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Digital Chemical Thermometers Vs Analog Thermometers

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Abstract:- The purpose of this project is the construction of a portable digital chemical thermometer and its comparison against analog thermometers to be applied as an experimental instrument in the chemistry laboratory where the temperature measurement is carried out in different chemical substances by students and teachers of the University. Technology of Tlaxcala. This article describes the comparison made after the construction of the digital chemical thermometer, a project carried out by students of the Industrial Maintenance career at the Technological University of Tlaxcala. First, a plastic structure was manufactured in a 3D printer, then an Atmel 328P microcontroller was used to control the thermometer, a 128x64 OLED screen to display the temperature, a J-type thermocouple adapted with a MAX6633 was used as a sensor that is responsible for obtaining temperature data and a recharging module for a rechargeable 9V lithium-ion battery.

Its purpose is to obtain a precise temperature measurement of substances, thus being a more reliable and easy-to-use measuring instrument for the student community. Its design is a rectangular box-shaped structure, this design was made in the Solid Works design software, once the design was finished it was exported to the Ultimaker software to print it in 3D, then the different pieces were assembled by joining them with bolts for later, assembling the electronic circuit inside the box, programming the Atmel 328P microcontroller, and finally calibrating the J-type thermocouple. By performing comparative tests in ice water up to the boiling point at different temperatures against an analog mercury device, as well as a device of alcohol, it was possible to observe a great similarity in the values obtained, for which it was verified that the thermometer works correctly, is reliable and meets the needs of the university.

Keywords:- *Temperature, thermocouple, measuring instrument, and thermometer.*

I. INTRODUCTION

A measuring instrument is an instrument, technique, or set of techniques that will allow a numerical assignment that quantifies the manifestations of a construct that is measurable only indirectly **[1]**. The thermometer is an instrument that measures temperature. The chemical thermometer of the present project is intended to be a useful instrument within the laboratories of the technological university of Tlaxcala according to its design it is intended to be practical and accurate compared to alcohol or mercury thermometers because these are usually more fragile and even pollutants. The digital thermometer became an instrument easy to use not only in medicine or industries but also in the study and research centers, so different types of digital thermometers have been developed by different students from universities around the world according to the need that arose and each one used different elements for their construction. One of these elements is the thermocouple being a useful sensor for taking temperature. Guadalupe EvaristoCedillo Garza **[2]** performed the first study of temperature measurement with thermocouples, but **[3]**, highlight the temperature monitoring of the industrial sector by thermocouples with Atmega2560 controller under analog data acquisition. To visualize the temperature, the use of a digital display is implemented as Olivar Ruiz Marta en 2015 **[4]**. The project is in the development stage and we are still working on tests for its adjustment with different liquids at different temperatures. This, to apply in the future statistical test of Student's T test of Chi-square to compare their variation and their common points to reduce the margin of error of the thermometer.

II. MATERIALS AND METHODS

The digital chemical thermometer prototype was developed under the following components:

A. ATmega328P Microcontroller

The microcontroller is an integrated circuit that contains a central processing unit (CPU), memory units (RAM and ROM), input and output ports and peripherals. These parts are interconnected within the microcontroller, and together they form what is known as a microcomputer. It can be rightly said that a microcontroller is a complete microcomputer encapsulated in an integrated circuit **[5]**. There are different types of microcontrollers, but in this article, we are going to focus on the ATmega328P microcontroller. The ATmega328P microcontroller is a controller chip created by Atmel and belongs to the mega

AVR series, high performance, low power and optimized for C compilers. The device operates between 1.8 and 5.5 volts. Its architecture allows it to execute instructions in a single clock cycle, reaching a power of 1 MIPS **[6]**.

B. TP4056 Charging Module

The TP4056 is a full constant current/voltage linear charger for single-cell lithium-ion batteries. Its SOP package and low number of external components make the TP4056 ideal for portable applications. Moreover, the TP4056 can work inside a USB adapter and the wall. No locking diode is required due to the internal architecture and MOSFET having prevented the negative charge of the current circuit. Thermal feedback regulates the load current to limit die temperature during high power or high ambient temperature operation. The charging voltage is set at 4.2 V, and the charging current can be programmed externally with a single resistor. The TP4056 automatically terminates the charging cycle when the charging current drops to 1/10th the programmed value after the final float voltage is reached **[7]**.

Other features include current monitoring, low locking voltage, automatic recharging and two status pins to indicate load termination and the presence of an input voltage.

C. Rechargeable 9V Lithium Battery

A 9v lithium battery was used in this project. A battery can be composed of two or more cells connected in series or in parallel. A cell is the basic unit of a battery capable of converting chemical energy into electrical energy through electrochemical reactions. Batteries consist of four fundamental parts which are the anode, cathode, separator and electrolyte. The anode undergoes an oxidation reaction during the discharge process while in the loading process it undergoes a reduction reaction. For the case of cathode, we have a reduction reaction during the discharge process and an oxidation reaction during the loading process **[8]**.Lithium-ion batteries have superior characteristics compared to others. That is why its use has increased considerably in recent years. For example, the use of this type of batteries has been significant in the market of electronic devices, specifically in cell phones, tablets and laptops **[8]**. Due to its smaller design, weight, high energy density and long lifespan, it was perfect to be used in our project.

D. Display OLED

It is a light-emitting diode made up of a very thin layer of organic polymers, that is, large molecules made up of chemical units in a chain that are capable of converting electrical energy into light when placed between two electrodes **[9]**. In this project, a display with OLED technology was used. OLED technology is more common, which is why it is more used, since it is one of the two main display technologies in the industry. After being invented in 1987 **[10]**. OLED screens are based on a photochemical principle by which certain organic molecules, when excited by an electric current, emit light. Displays based on this technology are slimmer and weigh less as they do not require backlighting. They are designed to have a wide visual angle of approximately 170º. Also, they generate brighter light and only require between two and ten volts to operate. Currently, this type of technology is being used for the development of what is called electronic paper, that is, very thin and flexible screens (thickness can vary between 100 and 500 nanometers **[9]**.

E. Thermocouple type J

The thermocouple is an invention of the nineteenth century, which allowed the industry to improve machinery, better quality in production and the development of new products. The German-Estonian physicist Thomas Johann Seebeck (1770-1831), was credited with discovering the operating system of this device. During an experiment he discovered that, by joining a tip of two different metals, which he called cold tip, they produced an electromotive force at the other two ends that were separated, called hot tip, where if a voltage measuring instrument was placed, a variation of the reading was produced. In this way, Seebeck produced the first models of thermocouples and experimented with metals of different types **[11]**.

There is a wide variety of thermocouples as shown in table 1 **[12]**.

Types of thermocouples		
Material	**Type**	**Temperature limit**
Copper	T	350°
Iron or stainless steel	J	700°
Chromel	K	1200°
Platinum Rhodium	R	1500°
Platinum rhodium	S	1000°

Table 1: Thermocouple materials and types

The materials are manufactured according to internationally accepted standards as set out in IEC 584 1.2, which is based on the international temperature scale ITS 90. The operating temperature maximums depend on the conductor thickness of the thermal elements. The thermocouple types can be separated into 2 groups, base metals and noble metals **[13]**.

Type J – Iron-Constantan: Although in thermometry type J is still popular, it is used less than type K due to its limited temperature range, - 200C to +750°C. Type J is mainly used in installations where we can find old instruments calibrated for this type of thermocouple. Its sensitivity rises to 55µV/°C. **[13]**.Other thermocouple specifications are: Type J thermocouple can be used in vacuum, reduction and inert atmospheres. A robust gauge (equal to or greater than 20) is recommended to prolong the life of the cable over 500°C because the iron element has high oxidation at such temperatures **[14]**.

F. 3D Printing

The history of 3D printing dates back to 1976, when the inkjet printer was invented. In 1984, some adaptations and advances in the concept of inkjet transformed ink printing technology to material printing. Over the past few decades, there have been a wide variety of applications of 3D printing technology that have been developed across various industries **[15]**.

It is important to know the origin of this technology, but it is also important to know what it consists of because that will help us to be able to use it as best as possible. 3D printing technology is the process by which a three-dimensional object is made, almost in any shape, from a 3D model, basically under a process of adding material. That's why it's also called additive manufacturing. That is, the object is formed by the superposition of layers of material that are added one and one **[16]**.

Different additive manufacturing techniques are employed in modern 3D printing. Depending on timelines, budget, and product requirements, some printing techniques and 3D printers will suit your project better than others. The project was printed on a fused deposition modeled type printer – FFF.

This type of printer creates objects by depositing layers of molten thermoplastic polymers. It is mostly used to build visual aids and prototypes. A wide variety of materials can be used, making it easy to cover any type of requirement. This technique can produce functional parts for a wide range of applications **[17]**.

Advantages:	**Disadvantages:**
Ability to create end-use parts	Less detail than other methods
Fast print speed	Visible layer lines
Wide range of compatible materials	

Table 2: Advantages and disadvantages of 3D printing

According to the author mentioned before **[17]** ,3D printing consists of advantages and disadvantages as shown in table 2, however, 3D printing was chosen due to the possibility of creating or designing end-use parts to realize the structure of the digital thermometer that will allow the proper interaction of the user with the instrument.

G. Experimentation with thermometers

In the creation of this digital thermometer prototype, experimentation was carried out to measure the temperature in ice water, which was heated to a certain temperature up to the boiling point, taking it with the type J thermocouple and comparing said sensor with the alcohol thermometer. as shown in table 3 and the mercury thermometer that can be seen in table 4 in an interval of two minutes showing in Fig 1 the comparison of the thermocouple, the alcohol thermometer and the mercury thermometer it is worth mentioning that the temperature was taken at 0.7 atmospheres. According to the Pueblos de America newspaper **[18]**, the community of El Carmen Xalpatlahuaya has an altitude of 2,491 meters above sea level, which was considered in the experimentation of the project. One of the reasons why the data collections were used during the experimentation with the prototype of the digital thermometer was to carry out a T-study of two samples, in addition to the fact that these data allow us to see how precise the prototype is compared to thermometers that already exist. they are standardized. Sampling was applied from 0° to the boiling point of water, which is 100°, since this allows an appreciation of the data that is distributed in the determined time intervals, in addition to a better comparison between the new prototype and already standardized devices. Finally, within the experimentation it has to be verified to what extent the thermocouple can resist when subjected to dangerous chemical substances, in this case, it was subjected to a redox reaction, which is composed of nitric acid (100 ml) and copper (5cm) as can be seen in equation (1), adding them in a test tube, since in most metallic materials redox reactions are the cause of the deterioration of metals establishes **[19]**.

$$Cu + HNO_3 \quad (1)$$

It was decided to subject this redox reaction due to the acidity that it usually presents when entering a metal, in this case, copper, it also works as a reference to verify the effectiveness, but also the quality of the material of the type J thermocouple in the case of a layer of steel stainless steel to check if you need to work on a coating or change the thermocouple.

III. RESULTS

The digital chemical thermometer that was built with the aforementioned materials was compared with the analog thermometers of the university laboratories. Temperature measurements were made at different times and the following results were obtained:

In the figure 1 shows the behavior between the alcohol thermometer and the digital thermometer, it shows the calibration curves the have a similar behavior, having a minimum difference between data.

The data to carry out this comparisonwas taken with an interval of two minutes, during periods of 30 min.

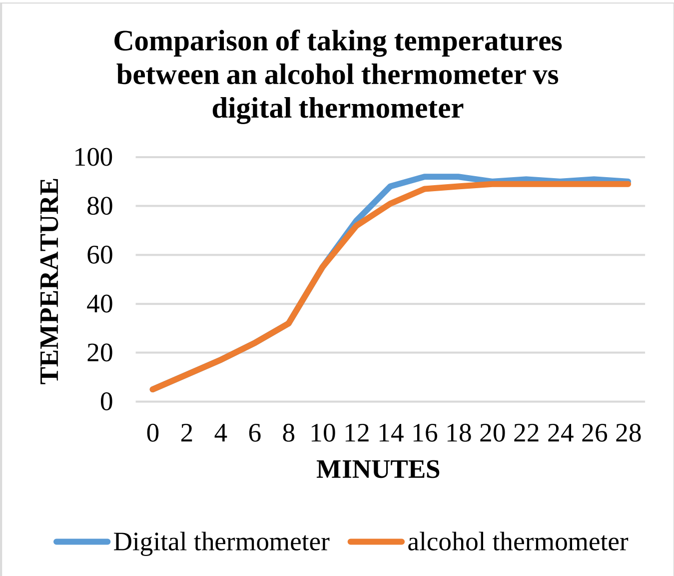

Fig 1: Digital Thermometer vs. Alcohol Thermometer
Following figure 1, the blue curve shows the temperature in degrees centigrade obtained by the type J thermocouple, concerning ice water, while the orange curve shows the temperature of the alcohol thermometer in the same substance

Next, there is the comparison of the digital thermometer against the mercury thermometer in ice water and this is shown in table 3 where the patterns of numerical behavior are observed.

Time (m)	Digital thermometer	Alcohol thermometer
0	5	5
2	11	11
4	17	17
6	24	24
8	32	32
10	55	55
12	74	72
14	88	81
16	92	87
18	92	88
20	90	89
22	91	89
24	90	89
26	91	89
28	90	89

Table 3: Comparison between sensor and alcohol thermometer

Later, continuing with the experimentation of the digital thermometer, in this part a comparison was made against a mercury thermometer where the following graphs were obtained:

In the graph of figure 2, you can see the calibration curves of the type J thermocouple.

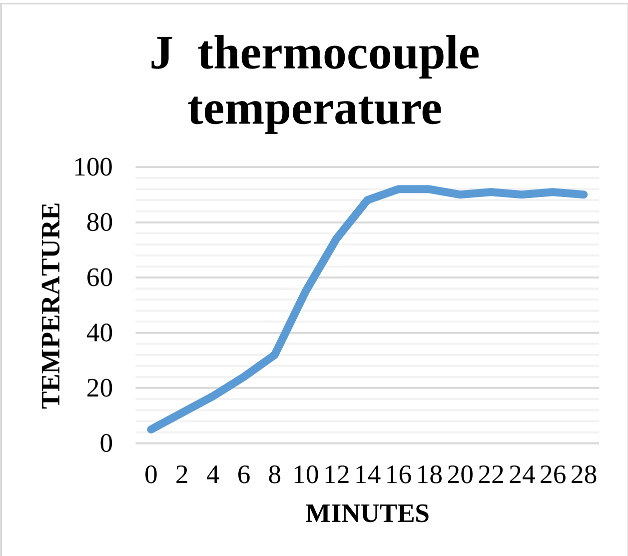

Fig. 2: Type J thermocouple temperature

The following graph represented in figure 3 shows the calibration curves of the analog mercury thermometer.

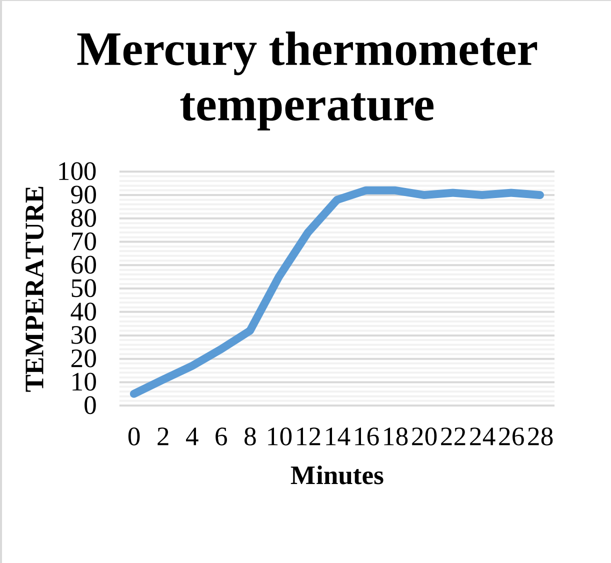

Fig. 3: Mercury thermometer temperature

The numerical behavior patterns of the type J thermocouple and the mercury thermometer can be seen in table 4.

Time (m)	Type J thermocouple	Mercury thermometer
0	5	5
2	11	11
4	17	17
6	24	24
8	32	32
10	55	55
12	74	74
14	88	88
16	92	92
18	92	92
20	90	90
22	91	91
24	90	90
26	91	91
28	90	90

Table 4: Comparison between sensor and mercury thermometer

A. Effectiveness of the digital thermometer against the alcohol thermometer

For the statistical analysis of these results, a T study of two samples was carried out, for which both data collections were taken as a basis and analyzed in the Minitab 2019 software, which yielded the following parameters shown in figure 4.

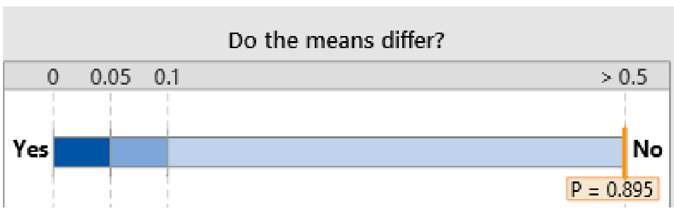

Fig. 4: Measurement difference

With the previous information presented in Figure 4, it can be said that the alcohol thermometers concerning the sensor differ minimally in the temperature measurements taken by the respective instruments (type J thermocouple and alcohol thermometer). It is observed that the samples between the alcohol thermometer for the sensor are slightly different, therefore the data shown in table 5 were obtained.

Individual samples

Statistics	Type J Thermocouple	Alcohol thermometer
Sample size	15	15
Mean	62.8	61,133
95% CI	(43.55, 82.05)	(42,160, 79,657)
Standard deviation	**34,757**	**33,449**

Table 5: Individual samples between thermometers

The difference in the samples between the alcohol thermometer to the sensor can be seen in table 6.

Difference between samples

Statistics	Difference
Difference	1.6667
95% CI	(-23,889, 27,222)
Difference	**Temperature sensor- Thermometer temperature**

Table 6: Difference between temperature samples

B. Comparison of the proposed thermometer against the alcohol thermometer

Figure 5 shows the probability of finding a difference that is minimal between the samples obtained.

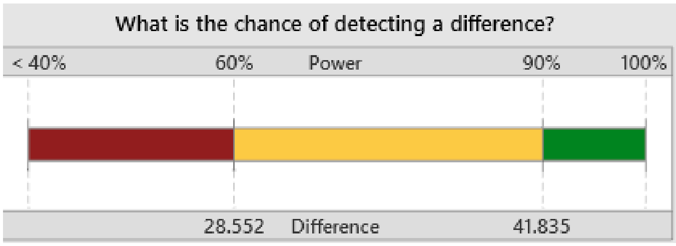

Fig. 5: Probability for a difference

There is a minimal difference in the size of the sample between the alcohol thermometer for the sensor as can be seen in table 7.

What difference can be observed with the sample size?

Difference	Power
28,552	60%
32,053	70%
36,151	80%
41,835	90%
Difference	**1.6667**

Table 7: Difference between sample sizes

A calibrated alcohol thermometer with respect to the proposed thermometer shows an effectiveness of 99% with a difference between the calibration of 1%.

C. Effectiveness of the digital thermometer against the mercury thermometer.

Continuing with the results of the proposed thermometer and the mercury thermometer, you can see in figure 6 the difference between the variables thrown by the aforementioned instruments.

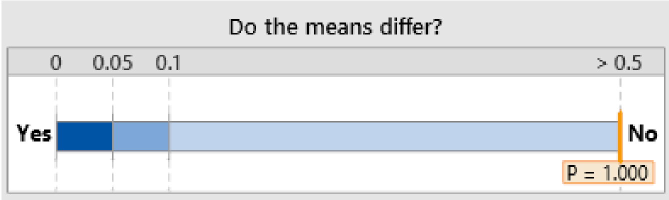

Fig. 6: Difference between sensor and mercury thermometer

It is observed previously in figure 6 that the means do not differ between the mercury thermometer. These results are also shown in table 8.

Individual samples

statistics	Mercury thermometer	thermocouple
Sample size	15	15
Mean	54,167	54,167
95% CI	(35.60, 72.73)	(35.60, 72.73)
Standard deviation	**37,332**	**37,332**

Table 8: Thermocouple samples and mercury thermometer

The difference between samples between the mercury thermometer concerning the sensor can be reviewed in table 9.

Difference between samples

Statistics	Difference
Difference	0
95% CI	(-25,289 , 25,289)
Difference	**Temperature sensor- Thermometer temperature**

Table 9: Difference between temperatures obtained

D. Comparison of the proposed thermometer against a mercury thermometer.

In figure 7, you can see the probability of finding a difference that is null between the samples obtained.

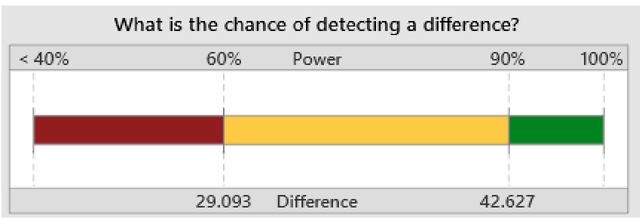

Fig. 7: Probability for a difference between thermometer

It is observed that the difference does not change with the size of the sample, between the mercury thermometer for the sensor as shown in table 10.

What difference can be observed with the sample size?

Difference	Power
28,552	60%
31,821	70%
35,887	80%
41,528	90%
Difference	**0**

Table 10: Final difference between instruments

A calibrated mercury thermometer, for the proposed thermometer, shows an effectiveness of 99% with a difference between the calibration of 1%.

E. Experimentation with redox reaction

Once the substances mentioned above were added to the test tube, a reaction was obtained that modifies the terms of equation (1) giving rise to equation (2).

$$Cu(NO_3)_2 + NO_2 + H_2O \quad (2)$$

During the reaction it was observed that when copper was added to the redox reaction, it turned a greenish color to what is called copper nitrate, which is represented in the first term of the equation, in an interval of half a minute it began to release ions, to which this reaction is known as nitrogen oxide which can be appreciated in the second term when the copper nitrate reacted, the sensor was subjected at the same time as the copper, consuming the copper until it was formed water without any activity, this expression is represented in the third member of the formula presented above, the thermocouple being subjected to said substance. Before experimenting with the redox reaction, the sensor was visualized as shown in figure 8, in an IROSCOPE model MG-64 microscope, taking the image at an angle for a detailed analysis, to observe its state without having interacted with the chemical reaction.

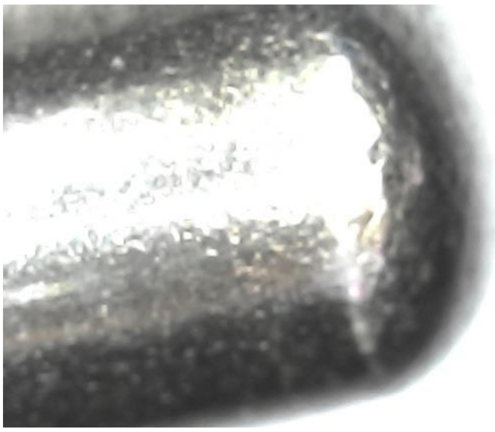

Fig. 8: Thermocouple before subjecting it to redox reaction

The microscope was adjusted to a view where the thermocouple is observed after being subjected to this reaction, it can be seen in figure 9, that there is no type of corrosion or cracking after the chemical test, the time that the sensor was subjected to the reaction was ten minutes.

Fig 9 Thermocouple after redox reaction

IV. CONCLUSIONS

As was shown throughout this project, the development of a digital thermometer was successfully achieved, where the margin of error was reduced when taking temperatures. Likewise, in addition to the design of the prototype that in the future will serve to replace alcohol and mercury thermometers in chemical laboratories. The advantage of this prototype is that it offers a pleasant display compared to the aforementioned instruments. However, the only disadvantage that this prototype would have is the response time of the sensor to the OLED display, having a slight delay compared to others. thermometers. We can conclude that the thermocouple and its material selected to replace the instruments already mentioned is resistant to dangerous reactions, which cause wear on metals, since after the reaction was consummated it was observed ten minutes in the substance, determining that it can take the temperature of substances as well as resist them. According to **[20]** in their research work pitting corrosion occurred in stainless steel tanks for the manufacture of shampoo, therefore, it is recommended not to put the sensor in substances with chlorine because the thermocouple coating is stainless steel, this can lead to pitting corrosion on the sensor as well as affect device performance.

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