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Calibration of electrical conductivity sensor

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ABSTRACT

Electrolytic conductivity (EC) sensors are widely used in diverse industries, including: pharmaceuticals, food, power, manufacturing, and environmental monitoring. This article presents an overview and analysis of EC sensors used in these industries from the lowest to the highest range of conductivities and in applications, where there are strong requirements for accurate and traceable conductivity measurements of water and electrolyte solutions. Conductivity measurement is ideal for this application as only one solution was flowing at a time. The curves in the graphs are particularly close from about 30–81 °C. A noticeable separation appears at 84 °C and especially 87 °C. The ascending and descending mean responses showed good agreement over most of the temperature range, while a noticeable deviation was observed at higher temperatures, indicating increased thermal hysteresis and variation in sensor response at elevated temperatures.

Keywords: Electrical Conductivity, Calibration, Sensor

Introduction

Electrical conductivity (EC) is an important parameter for evaluating the ionic content of aqueous solutions, water quality, soil salinity, and industrial process streams (Kumarathunga *et al.*, 2022) [1]. Conductivity sensors generally determine the conductance of a solution between electrodes and convert this measurement to specific electrical conductivity using the cell constant of the sensor. The cell constant depends primarily on the geometry and spacing of the electrodes. MC-20000 µS/cm provides standardized methods for determining electrical conductivity of a cleaning solution and resistivity of water over a broad range, including both laboratory and continuous in-line measurements (Kojima *et al.*, 2023) [2]. Calibration is essential because the measured conductance cannot be directly interpreted as conductivity without accounting for the geometry of the sensing cell. A commonly used calibration procedure employs potassium chloride (KCl) standard solutions, because their electrical conductivity is well characterized and reproducible.

Effect of temperature on electrical conductivity

Electrical conductivity can be used as an index of total dissolved solids and, in some cases, as a interpreter of concentrations for individual ions (Moore *et al.*, 2008) [3].

Temperature is one of the most important factors affecting conductivity measurements. In general, the conductivity of an electrolyte solution increases as temperature increases because ion mobility increases. Therefore, a conductivity sensor calibrated at one temperature may give a different reading when the same solution is measured at another temperature.

The influence of temperature on sensor measurements has also been demonstrated experimentally. Satoh *et al.* (2021) [4] investigated the effects of temperature and electrical conductivity on a low-cost soil sensor and developed calibration procedures to correct these influences. Their results demonstrated that incorporating temperature and EC corrections can improve sensor measurement accuracy, particularly under conditions of higher EC. Liu *et al.*, 2025) [5] developed a temperature-compensation approach for seawater conductivity measurements and reported reduced temperature-induced measurement errors after applying the compensation model (Sueker *et al.*, 2000) [6].

Materials and methods

Calibration of this sensor electrical conductivity sensor

The electrochemical sensor was purchased from the Spectrum Technology, 16-B Ashok Nagar, Ambala Cantt, Ambala, Haryana. The electrochemical sensor i.e. Electrical Conductivity sensor was assembled in the CIP return line in which the conductivity of recovering material was continuously monitored. If the conductivity is matched with the inline flow the recovery valve was open manually. Conductivity measurement is ideal for this application as only one solution was flowing at a time.

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Table. Specification of electrical conductivity sensor

Name	Electrical conductivity transmitter
Range	MC- 20000 $\mu\text{S}/\text{cm}$
Data output	4-20Ma
Make	Spectrum technology

Cleaning of sensor

1. Prepare 10% of HCl solution.
2. Dip the probe for ten minutes in the prepared HCl solution.
3. Remove the probe after ten minutes and put it into distilled water for two min.
4. Remove the probe and allow it for drying.

Procedure of calibration

1. Make a Solution of KCL
2. The solution temperature was controlled or recorded
3. The sensor output was allowed to stabilize before recording the measurement.
4. Put the sensor in a solution of KCL of having a temperature of 30 °C and note down the electrical conductivity reading, note this in three replicates
5. With an interval of three degree centigrade from 30 °C to 87 °C, note all the reading in three replicates sets.
6. Measurements were repeated to assess repeatability.
7. Repeat the same procedure for 1 Minutes and for 1.5 Minutes also and note down the readings.

Result and discussion

The dataset has an especially useful experimental feature: ascending and descending temperature measurements. It is measured the sensor response while temperature increased and then measured it again

while temperature decreased. This allows to evaluate not only calibration but also hysteresis, repeatability and thermal response.

Table 1. Conductivity reading in Ascending order

Temperature in °C	Time intervals and Conductivity reading in μS		
	30 Sec	1 Minute	1.5 Minute
30	651	649	647
33	654	653	656
36	659	658	658
39	661	659	662
42	669	669	665
45	676	678	680
48	686	686	685
51	692	695	694
54	708	711	715
57	726	720	720
60	736	738	736
63	754	749	750
66	768	771	768
69	801	800	799
72	806	816	821
75	858	857	862
78	865	863	865
81	879	886	886
84	927	920	936
87	1190	1157	1144
90			

Table 2. Conductivity reading in Descending order

Temperature in °C	Time intervals and Conductivity reading in μS		
	30 Sec	1 Minute	1.5 Minute
90	1057	1103	1138
87	929	938	969
84	888	883	879
81	872	864	868
78	853	858	854
75	813	821	827
72	804	792	817
69	762	760	782
66	761	758	753
63	744	734	738
60	725	726	725
57	718	719	713
54	703	712	719
51	688	690	683
48	682	675	675
45	662	668	658
42	660	663	655
39	658	654	653
36	649	648	647
33	643	645	646
30			

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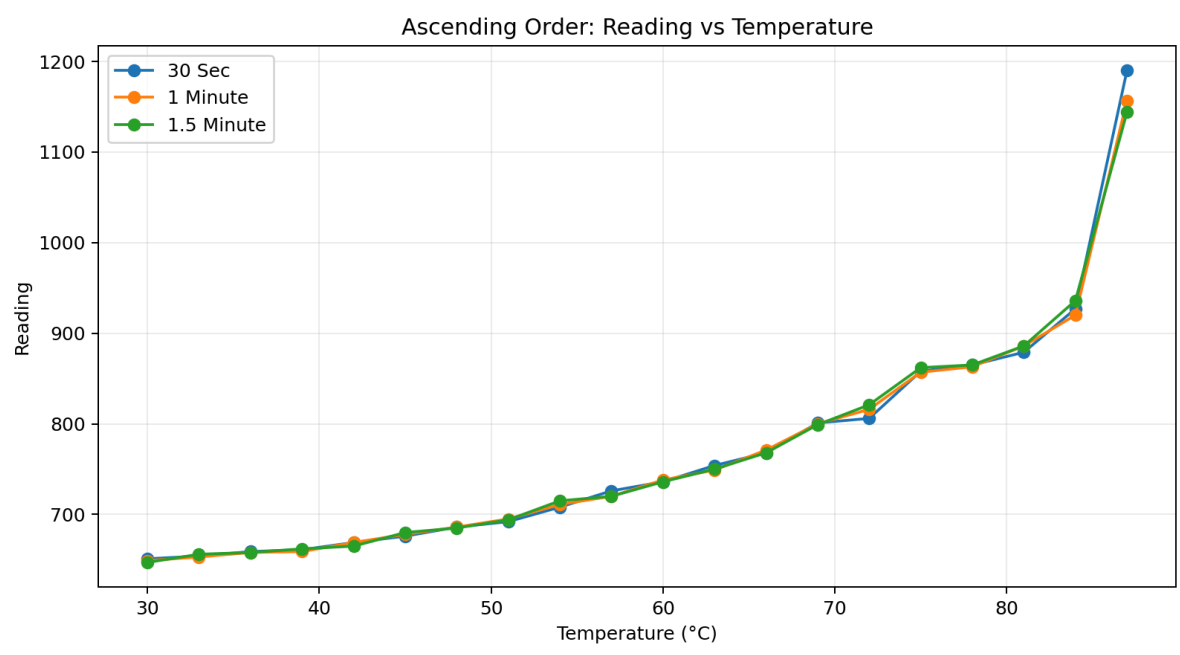


Figure 1. Temperature (°C) and the sensor reading at three different measurement times: 30 seconds, 1 minute, and 1.5 minutes in Ascending order

- **X-axis:** Temperature in °C
- **Y-axis:** Sensor reading
- **Blue line:** Reading recorded after 30 seconds
- **Orange line:** Reading recorded after 1 minute
- **Green line:** Reading recorded after 1.5 minutes
- Temperature increases from approximately 30 °C to 87 °C.

The term “Ascending Order” means that the temperature values are arranged from lower to higher temperature.

The three curves follow almost the same trend over most of the temperature range. At approximately 30–50 °C, the reading increases gradually, from around 650 to 690. The three measurements are very close to each other, indicating that the sensor response is relatively consistent at these temperatures. From approximately 50–70 °C, the reading continues to increase steadily, reaching about 800 near 69–70 °C. Again, the three curves overlap closely. Between approximately 70–82 °C, the reading increases further, reaching approximately 880–890. There are only small differences between the 30-second, 1-minute, and 1.5-minute readings. At the highest temperatures, particularly around 84–87 °C, the reading increases much more rapidly. At approximately 87 °C, the readings reach roughly:

- **30 s:** ~1190
- **1 min:** ~1160
- **1.5 min:** ~1145

Thus, the largest separation between the three measurement times occurs at the highest temperature.

Interpretation of the three-time curves

The close overlap of the curves from about 30 °C to 82 °C indicates that the sensor reaches a reasonably similar reading regardless of whether the measurement is taken after 30 seconds, 1 minute, or 1.5 minutes.

This suggests that, within this temperature range, **measurement time has relatively little influence on the recorded reading.**

However, at higher temperatures, the curves begin to separate. The 30-second reading becomes higher than the 1-minute and 1.5-minute readings. This could indicate that the sensor response is affected by **thermal stabilization, response time, or temperature-dependent sensor behaviour.**

Figure. Conductivity Reading Vs Temperature in Ascending order illustrates the variation in sensor reading with temperature under three different measurement intervals (30 s, 1 min, and 1.5 min). The sensor reading exhibited an increasing trend with increasing temperature throughout the investigated range. Between approximately 30 °C and 70 °C, the readings obtained at the three measurement intervals showed close agreement, indicating good consistency of the sensor response with respect to measurement time. Above approximately 70 °C, a gradual increase in the difference between the measurement intervals was observed. The most pronounced increase in sensor reading occurred at temperatures above approximately 80 °C. At the maximum investigated temperature, the 30-second measurement produced a higher reading than the 1-minute and 1.5-minute measurements.

Overall, the results indicate that the sensor response is temperature dependent and nonlinear over the investigated range, with comparatively greater variation at higher temperatures. These observations should be considered when developing the calibration relationship for the sensor.”

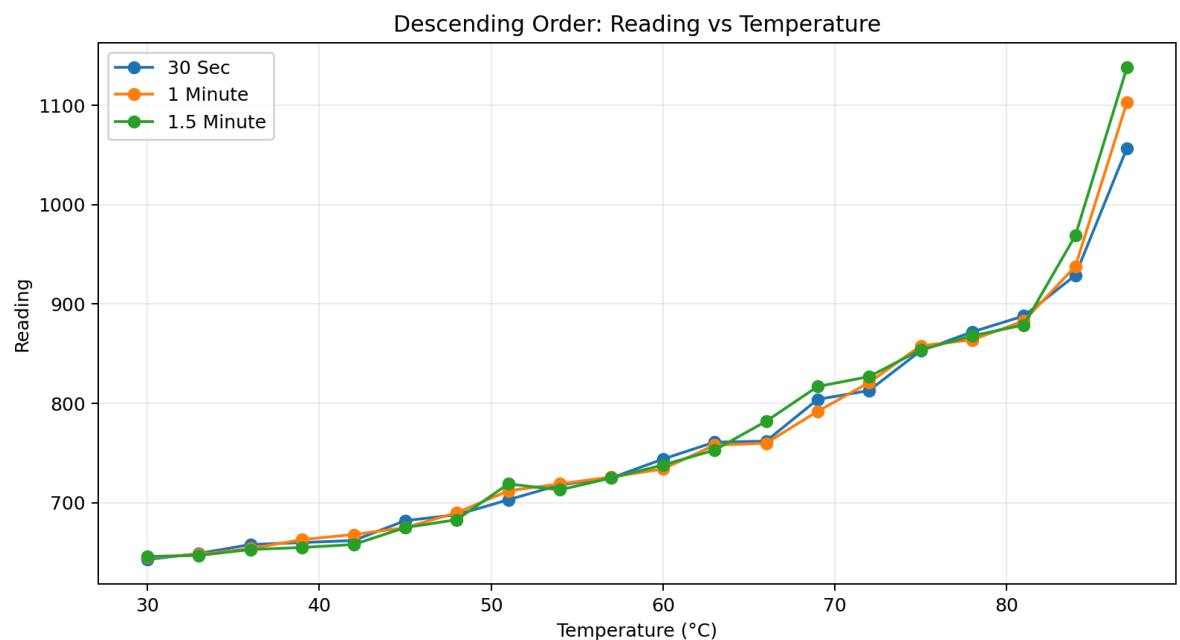


Figure 2. Sensor reading and temperature for measurements recorded at 30 seconds, 1 minute, and 1.5 minutes under the descending-order

Results and interpretation of the descending-order graph

The graph represents the relationship between sensor reading and temperature for measurements recorded at 30 seconds, 1 minute, and 1.5 minutes under the descending-order experimental condition.

X-axis: Temperature (°C)

Y-axis: Sensor reading

Blue: 30 seconds

Orange: 1 minute

Green: 1.5 minutes

Observed results

The sensor reading shows an overall increasing trend with temperature. At approximately 30 °C, all three measurement intervals give very similar readings of about 645–650. As the temperature increases, the readings gradually increase.

Between approximately 30 °C and 55 °C, the three curves remain relatively close to one another, indicating good agreement among the different measurement intervals. The readings increase from approximately 650 to 720.

From approximately 55 °C to 70 °C, a somewhat larger difference between the three measurement times becomes visible. The 1.5-minute reading generally becomes higher than the 30-second and 1-minute readings, particularly around 65–70 °C. Above approximately 70 °C, the sensor reading increases more rapidly. At around 80–82 °C, the readings are approximately 870–890 and remain relatively close. However, at the highest temperatures, the difference between the measurement intervals becomes more pronounced. At approximately 87 °C, the readings are approximately:

30 seconds: ~1060

1 minute: ~1100

1.5 minutes: ~1140

Thus, at the highest temperature, the 1.5-minute measurement gives the highest reading, while the 30-second measurement gives the lowest.

The increasing separation of the curves at higher temperatures suggests that measurement time has a greater influence on the sensor reading at elevated temperatures. The longer measurement time produces a higher reading in the upper-temperature region. This may indicate that the sensor requires some time to reach a stable response, particularly at higher temperatures. However, repeated measurements would be required to confirm whether this difference is statistically significant.

Figure Sensor reading and temperature for measurements recorded at 30 seconds, 1 minute, and 1.5 minutes under the descending-order presents the sensor readings obtained at different measurement intervals (30 s, 1 min, and 1.5 min) under the descending-order temperature condition. The sensor exhibited an increasing response with an increase in temperature. At lower temperatures, particularly between 30 °C and 55 °C, the readings obtained at the three measurement intervals were closely aligned, indicating good consistency of the sensor response. Between 55 °C and 70 °C, a gradual variation among the measurement intervals was observed, with the 1.5-minute readings tending to be slightly higher. Above 70 °C, the sensor response increased more rapidly, and the difference between the measurement intervals became more pronounced. At approximately 87 °C, the readings for 30 s, 1 min, and 1.5 min were approximately 1060, 1100, and 1140, respectively. The higher readings observed at longer measurement intervals at elevated temperatures suggest that response stabilization may influence the measured value. Overall, the descending-order measurements demonstrate a positive and nonlinear relationship between temperature and sensor reading, with greater variation among measurement intervals at higher temperatures.”

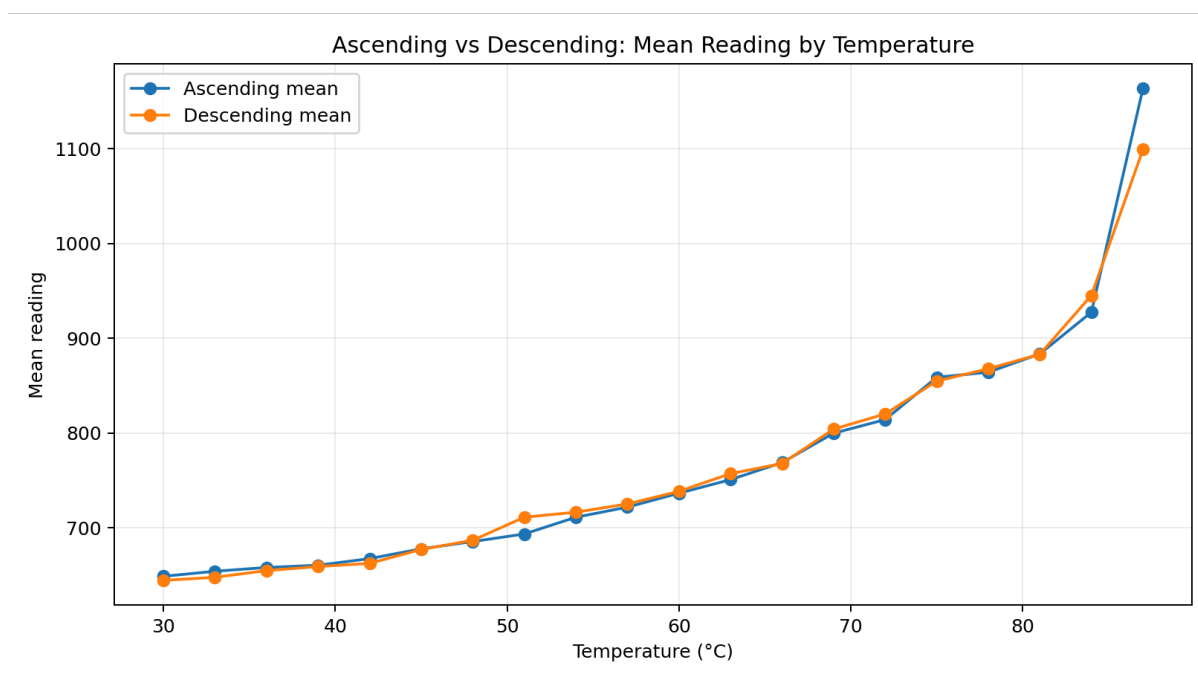


Figure 3. Conductivity Reading of Ascending order

Vs Descending order

The graph shows that the mean sensor readings for ascending and descending temperature conditions follow a very similar increasing trend.

- From 30 °C to about 80 °C, the ascending and descending mean readings are closely matched, indicating good agreement and repeatability.
- Above 80 °C, the difference between the two conditions becomes more noticeable.

- At approximately 87 °C, the ascending mean is about 1160, while the descending mean is about 1100, showing a higher reading during the ascending condition.
- Overall, the sensor response is temperature-dependent and non-linear, with a greater difference between ascending and descending measurements at higher temperatures.
- The difference between the two curves at the same temperature indicates the presence of thermal hysteresis in the sensor response.

Table 3. Overall comparison between the results:

Result	Ascending	Descending	Difference
Mean of all readings	767.50	766.35	-1.15
Minimum reading	647	643	-4
Maximum reading	1190	1138	-52

Main observation: The overall averages are very close (767.50 vs 766.35), indicating that the two directions give broadly similar mea-

surements. The largest difference occurs at the high-temperature end, particularly around 87 °C.

Table 4. Selected temperature comparison

Temperature	Asc. Mean	Desc. Mean	Desc - Asc
30 °C	649.0	644.7	-4.3
42 °C	667.7	662.7	-5.0
54 °C	711.3	716.7	+5.3
60 °C	736.7	738.7	+2.0
69 °C	800.0	804.3	+4.3
75 °C	859.0	855.0	-4.0
81 °C	883.7	883.3	-0.3
84 °C	927.7	944.7	+17.0
87 °C	1163.7	1099.3	-64.3

Conclusion

The graphs show that both datasets follow a similar increasing trend with temperature. The curves are particularly close from about 30–81 °C. A noticeable separation appears at 84 °C and especially 87 °C.

The ascending and descending mean responses showed good agreement over most of the temperature range, while a noticeable deviation was observed at higher temperatures, indicating increased thermal hysteresis and variation in sensor response at elevated temperatures.

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