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# Temperature Measurement And Calibration Setup (TH1)

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# Temperature Measurement and Calibration Setup (TH1)

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## ABSTRACT

The work investigated the responses of measuring and calibrating temperature in the range of 30 to 60°C in a computer controlled tray drier using a setup of TH1. The setup was configured with an ice flask, sensor installing unit, an electrical console, and a regulating bath, which can withstand temperatures in the range of 0°C to 100°C. Various sensors such as industrial platinum resistance thermometer PT100IND, type K thermocouple, and a thermistor were installed. The setup was configured with highly accurate reference sensors of platinum resistance device PT100 with NAMAS calibration certificate and temperature with linearized output. Extra reference sensors have been installed such as bi-metallic and liquid-in-glass thermometers to ensure high accuracy in measuring and calibrating data. The experimental data revealed that the PT100IND resistance changed linearly with temperature. The calibration error of PT100IND and according to the temperature data of the drier unit reached a maximum value of less than 1.60%. According to the temperature scale of ITS-90, the standard parameters of calibration equation of Callendar-van Dusen for PT100IND provided errors of less than 5.5% and 3.2% respectively. The type K thermocouple delivered a linear change in output with highly stable temperature response. According to NIST data, the calibration error for the thermocouple reached a maximum value of less than 0.98%. The thermistor resistance revealed weak and late response at low temperature, but its sensitivity improved with increasing the temperature. The calibration error according to experimental data of drier unit and the Steinhart-Hart equation for the thermistor sensor was less than 0.30%.

## I. INTRODUCTION

Temperature as a very important physical variable in the science of Meteorology and is considered a difficult concept to understand. This physical variable is normally defined as an indication of intensity of molecular activity. Not only is it a critical state parameter for all earth related systems, it is also used to characterize other state parameters like atmospheric moisture. Temperature measurement is a vital process for ensuring the safety and quality for majority of manufacturing products, health care, agriculture, and other engineering applications. Measurement of the temperature is generally achieved by placing a temperature sensitive sensor probe in direct or indirect contact with the targeting body, temperature is then generated as a change in some property of the probe. This change can be compared and related to the behavior of the sensors at known levels [1,2,3,4,10,13,14,15].

In this work, the Armfield temperature measurement and calibration setup TH1 [7,8] was used for measuring and calibrating the temperature profile in the range of $\vartheta$=30 to 60°C, all at normal pressure of p=1.013 bar. One of the main study objectives of this work was to integrate the TH1 setup with a computer controlled tray drier (EDIBON), as shown in Fig.1a,1b., to deep recognize the temperature profile inside the tray drier and to detect the temperature effects on the quality of the final products. The drying process consists of the removal of moisture from a substance, involving heat transfer and mass transfer phenomena at the same time. Mass transfer occurs when the solid loses moisture and heat transfer occurs when the air transfers heat to the solid, which is used to evaporate the water added to the air as the drying process takes place. The unit developed by (EDIBON) uses one of the most usual drying methods. It lies in making an air current circulate towards the material to be dried. The unit consists of a tunnel and some trays where the material to be dried is placed. There is an axial flow fan at the inlet of the tunnel which supplies the air required to dry the product. This air can be moistened at the inlet, since the unit also includes two additional inlets for the introduction of steam. After the fan, the unit is equipped with a heating resistance, which allows for the heating of air and control of temperature. The unit has three strategically located hygrometers that make it possible to determine the optimum humidity and temperature requirements, etc. for the drying process. These hygrometers are composed of two temperature sensors, one of them is wrapped by an absorbent cover (wet bulb) and the other is directly placed on the tunnel (dry bulb). The degree of humidity, enthalpy, etc. can be calculated from their measurements and a psychrometric diagram. An air flow sensor indicates the air flow in the tunnel at all times.

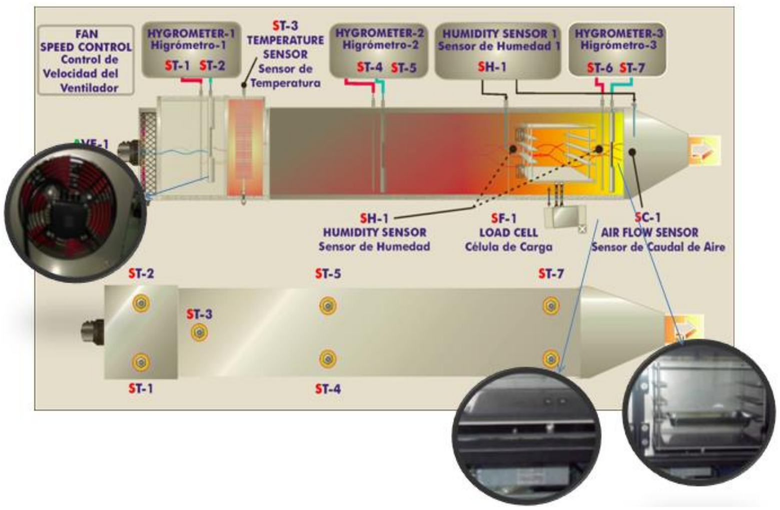


*Fig.1a: Unit elements of computer controlled tray drier (Edibon) [16].*

*Fig.1b: Sensor layout profile on Edibon tray drier [16].*

The setup TH1 is designed to investigate the thermoelectric properties of various temperature sensor probes. The main aims of designing the apparatus are investigating the effect of temperature on the physical behavior of the probes, the source of error in measuring the temperature, scrutiny of individual accuracy of these probes compared to reference points, and calibrating the industrial PRT100 probes. The thermometric properties and characteristics of temperature measuring devices are investigated and the sensor probes calibrated using precisely generated fixed points and an accurate reference thermometer [7,8]. The thermoelectric properties of a platinum resistance device, a thermocouple and a thermistor were investigated. The platinum resistance device PRT included for reference, is an accurate reference with five-point NAMAS calibration certificate and temperature with linearized output indicated directly in °C [7,8,12]. The measuring range of temperature is $\vartheta$ = -10 to 110°C. The thermocouple used is type-K thermocouple provided with a precision preamplifier to measure the thermoelectric voltage with cold junction compensation [7,8]. Moreover, the apparatus was equipped with an industrial platinum resistance device PRT with a bridge circuit to measure the resistance in Ohms. A liquid in glass thermometer, with dial gauge and a temperature range of $\vartheta$ = -10 to 110°C, is inserted inside a water regulating bath and is stated as an additional reference probe. Results of experimental work are analyzed, followed by tabulated data for each probe, and data fitting program was executed to identify probe calibrating parameters over the entire temperature range of $\vartheta$ = 30 to 60°C.

## II. EXPERIMENTAL SETUP

A bench-top unit of TH1 and computer controlled apparatus was installed in the unit operations lab at Khartoum University as shown in Fig.1, 1a and 1b. The setup TH1 comprised of digital display unit, a hot water bath, and an insulated flask which generates accurate fixed points and variable temperatures. The water bath, ice flask and electrical console are mounted on a common PVC base plate. An accurate platinum resistance thermometer PT100 with five-point NAMAS calibration certificate and temperature displayed directly in °C is included for reference [7,8]. Other temperature sensors were used, including industrial platinum resistance thermometer, type K thermocouples, and thermistor. The liquid in glass thermometer was used as an additional reference, which measures temperature in the range of $\vartheta$ = -10 to 110°C. This device does not produce an electrical output, and configured as standard spirit filled glass thermometer, depends on a change in volume to indicate the direct reading scale of the temperature. It has an accuracy of 0.027% [7,8,11]. The water bath, as shown in Fig.2, consists of an insulated stainless-steel vessel and has two functions depending on the amount of inlet water. When partially filled with pure water, a hypsometer is created which generates multiple fixed points for calibration purposes. This allows for all sensor probes to be fully immersed in water. A hot bath is created that allows the probes to experience variable temperatures between ambient and the boiling point of water, which identifies the behavior of each probe. The temperature of the condensing water vapor in the hypsometer can be determined accurately detecting the vapor pressure via a Bimetallic thermometer ranging of $\vartheta$=20 to 120ºC, providing knowledge of the barometric pressure. The water bath can withstand temperature in the range of $\vartheta$ = 0 to 100°C [7,8].

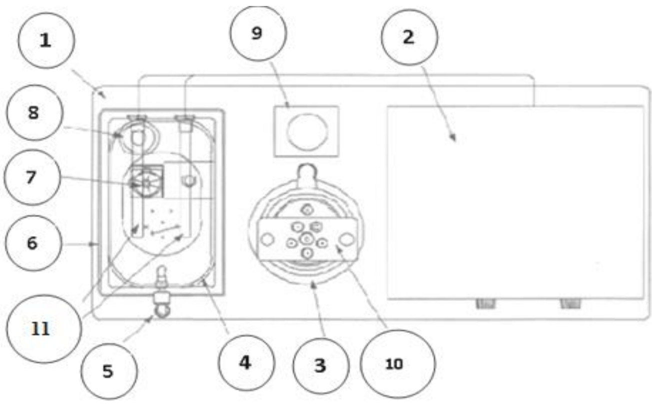


*Fig.1: General overview of TH1 setup [7,8].*

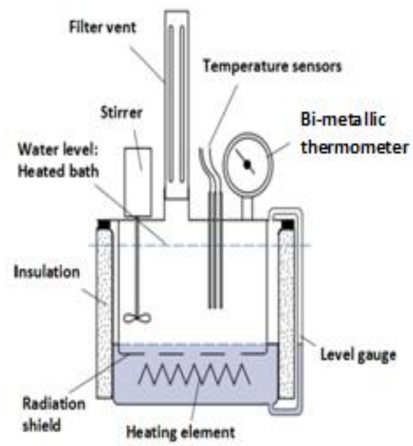


*Fig.2: TH1 regulating bath [7,8].*

| No. | Equipment name | No. | Equipment name |
|---|---|---|---|
| **1** | Base plate | **6** | Insulated stainless steel |
| **2** | Console | **7** | Stirrer |
| **3** | Insulated flask | **8** | Slotted chimney |
| **4** | Radiation shield | **9** | Stand probe carrier |
| **5** | Sight glass | **10** | Probe carrier |
| | | **11** | Electric heating element |

*TH1setup, equipment list [7,8].*

Furthermore, the electrical display unit is supplied by a heater power control that allows for the regulation of the amount of heat inside the water bath. The water bath is heated by a pair of electric heaters, elements with a power rating of 1KW, which have variable power control and over-temperature protection [7,8]. A rotary stirrer (RS, 330 r.p.m) inserted inside the bath maintained a continuous circulation of water flow. A radiation shield inside the vessel surrounded all probes to minimize any possible heat loss [7,8]. The sensor probes were held vertically in glands on a rigid probe carrier, as shown in Fig.3, which can be simply lifted off the insulated vessel onto the insulated flask [7,8]. A sight glass level gauge was provided at the front of the water bath allowing for the monitoring of the water level. The slotted chimney behind allows for the mixing of water steam with air before being released to the ambient environment, which minimizes the risk of scalding [7,8]. The vessel is filled directly via a filter vent, as shown in Fig.3, wherein the chimney has been pulled upwards. The electrical console is mounted on the base plate, as shown in Fig.1. The electric console houses all the necessary signal conditioning circuitry with appropriate current protection devices and an RCD. The console was provided by a digital meter with selector switch, and displayed all thermometric properties and temperatures measured. Corresponding signals are routed to an I/O port for connection to a PC, via an interface device [5,6,7,8,12]. The reference thermometer is a platinum resistance probe (0.1DIN,4 wires, PT100), which is supplied with a 5-point calibration NAMAS calibration certificate [7,8]. This sensor probe is installed inside a $D_o$= 2mm diameter protective stainless-steel sheath to provide a reasonably fast response to change in temperature [7,8]. Meanwhile, an additional industrial grade platinum resistance probe (DIN,3-wire, PT100) was connected. This probe was installed in $D_o$= 6mm diameter protective stainless-steel sheath to provide a slower response and to reduce accuracy when compared to a reference sensor [7,8]. The calibration of PT100 IND was carried out at water ice point temperature. The isolated flask was used instead of the hypsometer and it was filled with melting ice, while the sensors carrier was placed on top of it. Additionally, the apparatus is designed to hold three type K thermocouple probes, each with different construction so that the thermal response and conduction errors can be easily detected [7,8]. The straight naked bead thermocouple used in this work, is as shown in Fig.3. The sensor probe consists of a welded bead at the end of the wire, protruding from a $D_o$=3mm diameter stainless steel sheath and insulated with varnish to accelerate the thermal response [7,8]. This sensor probe is inserted on the front of the console, its conditioning circuit enables a display of the EMF generated by the junction of dissimilar metals, in μV [7,8]. The setup is also supplied by an additional thermocouple conditioning circuit which allows the voltage output from the straight probe to be displayed as a direct reading thermometer calibrated in ºC [5,6,7,8,12].


*Fig.3: Layout of the sensors in TH1 setup [7,8].*

In addition, the thermistor probe consists of a semiconductor material installed inside a $D_o$ = 3 mm diameter protective stainless-steel sheath [7,8]. The thermistor is a thermally sensitive variable resistor which exhibits a highly non-linear and negative characteristic [7,8]. The conditioning circuit of this probe passes a constant current through the thermistor and the voltage drop indicated a measurement of the resistance, in Ω. Above the water bath, a pre-installed standard Bi-metallic thermometer relies on differential expansion of two different metals to operate a Bourdon pressure gauge, calibrated in the units of temperature. The scale is non-linear and the thermometer exhibits a very slow response to change in temperature. The device reads out temperature in the range of $\vartheta$ = 20 to 120ºC, and does not produce any electrical output [7,8]. The bi-metallic thermometer device was considered as an additional reference of the setup, in addition to the liquid in glass thermometer. The rotary selector switch on the console was used to change the digital display between the sensor outputs from the reference PT100, the industrial PT100IND, the thermocouple, and the thermistor. Readings from the bi-metal thermometer and the liquid-in-glass thermometer were taken directly from the scales on the devices themselves. All sensor probes were immersed at a depth of 100 mm inside the regulating bath. During the measurement, it was assumed that a transient over-voltage was typically present in the main supply unit. The water temperature in the stirred bath is assumed to be uniformly distributed. It was checked that the water had a purity of 99.8% and was used without further purification. The uncertainty of PT100 reference thermometer measurement delivered by the supplier was ± 0.0Ω, which is equivalent to ± 0.05 ºC [5,6,7,8,12].

## III. RESULTS AND DISCUSSIONS

As the water bath temperature rises, results were recorded at intervals of 5ºC, indicated by the PT100 reference thermometer. The steady rising of the steam from the steam vent was observed following which the boiling point of water was recorded and the temperature was held steady for several minutes. Thereafter the stirrer and the heater were switched off and the cooling rate increased, as readings were recorded. The following graph shows the calibration results for the resistance of PT100 industrial devise immersed in the water bath for six hours, over a temperature range from $\vartheta$ = 30 to 60ºC, with 5ºC intervals. *Fig.4* describes the linear and stable temperature-resistance responses delivered by the TH1 setup. This indicates the unique properties of platinum, which has the most stable resistance over a wide range of temperature. *Fig.4* shows the quadratic basic fitting of temperature-resistance curve over the entire temperature range. The relationship between resistance and temperature for the platinum RTD can be described by the given equation [12].

$$R = R_0(1 + AT + BT^2) \qquad (1)$$

The results as described in *Fig.4* show that the calibration results for PT100IND and according to the preliminary estimates reached a maximum value of less than 1.60%. In addition, the equation of Callendar-van Dusen has been executed for this sensor over the entire temperature range. The equation provides the standard resistance value $R_0$ for the PT100IND at $\vartheta = 0$ °C which was obtained from the experimental data. The results of the comparisons of Callendar -van Dusen equation executed in this work and according to the temperature scale of ITS-90 [12], provided a value of $R_0$=99.83Ω, with an indicated maximum calibration error of less than 0.70% in resistance and 0.85% in temperature as shown in Fig.5,6.

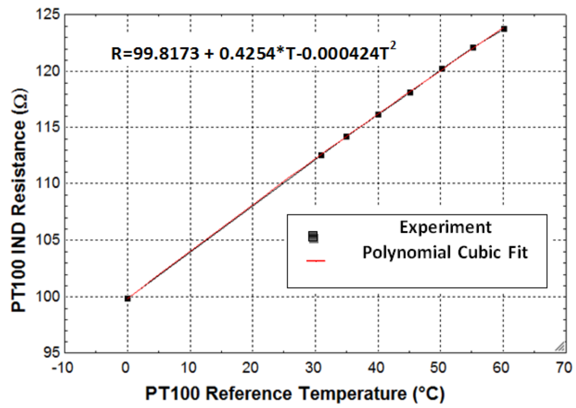


*Fig.4: Variation of PT100 reference temperature with PT100IND resistance.*

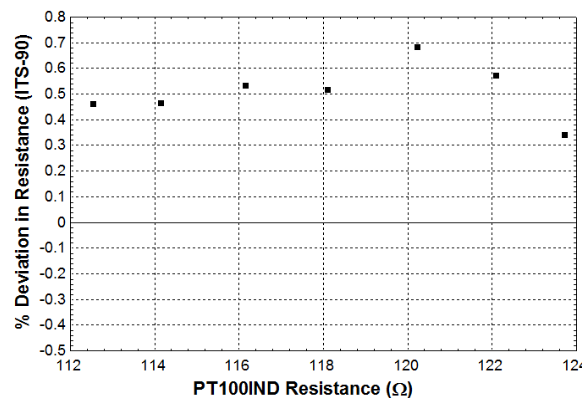


*Fig.5: Variation of PT100IND resistance with percentage deviation in resistance (ITS-90).*

The parameter A provided a value of A=0.0037 $^{o}C^{-1}$, with an indicated calibration error of less than 5.5%. The parameter B provided a value of B=-5.964*$10^{-7}$ $^{o}C^{-2}$, with an indicated calibration error of less than 3.2%. The equivalent form of this model has been executed for the PT100IND over the entire temperature range, using the following equation [12].

$$R_T = R_0\left\{1+\alpha\left[T+\frac{\delta T}{100}\left(1-\frac{T}{100}\right)\right]\right\} \quad (2)$$

According to the experimental data delivered and compared with the standard temperature scale of ITS-90, the value of α was 0.003739$^{o}C^{-1}$ and δ was 1.499°C. Both the values, of α and δ, indicated calibration errors of less than 2.9% and 0.067% respectively. The uncertainty applications were executed to equation (1) with the uncertainty provided by the experimental data of the PT100IND at $U_T$= ± 0.005°C. *Fig.7* describes a parametric execution of the variation of PT100IND resistance, and its uncertainty. The results show an absolute linear response between the resistance and its uncertainty, which reached a value of $U_R$ = ± 0.0019Ω at $\vartheta$ = 0°C.

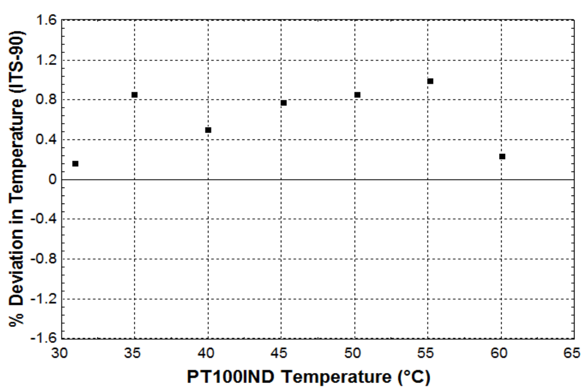


*Fig.6: Variation of PT100IND temperature with percentage deviation in temperature (ITS-90).*

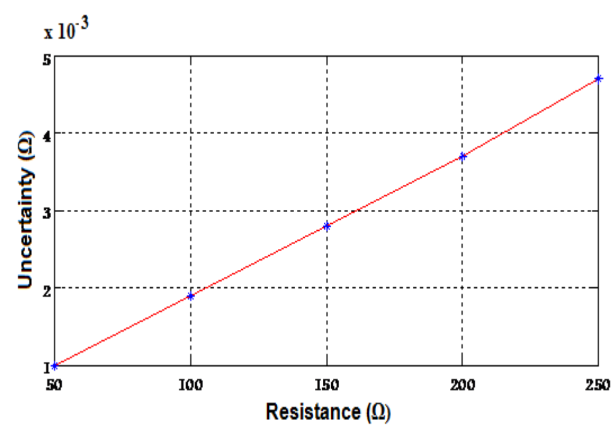


*Fig.7: Variation of PT100IND resistance with uncertainty.*

*Fig.8* shows the voltage- temperature response for the straight naked bead thermocoupleover a temperature ranges from ϑ =30 to 60ºC. This resulted in the thermocouple producing a linear change in output with a highly stable temperature profile. Compared to experimental data, there is nearly a 200μV difference in the sensor readings for every 5ºC temperature interval. *Fig.9* shows deviation of calibration data for the thermocouple compared to NIST data [5,9]. The calibration error for this sensor according to experimental data reached a maximum deviation of less than 0.98%. *Fig.10* shows the resistance of thermistor device in ohms over a temperature range of ϑ=30 to 60ºC. The curve describes the non-linear behavior of this sensor. It is clearly seen that change is most rapid at low temperature providing great resolution for determining the corresponding temperature and resistance responses, which is relatively less at high temperature values. The experimental data in Fig.11 shows high stability in measuring the temperature using this sensor. The work also executed a standard equation of Steinhart-Hart to calibrate the measuring data. The equation is described as follows [6]:

$$\frac{1}{T} = c_1 + c_2 \ln(R) + c_3 (\ln(R))^3 \tag{3}$$

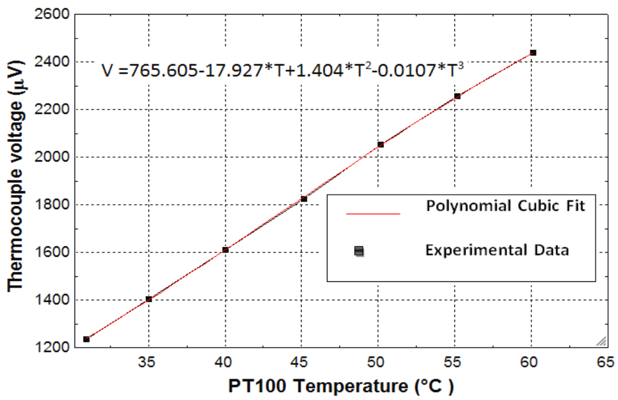


*Fig.8: Variation of thermocouple voltage with reference PT100 sensor temperature*

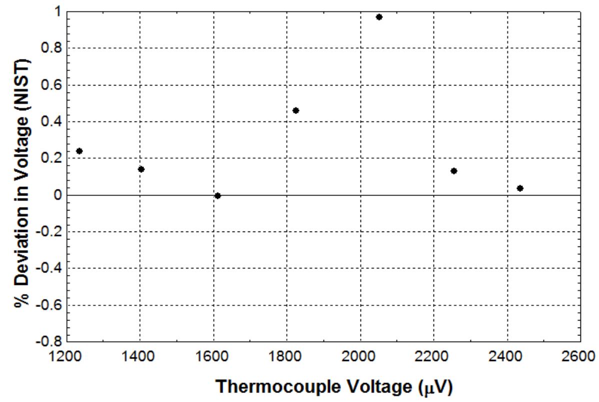


*Fig.9: Variation of thermocouple voltage with percentage deviation in voltage (NIST).*

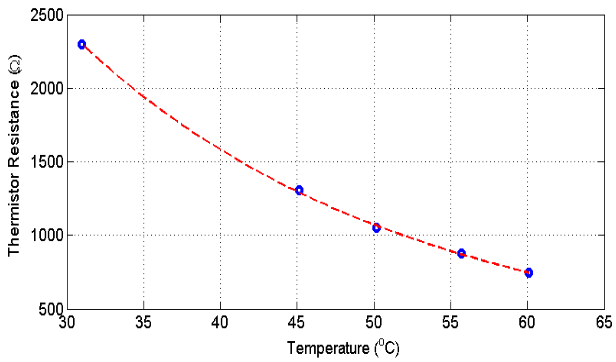


*Fig.10: Variation of thermistor resistance with reference sensor temperature.*

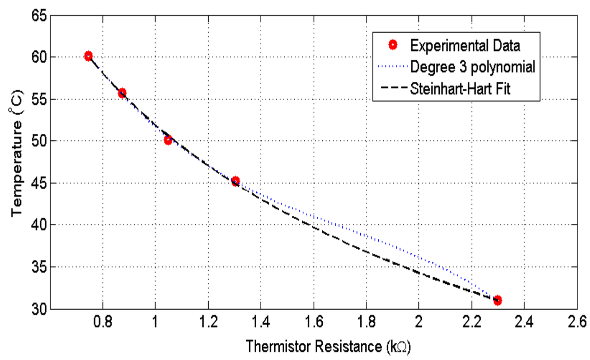


*Fig.11: Cubic polynomial of Steinhart-Hart fit for the thermistor data.*


*Fig.12: Layout of sensors in drier unit.*


*Fig.13: Final response of measuring the drier tunnel and trays with TH1 setup sensors.*

Using this standard equation, the calibration data of the thermistor reveals the value of $C_1$=1.2199*$10^{-3}$, $C_2$=2.7509*$10^{-4}$, and $C_3$=1.322*$10^{-7}$ for this sensor (regressed data in *Fig.11*). The calibration error according to experimental data by this sensor was less than 0.30%. As indicated in Fig.1a, and 12, the tray drier was equipped with 7 Temperature sensors of which 2 temperature sensors were of Dry and Wet Bulb, before the electrical resistance; 1 electrical resistance temperature sensor, 2 temperature sensors of Dry and Wet Bulb, after the electrical resistance, and 2 temperature sensors of Dry and Wet Bulb, after the drying chamber. Among these sensors the PT100IND, type K thermocouple and thermistor of the setup TH1 were installed successfully. Fig.13. shows the final response of each sensor compared with other sensors in the drier unit. The response exhibited a high stable measuring data with a linearized output. The overall error according to the final lab test was no more than 0.50%. Thus, the addition of TH1 setup sensors enabled us to conduct the temperature around the tray drier elements and to check the effects of the temperature on the final products carefully.

## CONCLUSIONS

This work has discussed the temperature measurement and calibration procedure for various sensors using the TH1 setup. The principles of measurement, calibration and the thermoelectric properties of platinum resistance thermometer, thermocouple, and thermistor have been widely explained. All results were agreed with standard temperature scales measuring and calibrating data.

## NOMENCLEATURE

***Abbreviation***

| | |
|---|---|
| TH1 | measuring and calibrating setup |
| PRT | platinum resistance thermometer |
| NAMAS | national measurement accreditation service |
| PVC | polyvinyl chloride |
| PT100 | standard platinum thermometer |
| r.p.m | revolutions per minute |
| DIN | German national organization for standardization |
| IND | industrial |
| RTD | resistance temperature detector |
| RCD | residual current device |
| ITS-90 | international temperature scale of 1990 |
| EMF | electromotive force |
| NIST | national institute of standards and technology |

***Latin letters***

| | |
|---|---|
| T | temperature |
| A,B | parameter of PT100 resistance temperature equation |
| R | resistance |
| $C_1$ | first parameter of thermistor Steinhart-Hart equation |
| $C_2$ | second parameter of thermistor Steinhart-Hart equation |
| $C_3$ | third parameter of thermistor Steinhart-Hart equation |
| $\vartheta$ | temperature |
| $\alpha$, $\delta$ | parameter of PT100 resistance temperature equation |

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