Al-Rafidain Engineering Journal (AREJ) Vol.27, No.2, September 2022,pp.117-126

Comparative Investigation on the Quality of Sensitivity of Six Different Types of Thermocouples

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Received: 26/1/2022 Accepted: 10/6/2022

Abstract:
Sensitivity quality of thermocouples is an important parameter in temperature measuring, it affects on the accuracy of measuring results. Metals type which used in thermocouples play a prominent role in determining level and quality of sensitivity.
Nine minerals were investigated and compared with each other, as these metals contribute to composition of six thermocouplesof types E, J, K, T, R and S. Three factors such as metal type, magnetic field, and chemical composition were studied to find out their effects in determining sensitivity quality of thermocouples due to their effects on the increasing and decreasing of sensitivity and accuracy of thermocouples.
Research methodology has used data collection and analyzing on related 6 thermocouples.
The results showed that E- type has higher sensitivity, then J, K, and T, but R and S types have lower sensitivity in most temperature measuring ranges, also, copper, nickel, and chromium can give higher quality of sensitivity more than platinum and rhodium.
Also, the results of this research can assist manufacturers to further connection between quality of sensitivity, temperature ranges, and accuracy, in addition, for selecting appropriate metal for the medium being measured.

Keywords: *Metals, Quality, Sensitivity, Thermocouple, Seebeck coefficient*.

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1. Introduction and literature review

1.1. Introduction

First: Thermocouples are sensor devices used for temperatures measuring, they consist of two dissimilar metal wires joined together at one end to form a junction, this point whose temperature is to be measured called hot junction, and the other end is called cold junction and reference end, this is to be at 0℃“32°F”, when the junction of both metals is heated or cooled, it generates a voltage, or an electromotive force "emf" is resulted when there is temperature difference between two metals, the voltage's amount depends on temperaturedifference between this two dissimilar metal wires at the junction[1].

Thermocouples are commonly used in various industrial applications as monitoring and control processes, apply safety, and ensure product quality[2], also, they are used for temperature measuring in electric power generation, home devices, manufacturing processes, furnace control, food processing, automotive and aircraft engines, rockets, spacecraft, and others[3].

Most thermocouples play a significant role in industrial measurements, the reason is of their low cost, durability, and tolerance of high temperatures[4].The working of a thermocouple is based on the Seebeck effect which refers to voltagegeneration in an electrical circuit due to difference of temperatures between hot and cold junction as shown in figure 1[5].

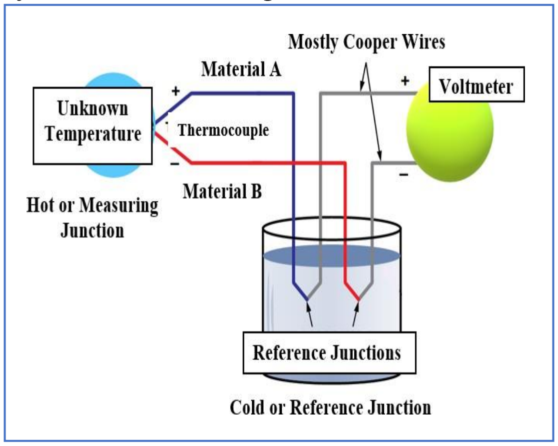

Figure 1**:** Seebeck effect in thermocouples

According to American Society for Testing and Materials, ASTM E230/E230M- 17, there are manytypes thermocouples, but most common are E, J, K,T, R, and S types, in relation with their uses, E-type used in power plants, J-type in injection molding, K-type in refineries, T-type used in cryogenics, freezers, and food production, R-type used in sulfurrecovery units, and S-type used in high temperature furnaces, biotech, pharmaceutical, and laboratories [6].

Second: about the metals, there are 3 metals and 3 metallic alloy compose these 6 types of thermocouples, therefore, the whole metals include nickel (Ni), chromium (Cr), copper (Cu), iron (Fe), aluminum (Al), manganese (Mn), silicon (Si), platinum (Pt), and rhodium (Rh), but thecomposition of each type is as follows [7]:

- E-type (Chromel/Constantan “Cu–Ni alloy”).
- J-type (Iron/Constantan “55%- 60% copper and45%- 40% nickel alloy”)
- K-type (Chromel “90% nickel and 10% chromium alloy”/Alumel “95% nickel, 2%aluminum, 2% manganese, and 1% siliconalloy”)
- T-type (Cupper/Constantan “Cu-Ni alloy”)
- R-type (Platinum-Rhodium/Platinum)
- S-type (Platinum-Rhodium/ Platinum)

Third: about the sensitivity, it could be identified that the sensitivity is the state of being sensitive, it is the ratio of respond to practical stimulation of technical actions in any system, also, the sensitivityis a level of quality of response reaction in the same system, here, sensitivity is resulted from thermocouples during temperature measuring, also, it is an assignment related to the metals used in thermocouples, its quality level comes from different metals which are main components in many thermocouples, in addition, it applies to describe the accuracy of results of temperature measuring, also, the obtained sensitivity and accuracy results will depend on other characteristics [8].

The sensitivity is a crucial parameter in thermocouples work, and level of quality of sensitivity has an effective role in their results, therefore, many processes have been done to improve metal sand alloys in order to enhance quality of sensitivity in thermocouples, also, thesensitivity outcomes of some other states and specifications related to metal type, here, the accuracy of thermocouples should meet the requirements of “Calibration Specification for BaseMetal Thermocouples” JJF 1637-2017 [9], also, the quantity of voltage on temperatures difference hasa great role in thermocouple sensitivity, as it equalsby the equation [10]:

$$Sensitivity\ "s" = \frac{\Delta V\ (\text{ quantity of voltage } \mu V\ )}{\Delta T\ (\text{ difference in temperature} ℃\ )} \left({}^{\mu V}/_{℃} \right)$$

To calculate the sensitivity (μV/°C) of a thermocouple (for instance of K-type), for the temperature range 0 °C to 100 °C., when the change in voltage that was developed is 4096 μV, here, the average sensitivity is equal to 4096 / 100 = 40.96 (μV/°C) .

1.2. Literature review:

1.2.1. A study [11] has investigated on relation between size of metals and level of sensitivity, it has studied the influence of size effect on sensitivity of Cu/Cu-Ni thin-film thermocouple, thestudy has selected this type because it widely used in thermocouples and with measuring range from - 200 to 400 ℃, it has applied experiments and used theoretical analysis. The study has proved that the level of sensitivity of Cu/Cu-Ni thin-film thermocouple is higher than that of the bulk Cu/Cu- Ni thermocouple, the level of sensitivity increases with reciprocal of thickness of the film, for this purpose the study has indicated results from other researches which proved that the electrical characteristics change with thickness of thin film. In addition, the study has referred to thermocouplesthat contain metals of Ni, Cu, and Fe, and contain alloys of Constantan, Chromel, and Alumel, the results were that the maximum thermoelectric power could be obtained from small thickness, also, the results were satisfactory because they havehigh stability and high level of sensitivity, for more enhancing, the study has referred to free electron theory and Wiedemann-Franz law which describes the relationship between thermal and electrical conductivity of the metal with temperatures measuring, thus, it has an equation on thermal conductivity of metal and sensitivity of metal.

12.2. A study [12] has performed an experiment about magnetic field sensitivity of thermocouples, the aims were to determine errors of temperature measuring and sensitivity to magnetic field at various temperature ranges, thus it has presented a table about the influence of magnetic field on sensitivity of encapsulated thermocouples of J-type and T-type.

The study worked on sensitivity related to both DC and AC magnetic fields by positioning thermocouples in a stable and an controlled temperatures, then the sensitivity to magnetic field was determined at various temperatures measuring,then, it has analyzed the final results according to each of metal properties, magnetization of metal sensors, and mechanical effects, then, it has proved that:

- Thermocouples in the metal enclosure has different errors due to magnetic sensitivity than the ones without metal enclosure.
- Sensitivity values to magnetic field was caused by the metal used and physical properties of a thermo-wire metal as well.

1.2.3. A study [13] has examined some metals and evaluated their roles in errors in temperatures measuring by thermocouples, it has showed that each of temperature curve, voltage curve, purity of metals, and the homogeneity are depending on metals type or metallic alloys, thus, the sensor faults occur due to metals impurity and in homogeneities, and this was affected on both of shape of temperature curve and voltage curve, hence, this changed the sensitivity of thermocouples, in addition, the study proved that:

- The voltage is actually generated by the temperature gradient along wire metals; therefore, for this purpose, the quality of wire metals should be maintained along entire lengthof the used wire.
- For greater precision, the modern manufacturing process in thermocouple wire fabrication have increased the quality of metals and metallic alloys.

1.2.4. A study [14] has investigated about the base metals that are mostly used such as copper, iron, and their alloys, it showed that they are cheap in cost and operates at lower temperatures, it indicated that they have suitable magnetic response. Then, the study investigated about noble metals such as platinum and its alloys that are mostly used with Rhodium, it indicated that they are more costly and operate at higher temperatures, also, they have small magnetic response. Then, it showed that the sensitivity value (Seebeck coefficient) may be positive or negative which depends on the nature ofused metals, it represented by the equation:

$E = SA\ (T1 - T2)$ in which is the E is thermo emf, SA is Seebeck coefficient of the metal, and T1 and T2 are temperatures of hot end and cold end respectively.

1.3. Aims of the research:

The aims of this research are:

- Revealing interrelation between quality of sensitivity and metals type that used as dissimilar conductors in thermocouples.
- Assessing six types of E, J, K, T, R, and S thermocouples which are composed with 9 metals of Ni, Cr, Cu, Fe, Al, Mn, Si, Pt, and Rh in sight of their effects on sensitivities at different temperatures, then comparison between them.
- Revealing sort of effects that caused by the 3 factors such as metals type, magnetic field, and chemical composition on the quality of sensitivity.

1.4. Importance of the research:

The importance of this study is to indicate:

- Revealing interrelation between quality of sensitivity and metals type may give us the actual value of each of sensitivity and accuracy level, also, it gives an illustration on kind of medium being measured by thermocouples which are containing metals or alloys with specific type.
- Assessing types of thermocouples with composed metals, this give more compatibility between them in practice, because indicates Mutual influences,

then doing the comparison between them will enhance the process accuracy of temperature measuring wider, because several values and quality of sensitivity are become evident.

- Revealing the effects that come out from 3 factors give data to designers and users to choose suitable typical metals in order to be fit with the medium being measured.

1.5. Methodology of the research:

The methodology of the research is as indicated infigure 2.

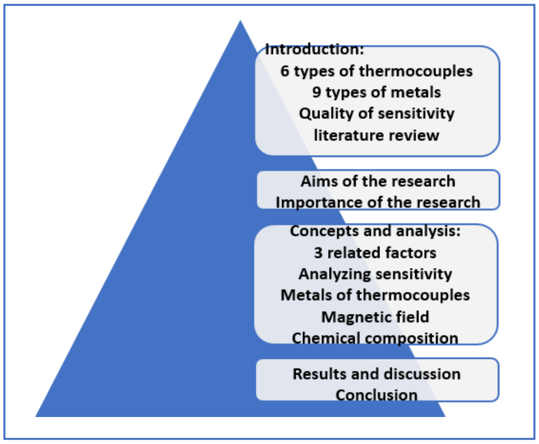

Figure 2: The methodology of the research

2. Concepts and analysis:

2.1. Analyzing sensitivity:

Sensitivity of 6 types of thermocouples composed commonly with 9 types of metals is analyzed in accordance with 3 related factors such as metaltype, magnetic field, and chemical composition, it is crucial theme to determine quality of sensitivity, because the quality of sensitivity will depend on these factors, and it becomes clear for each of temperature range and to kind of medium being measured, then this can give an illustration, then to determine values of sensitivity, because the factors have real effects on the final temperature measuring results, but it should be mentioned that they are susceptible and could be affected by any of mechanical damage, chemical environment, and heat treatment [15].

2.2. Metals of thermocouples:

Metals are the most influential factors that influencing the quality level of sensitivity of thermocouples, because they are determine accurate results and true values, there are many metals and metallic alloys appropriate to be used inthermocouples, but they are selected on basis of having maximum sensitivity (Seebeck coefficient) throughout whole ranges of temperature measuring,also, metals are selected that have high temperature stable and low thermal conductivity which are significant at cryogenic temperatures, homogeneity, and compatible with the available instrumentation [16]. Here, the common sensitivities of some metals or metallic alloys at 0℃ are showed in table 1 [17], in addition, the table 1 can be used to obtain the sensitivity of a thermocouple made from any pair of metals at 0°C (32°F), for example, the sensitivity (S) of a J-type of Iron/Constantan thermocouple is:

$$S = {}_{\text{type J: Iron/Constantan “Cu-Ni”}} = +17.91 - (-32.47) = 50.38\ \mu V/℃$$

Hence, for any pair of metals which fabricated together, the related sensitivity value can bedetermined, thus, a new quality level of sensitivity is formed.

Table 1: Sensitivity S $\mu V/℃$ of several metals at 0 ℃

Metals	Sensitivity ($\mu V/℃$)	Metals	Sensitivity ($\mu V/℃$)	Metals	Sensitivity ($\mu V/℃$)
Bismuth	-72	Carbon	+3	Iron	+17.91
Constantan alloy (E & T-types)	-32.86	Aluminum	+3.5	Chromel alloy (E & K-types)	+25.8
Constantan alloy (J-type)	-32.47	Lead	+4	Germanium	+300
Nickel	-15	Silver	+6.5	Silicon	+440
Alumel alloy (K-type)	-13.6	Copper	+5.89	Tellurium	+500
Platinum	0	Gold	+6.5	Selenium	+900
Mercury	+0.6	Tungsten	+7.5		

In regards with sensitivity, it should be mentioned as well, that there are difference between base and noble metals about its quality level, the noble metals used in R and S types which are platinum- oriented that have great reliable but they are at lowest sensitivity, but the base metals that used in E, J, K, and T types can result greater sensitivity than noble metals [18].

Therefore, in relation with thermocouples, the calculated sensitivities of E, J, K, and T types are 58.666, 50.381, 39.450, and 38.748$\mu V/℃$, respectively at 0°C, but they are smaller for R and S types which are 5.290 and

5.403μV/°Crespectively, this compared with the International Temperature Scale of 1990 (ITS-90) that with possible ranges of temperature measurement are indicated in table 2 [19], which is relying on the International Practical Temperature Scale of 1968 (IPTS-68) reference tables for thermocouples and represents the sensitivity of six different thermocouple types at different temperatures depending on metals [20]. Here, due to the nature and purity of the metals, and among these six types of thermocouples, it was revealed that E-type is most sensitive, and this different of value of sensitivity is stay true at various ranges of temperatures measuring, but the range between 200- 400 ℃ the E-type will hold higher quality ofsensitivity than J, k, and T types, in addition, R andS types can measure higher temperatures, but both have lower quality of sensitivity.

Table 2: Sensitivity S $\mu V/$℃ for six types of thermocouples at 0℃ based on ITS-90

Temperature ℃	E -270 to 1000℃	J -210 to 1200℃	K -270 to 1372℃	T -270 to 400℃	R -40 to 1768℃	S -40 to 1768℃
-270	1.565	-	0.735	1.008	-	-
-70	49.793	44.651	33.876	31.761	-	-
0	58.666	50.381	39.450	38.748	5.290	5.403
200	74.0	55.506	39.965	53.150	8.843	8.460
400	80.056	55.152	42.241	61.805	10.374	9.568
600	80.930	58.492	42.505	-	11.357	10.207
800	78.431	64.63	41.000	-	12.312	10.869
1000	75.156	59.26	38.981	-	13.231	11.539
1200	-	57.24	36.494	-	13.916	12.028
1400	-	-	-	-	14.129	12.129
1600	-	-	-	-	13.883	11.851
1768	-	-	-	-	12.258	10.313

The same ratio and increase or minimize of sensitivity will remain during when measuring temperatures below zero degrees Celsius, as comes from reference tables for low-temperature thermocouples from National Bureau of Standards, table 3 [21] which indicates the sensitivity valuesin different temperatures of E, K, and T types which composed with metals of Cu, Ni, Cr, Al, Mn, and Si with different ratios, they have different values and quality of sensitivity, but some of them are small.

Here, as comes from American Society for Testing and Materials (ASTM), the E-type has low range cryogenic below (- 273.15 ℃) due to significantly higher sensitivity, but K and T types are found that have fewer sensitivity levels [22].

Magnetic field:

Magnetic field is produced by moving electric charges in the metals, both of magnetic field and electric field are interrelated and they are two components of electromagnetic force, it influences on moving electric charges and electric current in metals, therefore, it will be around area of metals inwhich the current passed, its density depends on number of magnetic field lines, but the strength of magnetic fields depends on number of magneticfield lines at a particular area [23].

Table 3: Sensitivity S $\mu V/$℃ for types E,K,and T at different temperatures

Temperature in ℃	Sensitivity S ($\mu V/$℃)			Temperature in ℃	Sensitivity S ($\mu V/$℃)		
	E-type	K-type	T-type		E-type	K-type	T-type
-273.15	-0.203	0.241	-0.400	-135.15	39.070	25.821	24.173
-259.15	6.254	2.843	4.125	-121.15	41.595	27.772	25.887
-245.15	11.393	5.942	7.513	-107.15	43.997	29.604	27.560
-231.15	16.181	9.040	10.649	-93.15	46.279	31.316	29.181
-217.15	20.497	11.961	13.193	-79.15	48.440	32.904	30.754
-203.15	24.326	14.678	15. 302	-65.15	50.483	34.366	32.287
-189.15	27.787	17.220	17.235	-51.15	52.419	35.701	33.770
-175.15	30.989	19.618	19.102	-37.15	54.259	36.907	35.193
-163.15	33.568	21.576	20.661	-23.15	56.006	37.986	36.579
-149.15	36.403	23.755	22.433	-0.15	58.680	39.467	38.728

Magnetic field intensity is measured in units according to International System of Units (SI), the standard unit of magnetic field intensity is Tesla (T), one Tesla is defined as the field intensity generating one Newton of force per ampere of current per meter of conductor ($T = N \cdot A^{-1} \cdot m^{-1}$),or it represents one kilogram per second squaredper ampere ($Kg \cdot S^{-2} \cdot A^{-1}$) [24].

Secondly, the sensitivity is greatly reliant on magnetic field of majority of metals that compose the thermocouples, as mentioned in table 3, Cu, Ni, Cr, Al, Mn, and Si are generate different magnetic fields, this can influence on values and quality of sensitivity, but magnetic field is a significant factor in influencing super conductivity[25], i.e. the ability of metals to conduct electric current with little resistance practically, this can produce high quality of sensitivity, but there are limits such as: all conductors have no substantial thermoelectric sensitivity at (-273.15 ℃), and metals are significantly reduce their sensitivity under the temperature (0 ℃), but developed metals will increase the superconducting temperature to around (-153.15 ℃) [26].

Other investigations were conducted by some researchers [27], they performed a technique to calibrate the E-type from Chromel and Constantan with metal wire diameters 12.7 and 25 mmrespectively, the aims were about assessment on how the thermopiles sensitivity is affected by a magnetic field, they indicated that the sensitivity changes with range of temperature between (-268 ℃) and (-157.55 ℃) in a magnetic field up till 9 Tesla, but over (-265.77 ℃), the sensitivity wasinfluenced between 2% - 6%.

2.4. Chemical composition:

Chemical composition of metals has a strong role on limiting quality of sensitivity of thermocouples during temperatures measuring, but it will be different from a metal type to another, in most cases, the chemical composition of metals impacts on the sensitivity of thermocouples, for instance, the sensitivity of Constantan in E and T types is found to be 32.854 µV⁄℃ at 0 ℃, but the sensitivity of Constantan in J-type is found to be 32.468 µV⁄℃ at 0 ℃, this variation occurs because the Constantan (Cu-Ni alloy) of J-type typically not interchangeable with Constantan (Cu-Ni alloy) of Eand T types [28].

Also, the sensitivity of (Platinum-Rhodium) of R- type is 5.290 µV⁄℃ at 0℃, but the sensitivity of (Platinum-Rhodium) for S-type is 5.403 µV⁄℃ at 0℃, this variation comes due to the difference in Rhodium content in the positive thermo element of both types [29]. The sensitivity has nothing to do with the length and diameter of metal conductors, but related to composition of metals and temperature difference between two ends [30].

Based on the chemical composition of metals, it was found that E-type is the most sensitive, it holdshigher quality of sensitivity compared with others [31].

3. Results and discussion:

The results showed that 6 thermocouples can be divided into two groups, first E, J, K, and T, secondis S and R, as indicated in Figure 3, they have different levels of sensitivity at the same range of temperature measuring, the results indicated thatthe first group has more quality of sensitivity and the second has more declined values, but E, J, andK are the best, then T comes after them. Also, itwas showed that S and R can withstand continual and higher temperature measurement more than first group, these differences are due to purity and metal properties.

Also, the other results were as follows:

First: Metals type:

- ✓ It was showed that the metal types have huge influences on quality of sensitivity. Therefore, the metal type is selected which has low thermal conductivity, homogeneity, and compatibility with instrumentation system. Thiscan give maximum sensitivity, accurate, and true results for whole ranges of temperature measuring.
- ✓ E-type has the highest sensitivity of 80.930µV⁄℃, but type S has lowest sensitivity of 12.139µV⁄℃. This is because of typical metalcomposition of Chromel and Constantan “Cu– Ni alloy” which will be suitable in most operating ranges.

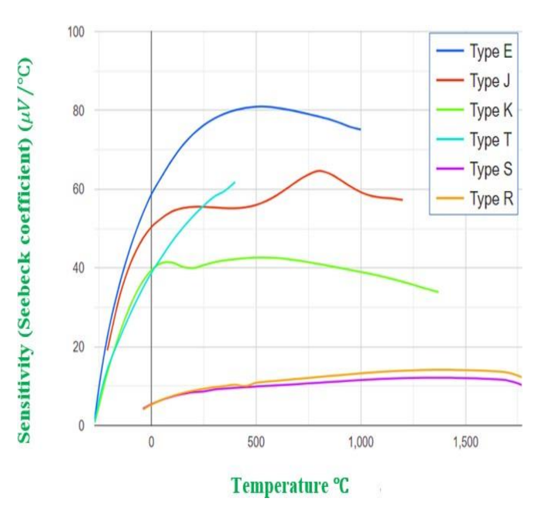

Figure 3: Sensitivity vs. temperature for sixdifferent thermocouple types.

- ✓ E, J, and K types will result in high sensitivity, because they hold base metals, but this advantage is not fixed in all cases or locations.

- ✓ R and S types will result in lower sensitivity, because they hold noble metals, but they have high reliable with measure higher temperature. This is because of platinum which can produce negative and positive sensitivities. Therefore, it is regarded as a suitable metal for quality of sensitivity. Therefore, it is mostly used with Rhodium.
- ✓ Cu-Ni alloy (used of E, J, and T types) is widely used in temperatures measuring because of its linearity, high stability, and high level of sensitivity.

Second: Magnetic field:

- ✓ Quality of sensitivity is highly dependent onmagnetic field. This is true for majority of metals used in thermocouples, because the magnetic field is a substantial factor in influencing superconductivity.
- ✓ Magnetic field with sensitivity level has interrelated and connected. It was indicated thatthe sensitivity value will be changed up till 9 Tesla in a range of temperature between (-268 ℃) and (-157.55 ℃), but the sensitivity will be influenced by (2% - 6%) over (-265.77 ℃).
- ✓ Cu, Fe, and their alloys have suitable magnetic response, therefore and this can lead to more quality of sensitivity in work.

Third: Chemical composition:

- ✓ Chemical composition of metals has a vital influence on quality of sensitivity of thermocouples, but this is depending on the purity level and specific specifications of each metal.
- ✓ Sensitivity of Constantan in E and T type is 32.854 µV⁄℃ at 0 ℃, but for J-type is 32.468 µV⁄℃ at 0 ℃. This variation occurs because Cu- Ni alloy is not similar and the range of temperature measuring is different, other reasonis because the both Constantan is not interchangeable.
- ✓ Sensitivity of Pt-Rh in R-type is 5.290 µV⁄℃ at 0℃, but for S-type is 5.403 µV⁄℃ at 0℃. This variation occurs because there is a difference in Rh contents in both types.

The research recommends that the manufacturers advised to select suitable metals in thermocouples manufacturing processes which can serve in different field applications. There are two service categories preferred to be followed regarding the spatial circumstances. First are fields that need more accuracy such as electric power generation plants, food processing factories, aircraft engines and missiles industry. Second, fields that need a wider range of temperatures such as household appliances, auto industry, and other industrialapplications.

4. Conclusion:

This study is about quality of sensitivity of six types of thermocouples which are formed with different types of metals and metallic alloys. Comparative investigation has been done about levels and quality of sensitivity of 6 types of E, J,K, T, R, and S thermocouples in which they are composed with Ni, Cr, Cu, Fe, Al, Mn, Si, Pt, and Rh metals and their alloys.

Quality of sensitivity is a crucial parameter becauseit has an effective role in accurate results of temperature measuring. Three factors of metals, magnetic fields, and chemical composition take a vital role in this case, also, the location kind has a role in limiting type of thermocouple.

The investigation presented several tables aboutsensitivity of 6 types of thermocouples, and 9metals that composed them. Also, it presentedsensitivity of E, K, and T at different temperaturesand because they hold higher quality of sensitivity. Stability, thermal conductivity, homogeneity, andcompatibility are main properties of metals thatinfluences on sensitivity level of thethermocouples.

It was proven that the base metals used in E, J, and K types will produce greater sensitivity than the noble metals used in R and S types, and E-type is most sensitive in comparison with others because of specific composition of metals used in Chromel and Constantan. It was confirmed that Cu, Fe, and their alloys have suitable magnetic response and they can be operated at lower temperature, but they have suitable quality of sensitivity during temperatures measuring process.

Also, it was designated that Pt used in R and S types has small sensitivity, but it was regarded suitable because it can produce negative and positive sensitivities if mixed with the other metals, then it gives reliable results, others, Cu-Ni alloy used in E, J, and T types is widely used because it has good stability and high quality of sensitivity. In addition, E-type is most sensitive at the whole ranges of temperatures measuring, then comes J- type and K-type, but R and S types have wider ranges until 1768℃ of temperatures measuring.

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تحقيق مقارن حول جودة حساسية ستة أنواع مختلفة من المزدوجات الحرارية

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الملخص :

ان حساسية جودة المزدوجات الحرارية تعد من العوامل المهمة في قياس درجة الحرارة وتؤثر على دقة نتائجها، وكذلك فان نوع المعدن يلعب دورا بارزا في تحديد مستوى ونوعية الحساسية للمزدوجات الحرارية.
تم فحص تسعة معادن ومقارنتها مع بعضها البعض ، حيث تساهم هذه المعادن في تركيب ستة المزدوجات الحرارية من نوع E و J و K و T و R و S ، وتمت دراسة ثلاثة عوامل مثل نوع المعدن والمجال المغناطيسي والتركيب الكيميائي لمعرفة تأثيراتها في تحديد جودة حساسية المزدوجات الحرارية لانها تؤثر على زيادة ونقصان الحساسية والدقة للمزدوجات الحرارية .
استخدمت منهجية البحث جمع البيانات وتحليلها على 6 مزدوجات حرارية ذات صلة. اظهرت النتائج بان النوع E لديه حساسية اعلى ، ثم J و K و T ، لكن النوعين R و S لديهما حساسية اقل في اغلب قياسات درجات الحرارة ، كما يمكن ان يعطي النحاس والنيكل والكروم جودة اعلى من الحساسية مقارنة بالبلاتين والروديوم.
ان نتائج هذا البحث يمكن ان تساعد الشركات المصنعة على زيادة الربط بين جودة الحساسية ونطاقات درجة الحرارة والدقة ، بالإضافة إلى اختيار المعدن المناسب للوسط الذي يتم قياسه.

الكلمات الدالة : *المعادن ، الجودة ، الحساسية ، المزدوج الحراري ، معامل سيبيك .*