25C/min up to 500C and trial 2 had a sample weighing 20mg a heating rate of 7.5C/min up to 600C. The pan weighed 20mg in both the trials.

Trial 1:

Graph1: %change in weight vs. Time(hrs) and vs. Temperature(C)

Sample: polyurethane
Weight: 50mg
Run date: 13-07-2015

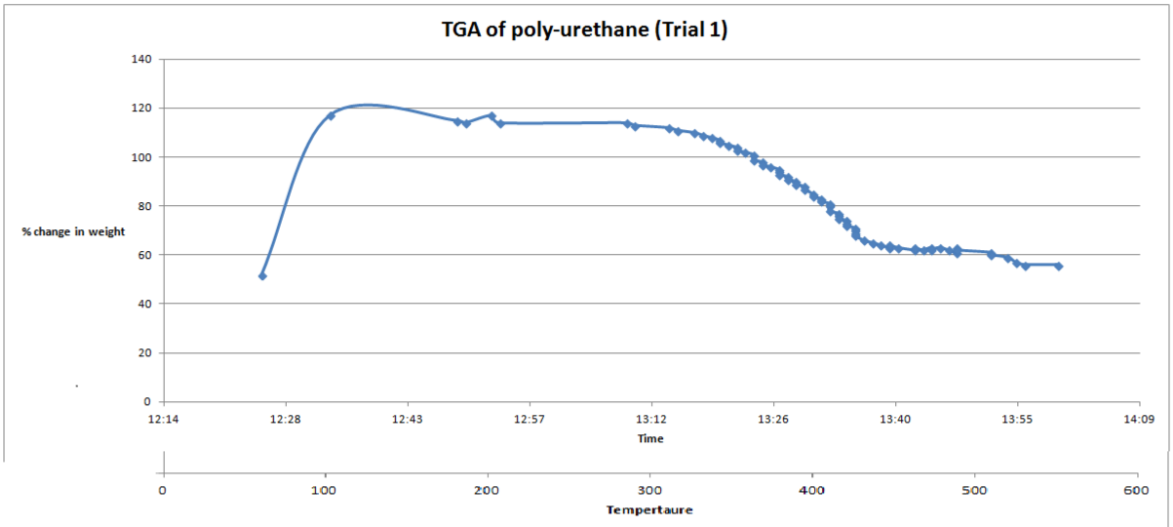

Figure 25: TG curve of polyurethane in trial 1. %change in weight vs. Time(hrs) and Temperature(C)

Trial 2:

Graph 1: %change in weight vs. time

Sample: polyurethane
Weight: 20mg
Run Date: 13-07-2015

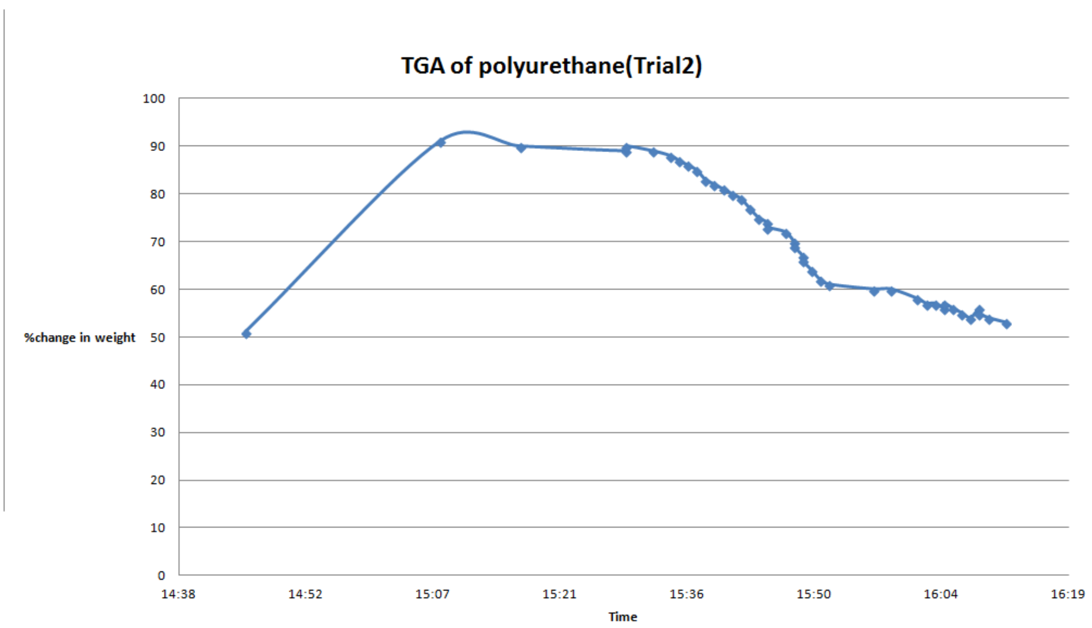

Figure 26: TG of polyurethane in trial 2, % change in weight vs. Time(hrs)

Graph 2:% change in weight vs. temperature(set point)

Sample: polyurethane
Weight: 20mg
Method: 7.5C/min to 600C
Run date: 13-07-2015

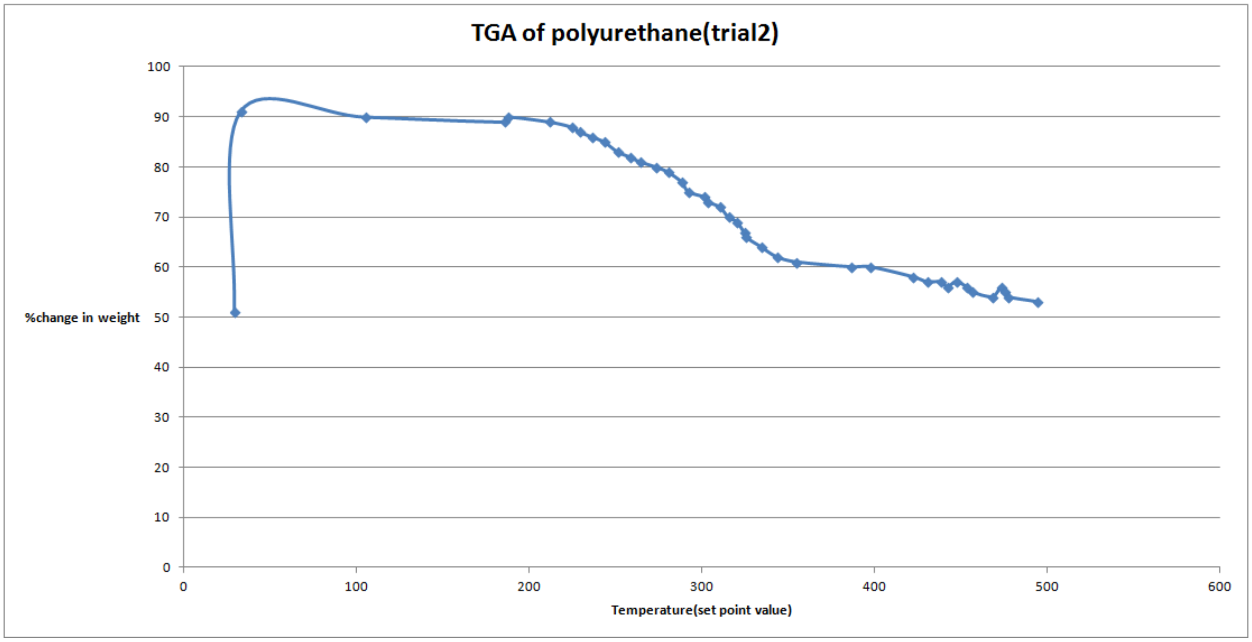

Figure 27: TG curve of polyurethane in trial2 , % change in weight vs. set point Temperature(C)

3.2 Table of Comparisons

The ideal TG curve for polyurethane and the obtained curve are as compared below:

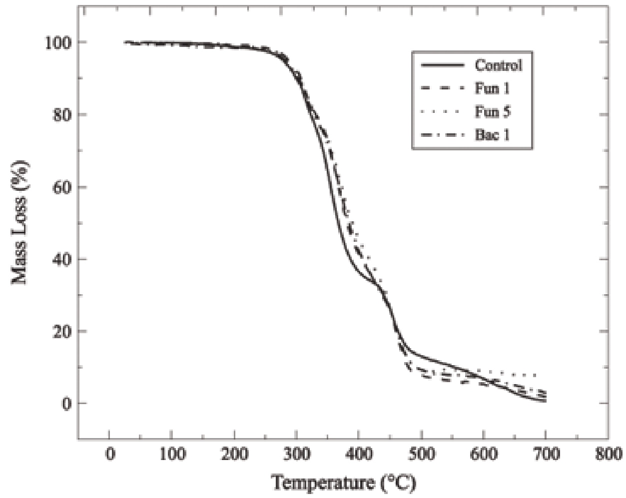

Figure 28: The ideal TG curve of polyurethane [23]

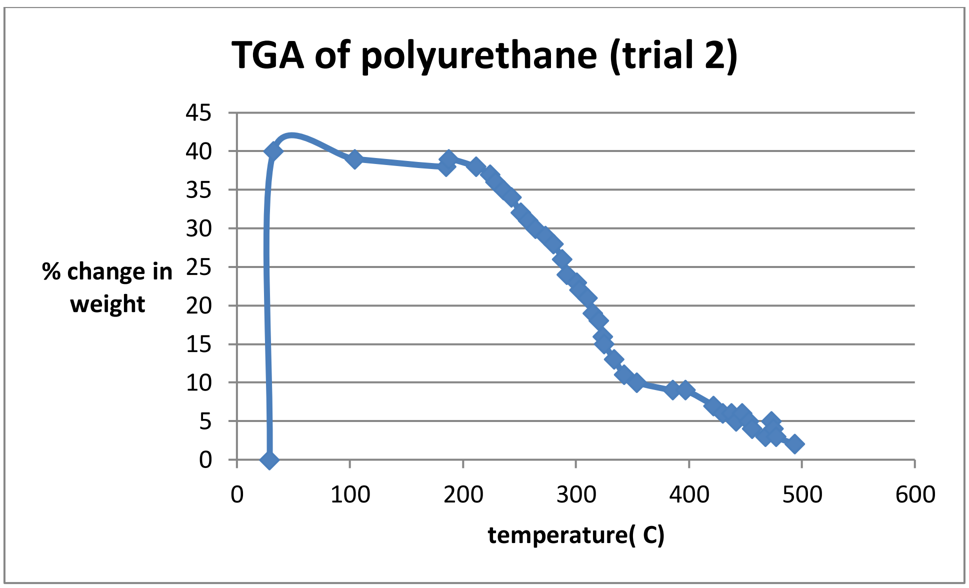

Figure 29: The obtained TG curve of polyurethane

By looking at the above two graphs, it can be compared and analysed that the obtained curve almost matches the ideal curve.

RESULTS AND CONCLUSION

Chapter 4

Results and Conclusion

Thermo gravimetric analysis has been successfully performed on a few samples of polyurethane. There were two trials being conducted with controlled temperature. The TG curve for polyurethane is plotted and compared with the plot found on the internet performed on other TGA instruments. While comparing the two graphs, it is seen that the curve formed while plotting the data from this TGA almost matches that of the curve plotted from the data from other TGAs taken as an ideal curve.

Thus, it can be concluded that the TGA built is a success and it can be utilised to analyse a sample in a successful manner and the TGA has been built successfully with off the shelf components.

S & T BENEFITS

Chapter 5

S &T Benefits Accrued

FINANCIAL POSITION

Description	Quantity	Unit Price	Taxes	Amount
Arduino UnoR3.0 Original Arduino Uno Rev.3(made in ITALY)	2	1500.00	Output VAT 14.5%	3000.00 ₹
Raspberry Pi Model B+ Raspberry pi w/built in case	1	3200.00	Output VAT 14.5%	3200.00 ₹
Max31855 Thermocouple Amplifier	1	950.00	Output VAT 14.5%	950.00 ₹
OSPIDV2.0 Open Source Arduino based PID controller with built in relay and SSR control	1	9879.00	Output VAT 14.5%	9879.00 ₹
Omron optoisolator:EE-SX1108 Omron Optical Switches,Transmissive, Phototransistor Output US HTS:8541408000ECCN:EAR99COO:JP	2	150.00	Output VAT 14.5%	300.00 ₹
5K Potentiometer	1	90.00	Output VAT 14.5%	90.00 ₹
24VDCSMPS,4A max current :230VAC Input	1	1500.00	Output VAT 14.5%	1500.00 ₹
12VDC, 1ASMPS Power Adapter	1	750.00	Output VAT 14.5%	750.00 ₹
5VDC, 2ASMPS Power Supply for Arduino	1	550.00	Output VAT 14.5%	550.00 ₹
Galvanometer 100-0-100: 100mA maximum current, generic galvanometer.	1	800.00	Output VAT 14.5%	800.00 ₹
Voltmeter (0-400V):Analog Voltmeter 0-400V I/P 0-230V display.	1	950.00	Output VAT 14.5%	950.00 ₹
Ammeter (0-15A): 0-15A series Ammeter with built in shunt.	1	950.00	Output VAT 14.5%	950.00 ₹
Kanthal Heater Wire : 1mm Diameter x 20m long .Cost per meter	20	90.00	Output VAT 14.5%	1800.00 ₹
Quartz Furnace Tube: OD 12mm , WT1mm, Length 1.2m	1	1900.00	Output VAT 14.5%	1900.00 ₹
Male Jumper Wire :Premium Male/Male Jumper Wires -40 x 3”(75mm) [ID :759]	1	245.00	Output VAT 14.5%	245.00 ₹
[TH-K-INC-3-350]K-type Thermocouple K-3-350	1	1550.00	Output VAT 14.5%	1550.00 ₹
ADS1115 ADC: 1 x ADS1115 16-Bit ADC -4 Channel with Programmable Gain Amplifier[ID:1085]	1	1327.00	Output VAT 14.5%	1327.00 ₹
MOC7811:GenericOptoIsolator	1	75.00	Output VAT 14.5%	75.00 ₹
MS Fabrication :Fabrication of TGA as peer drawings	1	2500.00	Output VAT 14.5%	2500.00 ₹

Total Without Taxes	32316.00 ₹
Taxes	4685.84 ₹
Total	37001.84 ₹

Tax	Base	Amount
Output VAT 14.5%	32316.00 ₹	**4685.84 ₹**

Acknowledgements

We thank **Nopo Nanotechnologies Pvt. Ltd**. And **Srushti Automations** for helping us fabricate our TGA. We would also like to thank **Sujay H.G.** and **Abhishek S.S.** for extending their helping hands in designing electrical and mechanical devices for the instrument.

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ANNEXURE

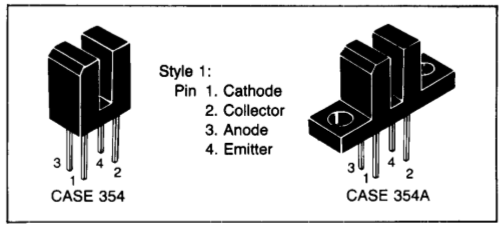
Annexure 1:

OPTOELECTRONICS — (continued)

Couplers/Interrupters

Slotted Couplers/Interrupter Modules

Slotted couplers consist of an infrared emitting diode facing a photodetector in a molded plastic housing. A slot in the housing between the emitter and the detector provides a means of interrupting the signal. A wide selection of standard and custom housings and detector functions is available. All IREDs and photodetectors in the miniature Case 349 (see Silicon Photodetectors) can be used in these housings.



Transistor Output ($V_{(BR)CEO}$ = 30 V)

Device	Current Transfer Ratio (CTR) % Min	@ I_F mA	V_{CE} Volts	$V_{CE(sat)}$ Volts Max	@ I_F mA	I_C mA	t_{on}, t_{off}* Typ µs	V_{CC} Volts	R_L Ω	I_F mA	V_F Volts Max	@ I_F mA	Case
MOC7811	5.0	20	5.0	0.4	30	1.8	12/60	5.0	2.5K	30	1.8	50	354A Style 1
MOC7812	10	20	5.0	0.4	20	1.8	12/60	5.0	2.5K	30	1.8	50	
MOC7813	20	20	5.0	0.4	20	1.8	12/60	5.0	2.5K	30	1.8	50	
MOC7821	5.0	20	5.0	0.4	30	1.8	12/60	5.0	2.5K	30	1.8	50	354 Style 1
MOC7822	10	20	5.0	0.4	20	1.8	12/60	5.0	2.5K	30	1.8	50	
MOC7823	20	20	5.0	0.4	20	1.8	12/60	5.0	2.5K	30	1.8	50	

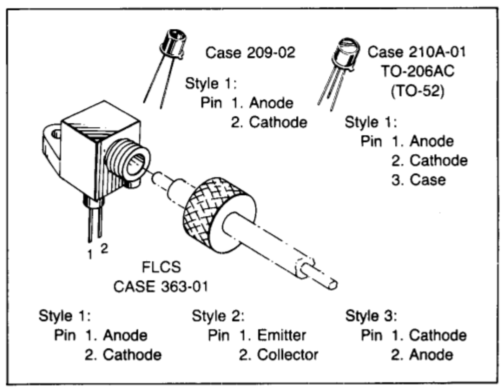
3

Fiber Optic Devices

Motorola offers high performance Infrared Emitters and Detectors for fiber optic systems. Devices are available for systems requiring greater than 100 MHz analog bandwidth over several kilometers or requiring very low cost with up to 10 MHz bandwidth over short distances.

The packages fit directly into standard fiber optic connector systems. All devices are spectrally matched to minimum attenuation regions of most fiber optic cables.

The Fiber Optic Low Cost System (FLCS) package houses infrared emitters and detectors and has a molded lens which efficiently couples the light to and from the cable. The package is complete with the fiber alignment and locking mechanism and the means for attaching to a board.



Infrared Emitters

Designed as infrared sources for fiber optic systems. MFOE200 is compatible with AMP #227015; MFOE1200, MFOE1201 and MFOE1202 are compatible with AMP #228756-1 and Amphenol #905-138-5001 receptacles.

Device	Total Power Output mW Typ	@ I_F mA	t_{on}/t_{off} ns Typ	λ nm Typ	Case
MFOE71	3.5	100	25	820	363-01 Style 1 (FLCS)
MFOE200	3.0	100	250	940	209-02 Style 1
MFOE1200	0.9	100	(>70 MHz bw)	820	210A-01 Style 1
MFOE1201	1.5	100	(>100 MHz bw)	820	
MFOE1202	2.4	100	(>100 MHz bw)	820	

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