

H₂S sensor calibration kit

For H₂S and SULF sensors

Manual



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1 Warranty and liability

1.1 Notice to Purchaser

This product is for research use only. Not for use in human diagnostic or therapeutic procedures.

1.2 Warning

Microsensors have very pointed tips and must be handled with care to avoid personal injury and only by trained personnel. Unisense A/S recommends users to attend instruction courses to ensure proper use of the products.

1.3 Warranty and Liability

The H₂S Calibration Kit is guaranteed to give the concentration indicated on the package label until expiry as indicated on the package label. The warranty does not include replacement necessitated by accident, neglect, misuse, unauthorized repair, or modification of the product. In no event will Unisense A/S be liable for any direct, indirect, consequential or incidental damages, including lost profits, or for any claim by any third party, arising out of the use, the results of use, or the inability to use this product.

2 Support, ordering, and contact information

If you wish to order additional products or if you encounter any problems and need scientific or technical assistance, please do not hesitate to contact our sales and support team. We will respond to your inquiry within one working day.

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Further documentation and support are available at our website: www.unisense.com.

3 Content of the calibration kit

| Item | Number |
|---|--------|
| Exetainer with ZnS suspension - H ₂ S stock solution | 10 |
| Exetainer with HCl (pH = 2.1) and glass beads - Mixing vial | 10 |
| Calibration cap with O-ring and 3 cm Viton tubing | 1 |
| 10 ml syringe | 1 |
| 1 ml syringe | 2 |
| 80 x 2.1 mm needle (green) | 1 |
| 30 x 0.6 mm needle (blue) | 1 |
| 50 x 1.2 mm needle (red) | 1 |



Figure 1: Calibration kit contents: A: Calibration kit box with Exetainers, B: 80 x 2.1 mm needle (green), C: 1 ml syringes, D: 10 ml syringe, E 50 x 1.2 mm needle (red), F: 30 x 0.6 mm needle (blue), G: Calibration Cap with tubing, H: O-ring.

4 Principle of calibration

Unisense Hydrogen Sulfide sensors (H₂S and SUF) respond linearly to H₂S concentrations within their linear range (see specifications for your sensor at <https://www.unisense.com/H2S>). Therefore, a two-point calibration is sufficient. One calibration point is the signal for zero H₂S, which can be water equilibrated with atmospheric air, and the other calibration point is the signal for one known H₂S concentration.

In this calibration kit, the sulfide is shipped in the form of zinc sulfide precipitate (ZnS) which is insoluble in water (Solubility product = ca. 2×10^{-25}). During the calibration procedure, ZnS is injected into a dilute HCl (pH = 2.1). This causes the ZnS to dissolve and H₂S is formed quantitatively.

H₂S will react slowly with O₂ if this is present. To minimize this, the ZnS suspension and the dilute HCl are anoxic when dispensed into the Exetainers. However, during storage and handling a small amount of O₂ will enter the solution. Therefore, the calibration must be performed relatively rapid, as described below, to keep this reaction at a negligible level.

5 Correction for salinity

During calibration, a relationship between sensor signal and concentrations is established. However, the sensor responds to the partial pressure of H₂S which at a given concentration varies with salinity. Therefore, a correction for salinity must be applied.

Henry's law describes how partial pressure depends on the concentration and solubility of a gas:

$$\text{Partial pressure} = \frac{\text{Concentration}}{\text{Solubility}} \quad (\text{Equation 1})$$

The calibration solution, prepared as described in section 6.1 below, will have the H₂S concentration stated on the package label. The solubility of H₂S will decrease with increasing salinity. Therefore, at a given concentration, the partial pressure will increase with increasing salinity. As the sensor responds to partial pressure, the sensor signal will increase as well when salinity increases at a constant H₂S concentration. The conversion of sensor signal to concentration must, therefore, take the relationship between salinity and solubility into account.

The salinity in the calibration solution (0.36‰) corresponds to freshwater. If measuring at other salinities, a correction must be made. This correction is done by assuming a H₂S concentration different from that given on the package label. This *Virtual concentration* is the one that, at the measuring salinity, gives the same partial pressure of H₂S as that in the calibration solution. If the measuring salinity is higher than that in the calibration solution, the *Virtual concentration* will be lower than that given on the package label. The reason is that when salinity is higher than in the calibration solution, a lower H₂S concentration is needed to give the same partial pressure as that in the calibration solution (see Henry's law above).

The *Virtual concentration* is calculated as (see Appendix 1):

$$Conc. (Virtual) = Conc. (Kit) \times \frac{Sol.(Virtual)}{Sol.(Kit)} \quad (\text{Equation 2})$$

⇕

$$Conc. (Virtual) = Conc. (Kit) \times Corr. factor \quad (\text{Equation 3})$$

where *Conc. (Virtual)* is the *Virtual concentration*, *Conc. (kit)* is the H₂S concentration given on the calibration box label, *Sol. (Virtual)* is the solubility of H₂S at the measurement salinity and temperature, *Sol. (Kit)* is the solubility of H₂S at the salinity in the calibration solution and the measurement temperature, and *Corr. factor* is the correction factor. Note that calibration and measurements must be carried out at the same temperature.

The *Virtual concentration*, calculated from Equation 3, is the concentration that must be entered as the *Known value* (μmol/L) in the SensorTrace software.

Example:

Measure at 30‰ and 20°C.

Calibrate at 20°C.

Concentration of H₂S in the calibration solution (*Conc. (Kit)*) = 104.3 μM

Correction factor (*Corr. factor*, Table 1) = 0.871

Virtual H₂S concentration (*Conc. (Virtual)*) = 104.7 μM × 0.871 = 91.2 μM

In this example a concentration of 91.2 μM will give the same sensor signal as the concentration of 104.3 μM in the calibration solution due to the difference in solubility of H₂S at the two salinities. Therefore, 91.2 μM is the value to be entered as the *Known value* in the SensorTrace software.

6 Calibration procedure

For calibrating the H₂S sensor, a low and a high calibration point are needed. Note that MicroRespiration sensors and sensors with flow cells will not fit the calibration cap and must be calibrated as described in section 6.4 and 6.5 This calibration kit is not for calibrating High Range H₂S sensors that work in the mM range.

6.1 Preparation of the H₂S calibration solution

1. Mount the 50 x 1.2 mm needle (red) on one 1 ml syringe, mount the 30 x 0.6 mm needle (blue) on the other 1 ml syringe, and mount the 80 x 2.1 mm needle (green) on the 10 ml syringe.
2. Adjust the temperature of the Exetainers with ZnS and HCl to the wanted calibration temperature (see note A, section 2).
3. Shake the Exetainer with the ZnS precipitate vigorously for 30 seconds (see note B, section 2).
4. Open the Exetainer with the ZnS precipitate.
5. Aspirate ca. 0.3 ml with the 1 ml syringe with the red needle, turn the needle upwards, tap it gently to get the bubbles to the top and eject these.
6. Empty the syringe and aspirate 1 ml ZnS suspension and eject this back into the Exetainer with the needle immersed. Repeat this three times before filling the syringe.
7. Adjust the volume in the syringe to exactly 1.0 ml.
8. Insert the blue needle, mounted on the second 1 ml syringe, through the septum of the Exetainer with HCl. Leave the tip of the needle right below the septum.
9. Insert the red needle, mounted on the syringe with ZnS, fully into the HCl Exetainer and inject the ZnS. The excess liquid is pushed into the empty syringe (See note C, section 2).
10. Remove first the ZnS syringe, then the syringe with the excess liquid.
11. Shake the Exetainer vigorously for 10 seconds.
12. Leave the Exetainer for 15 minutes for the formation of H₂S from ZnS to complete.



Figure 2: Sulfide sensor with the calibration cap mounted. Calibration solution is injected with the 10 ml syringe.

6.2 Preparation of the hydrogen sulfide sensor

IMPORTANT:

- The pre-polarization period of the H₂S sensor must have been completed before doing the calibration. See the H₂S sensor manual for details: <https://www.unisense.com/manuals/>
- The temperature of the low and high calibration solutions must be the same.
- Perform the calibration at the same temperature as the measurements if possible. The UniAmp series of amplifiers has a built-in temperature compensation within $\pm 3^{\circ}\text{C}$ of the calibration temperature.
- If doing the low calibration point with the calibration cap, make sure to do this before the high calibration point to avoid carry over from the H₂S standard.

6.3 Calibrating most hydrogen sulfide sensors

(All sensors except those in Flow Cells and for the Microrespiration System - see 6.4 and 6.5)

6.3.1 Obtaining the low calibration point

6.3.1.1 Using the Unisense Calibration Chamber

1. Place the sensor with the protection tube in sulfide free water (see the H₂S microsensor manual (<https://www.unisense.com/manuals/>))
2. Allow the sensor to respond and stabilize and record the calibration value in SensorTrace (see the SensorTrace manual for details: <https://www.unisense.com/manuals/>)

6.3.1.2 Using the Calibration Cap

1. Mount the calibration cap on the protection tube with the H₂S sensor (Figure 2). Make sure that the O-ring is in place at the bottom of the calibration cap creating a seal between this and the protection tube.
2. Fill the 10 ml syringe with sulfide free water.
3. Inject this water into the calibration cap until the sensor tip is immersed at least 2-3 cm.
4. Allow the sensor to respond and stabilize. Then record the calibration value in SensorTrace (see the SensorTrace manual for details: <https://www.unisense.com/manuals/>)

6.3.2 Obtaining the high calibration point

1. Mount the calibration cap, if not already mounted, as described above in 6.3.1.2.
2. Open the Exetainer with the H₂S calibration solution prepared as above in 6.1.
3. Aspirate ca. 10 ml of the H₂S calibration solution with the syringe and needle.
4. Keep the syringe vertical and avoid mixing of the calibration solution with the air bubble inside.
5. Remove the needle and attach the 10 ml syringe to the calibration cap tubing.
6. Inject the calibration solution slowly until the sensor tip is immersed at least 2-3 cm.
7. Allow the sensor to respond and stabilize. Then record the calibration value in SensorTrace (see the SensorTrace manual for details: <https://www.unisense.com/manuals/>) (See note D, section 7). If the response is much slower than expected, the ZnS may not have been converted fully into H₂S (See note E, section 7)
8. Remove the H₂S calibration solution with the syringe.
9. Rinse the calibration cap and protection tube carefully, removing all the H₂S calibration solution using the 10 ml syringe.

6.4 Calibrating hydrogen sulfide sensors for the Microrespiration system

Sensors of the Microrespiration type (SULF-MR or H₂S-MR) cannot be calibrated using the calibration cap. Instead, it is recommended to follow the procedure outlined below. Pay attention to the general information in section 6.1 and 6.2, the Notes and recommendations in section 7, and follow the procedure below



Figure 3: H₂S sensor in the Microrespiration guide.

6.4.1 Obtaining the high calibration point

1. Prepare the H₂S calibration solution as described in section 6.1.
2. Aspirate 5 ml of the H₂S calibration solution with the syringe and needle. Do this slowly to avoid bubble formation.
3. Dispense the H₂S calibration solution into a MicroRespiration chamber. Place the needle at the bottom of the chamber, filling from below, to avoid bubbles and splashing.
4. Mount the lid in the MicroRespiration chamber making sure that no air bubbles are trapped.
5. Place the MicroRespiration chamber in the stirrer rack.
6. Place the H₂S sensor in the stirrer rack with its plastic tip in the opening of the lid.
7. Insert the sensor into the chamber.
8. Allow the sensor to respond and stabilize and record the calibration value in SensorTrace (see the SensorTrace manual for details: <https://www.unisense.com/manuals/>).
9. Retract the sensor tip and remove the sensor from the stirrer rack.

6.4.2 Obtaining the low calibration point

6.4.2.1 Using the Unisense Cal300 Calibration Chamber

1. Place the sensor in the Cal300 Calibration Chamber containing H₂S free water (see the H₂S microsensor manual (<https://www.unisense.com/manuals/>)).
 - The H₂S sensor must be mounted in the blue Microrespiration guide and the tip must be retracted.
 - Temperature of the water must be the same as where the measurements are done.
2. Allow the sensor to respond and stabilize and record the calibration value in SensorTrace (see the SensorTrace manual for details: <https://www.unisense.com/manuals/>)

6.4.2.2 Using a Microrespiration Chamber

1. Prepare a volume of H₂S free water at the same temperature as the H₂S calibration solution used in 6.4.1.
2. Transfer this water to a MicroRespiration chamber and mount the lid.
3. Place the MicroRespiration chamber in the stirrer rack
4. Place the H₂S sensor in the stirrer rack with its plastic tip in the opening of the lid.
5. Insert the sensor into the chamber.
6. Allow the sensor to respond and stabilize and record the calibration value in SensorTrace (see the SensorTrace manual for details: <https://www.unisense.com/manuals/>) (See note D,

section 7). If the response is much slower than expected, the ZnS may not have been converted fully into H₂S (See note E, section 7)

7. Retract the sensor tip and remove the sensor from the stirrer rack.

6.5 Calibrating hydrogen sulfide sensors in flow cells

Sensors with flow cells cannot be calibrated using the Calibration Cap. Instead, it is recommended to follow the procedure outlined below. Pay attention to the general information in section 6.1 and 6.2, the general calibration procedure in section 6.3, the Notes and recommendations in section 7, and follow the procedure below.

6.5.1 Create a calibration setup

In order to calibrate a sensor in a flow cell, the sensor tip must be exposed to the calibration liquid prepared in the Exetainer (described in section 6.1). The optimal way to do this depends on the actual setup, however, it is recommended to make a setup that allows calibration of the sensor without removing it from the flow cell and from the setup. Generally, this could be a Luer connector connected to the flow cell, directly or via tubing, that allows injection of the calibration liquid into the flow cell. A three-way valve on either side of the flow cell will allow easy injection of the calibration liquid with the sensor and flow cell in place.

Connection of the syringe with calibration liquid to the flow cells:

- PEEK flow cells: The syringe may be attached directly to the flow cell via a Luer adaptor that is mounted directly in the flow cell (Figure 4, left)
- Glass and Swagelok stainless steel flow cells: The syringe may be attached via rubber tubing. The syringe may be connected directly to the rubber tubing or via a barbed Luer adaptor (Figure 4, right)



Figure 4: Left: Luer adaptor for direct mounting in the flow cell (e.g., IDEX P-624). Right: Barbed Luer adaptor for tube connection

6.6 Notes and recommendations

- A. Perform the calibration at the same temperature as the measurements if possible. The UniAmp series of amplifiers has a built in temperature compensation within $\pm 3^{\circ}\text{C}$ of the calibration temperature.
- B. It is important to shake the ZnS suspension very well and obtain a homogenous distribution of the precipitate. If not, the aliquot of suspension transferred to the HCl Exetainer will not contain the correct amount of ZnS and the final H₂S concentration will be wrong.
- C. Injection of the H₂S containing water is done with the needle inserted fully while the blue needle on the empty syringe is inserted just below the septum. Thereby the injected H₂S containing water will not be lost.
- D. The calibration point should be saved within ca. 30-60 seconds after injecting the H₂S calibration solution. The period between injection and saving the calibration point should be long enough to obtain almost full response which depends on the sensor response time.

Furthermore, it should not be longer than needed because the H₂S calibration solution will be contaminated with O₂ during handling, and consumption of H₂S due to reaction with O₂ will occur. This reaction is slow but can be seen as a slow decrease in signal over a few minutes.

- E. If the sensor signal keeps rising for several minutes, the formation of H₂S from ZnS may not have been completed. Leave the sensor in the H₂S until the signal is stable. For the next calibration, extend the time for the ZnS to be converted to H₂S (Section 6.1).

7 Calibrating at other concentrations

It is possible to obtain a lower concentration than that obtained using the standard procedure in section. This may be done either injecting less than 1.0 ml or by diluting the calibration solution obtained using the standard procedure in section.

Dilution of the solution made in section 6.1.

1. Prepare two Mixing Exetainers.
2. Transfer 1.0 ml the ZnS suspension into the first Mixing Exetainer as described above in section 6.1.
3. After shaking the Exetainer vigorously to obtain a homogenous distribution of H₂S, open the Exetainer and aspirate a volume with a syringe.
4. Inject a known volume into the second Exetainer with the blue needle on a syringe inserted just below the septum to collect the excess liquid (this volume of this syringe must be sufficient to accept all the excess liquid).
5. Shake the Exetainer vigorously.

Now the sensor may be calibrated, as described above for the different types of sensors, using the calibration solution in the second Exetainer.

The concentration of H₂S in the second Exetainer may be calculated as:

$$\text{Final conc. } (\mu\text{M}) = \text{Inj. vol. (ml)} / \text{Exetainer vol. (ml)} \times \text{Certified conc. } (\mu\text{M})$$

where *Final conc. (μM)* is the concentration obtained in the second Exetainer, *Inj. vol (ml)* is the volume injected transferred from the first to the second the Exetainer, *Exetainer vol. (μM)* is the volume of the second Exetainer and *Certified conc. (μM)* is the H₂S concentration obtained when following the standard procedure in section. The *Certified conc.* and the *Exetainer volume* are shown on the label on the calibration kit box.

Please note that when injecting less than the full volume of a syringe, the accuracy of the injection will become lower. Therefore, always use a syringe with a full volume that is close the amount to be injected. E.g., if 3 ml is injected with a 10 ml syringe the accuracy is low.

8 Specifications

- Volume of ZnS suspension in Exetainer¹: 12.5 ml
- Volume of HCl (pH = 2.1) in Exetainer¹: 12.5 ml
- Lifetime of the calibration kit: See label on the calibration box
- Concentration of H₂S in calibration solution²: See label on the calibration box

¹The zinc sulfide suspension and the HCl solution are made anoxic with Ar bubbling before these liquids are dispensed into the Exetainers.

²The actual concentration of H₂S in the final calibration solution is determined from measurements with a H₂S sensor calibrated with a certified calibration gas. The number of this certificate is specified on the calibration kit box. The H₂S concentration in the final calibration solution, following the procedure in section 6.1, is specified in the label on the calibration kit box.

9 Appendix 1: Calculation of the correction factor for salinity

The relationship between partial pressure, concentration and solubility for a gas is given by Henry's law:

$$\text{Part. press.} = \text{Conc.}/\text{Sol.}$$

where Part. press. is partial pressure of H₂S, Conc. is the molar concentrations of H₂S, Sol. is the molar solubility of H₂S at the given temperature and salinity.

In the calibration solution:

$$\text{Part. press (Kit)} = \frac{\text{Conc. (Kit)}}{\text{Sol. (Kit)}}$$

During measurement at a different salinity:

$$\text{Part. press (Meas)} = \frac{\text{Conc. (Meas)}}{\text{Sol. (Meas)}}$$

The aim is to calculate which concentration at the measuring salinity that will give the same partial pressure as in the calibration solution. The partial pressure at the measurement salinity and that at the calibration salinity are thus set to be equal:

$$\text{Part. press (Meas)} = \text{Part. press (Kit)}$$

⇕

$$\frac{\text{Conc. (Meas)}}{\text{Sol. (Meas)}} = \frac{\text{Conc. (Kit)}}{\text{Sol. (Kit)}}$$

⇕

$$\text{Conc. (Meas)} = \frac{\text{Conc. (Kit)} \times \text{Sol. (Meas)}}{\text{Sol. (Kit)}}$$

⇕

$$\text{Conc. (Meas)} = \text{Conc. (Kit)} \times \frac{\text{Sol. (Meas)}}{\text{Sol. (Kit)}}$$

⇕

$$\text{Conc. (Meas)} = \text{Conc. (Kit)} \times \text{Corr. factor}$$

where:

$$\text{Corr. factor} = \frac{\text{Sol. (Meas)}}{\text{Sol. (Kit)}}$$

Example

Concentration calculated based on the calibration = 100 μM

Conditions at measuring: Temperature = 20°C, Salinity = 32‰ => Correction factor = 0.863 (Table 1)

Virtual concentration at 20°C, 32‰ = 100 μM x 0.863 = 86.3 μM

10 Table 1. Correction factors for calculating virtual concentration

| Temp (°C) | Salinity (‰) | | | | | | | | | | | | | | | | | | | | |
|-----------|--------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 | 30 | 32 | 34 | 36 | 38 | 40 |
| -1 | 1.001 | 0.993 | 0.985 | 0.978 | 0.970 | 0.962 | 0.954 | 0.946 | 0.939 | 0.931 | 0.924 | 0.916 | 0.909 | 0.902 | 0.895 | 0.887 | 0.880 | 0.873 | 0.866 | 0.859 | 0.852 |
| 0 | 1.001 | 0.993 | 0.985 | 0.977 | 0.969 | 0.962 | 0.954 | 0.946 | 0.938 | 0.931 | 0.923 | 0.916 | 0.908 | 0.901 | 0.894 | 0.887 | 0.879 | 0.872 | 0.865 | 0.858 | 0.851 |
| 1 | 1.001 | 0.993 | 0.985 | 0.977 | 0.969 | 0.961 | 0.953 | 0.946 | 0.938 | 0.930 | 0.923 | 0.915 | 0.908 | 0.900 | 0.893 | 0.886 | 0.879 | 0.871 | 0.864 | 0.857 | 0.850 |
| 2 | 1.001 | 0.993 | 0.985 | 0.977 | 0.969 | 0.961 | 0.953 | 0.945 | 0.938 | 0.930 | 0.922 | 0.915 | 0.907 | 0.900 | 0.892 | 0.885 | 0.878 | 0.871 | 0.863 | 0.856 | 0.849 |
| 3 | 1.001 | 0.993 | 0.985 | 0.977 | 0.969 | 0.961 | 0.953 | 0.945 | 0.937 | 0.929 | 0.922 | 0.914 | 0.907 | 0.899 | 0.892 | 0.884 | 0.877 | 0.870 | 0.862 | 0.855 | 0.848 |
| 4 | 1.002 | 0.993 | 0.985 | 0.977 | 0.969 | 0.961 | 0.953 | 0.945 | 0.937 | 0.929 | 0.921 | 0.914 | 0.906 | 0.898 | 0.891 | 0.883 | 0.876 | 0.869 | 0.862 | 0.854 | 0.847 |
| 5 | 1.002 | 0.993 | 0.985 | 0.977 | 0.968 | 0.960 | 0.952 | 0.944 | 0.936 | 0.928 | 0.921 | 0.913 | 0.905 | 0.898 | 0.890 | 0.883 | 0.875 | 0.868 | 0.861 | 0.853 | 0.846 |
| 6 | 1.002 | 0.993 | 0.985 | 0.976 | 0.968 | 0.960 | 0.952 | 0.944 | 0.936 | 0.928 | 0.920 | 0.912 | 0.905 | 0.897 | 0.889 | 0.882 | 0.874 | 0.867 | 0.860 | 0.853 | 0.845 |
| 7 | 1.002 | 0.993 | 0.985 | 0.976 | 0.968 | 0.960 | 0.952 | 0.943 | 0.935 | 0.927 | 0.920 | 0.912 | 0.904 | 0.896 | 0.889 | 0.881 | 0.874 | 0.866 | 0.859 | 0.852 | 0.844 |
| 8 | 1.002 | 0.993 | 0.984 | 0.976 | 0.968 | 0.959 | 0.951 | 0.943 | 0.935 | 0.927 | 0.919 | 0.911 | 0.903 | 0.896 | 0.888 | 0.880 | 0.873 | 0.865 | 0.858 | 0.851 | 0.843 |
| 9 | 1.002 | 0.993 | 0.984 | 0.976 | 0.967 | 0.959 | 0.951 | 0.943 | 0.935 | 0.926 | 0.918 | 0.911 | 0.903 | 0.895 | 0.887 | 0.880 | 0.872 | 0.864 | 0.857 | 0.850 | 0.842 |
| 10 | 1.002 | 0.993 | 0.984 | 0.976 | 0.967 | 0.959 | 0.951 | 0.942 | 0.934 | 0.926 | 0.918 | 0.910 | 0.902 | 0.894 | 0.886 | 0.879 | 0.871 | 0.864 | 0.856 | 0.849 | 0.841 |
| 11 | 1.002 | 0.993 | 0.984 | 0.976 | 0.967 | 0.959 | 0.950 | 0.942 | 0.934 | 0.925 | 0.917 | 0.909 | 0.901 | 0.894 | 0.886 | 0.878 | 0.870 | 0.863 | 0.855 | 0.848 | 0.840 |
| 12 | 1.002 | 0.993 | 0.984 | 0.975 | 0.967 | 0.958 | 0.950 | 0.941 | 0.933 | 0.925 | 0.917 | 0.909 | 0.901 | 0.893 | 0.885 | 0.877 | 0.869 | 0.862 | 0.854 | 0.847 | 0.839 |
| 13 | 1.002 | 0.993 | 0.984 | 0.975 | 0.967 | 0.958 | 0.950 | 0.941 | 0.933 | 0.924 | 0.916 | 0.908 | 0.900 | 0.892 | 0.884 | 0.876 | 0.869 | 0.861 | 0.853 | 0.846 | 0.838 |
| 14 | 1.002 | 0.993 | 0.984 | 0.975 | 0.966 | 0.958 | 0.949 | 0.941 | 0.932 | 0.924 | 0.916 | 0.908 | 0.899 | 0.891 | 0.883 | 0.876 | 0.868 | 0.860 | 0.852 | 0.845 | 0.837 |
| 15 | 1.002 | 0.993 | 0.984 | 0.975 | 0.966 | 0.957 | 0.949 | 0.940 | 0.932 | 0.923 | 0.915 | 0.907 | 0.899 | 0.891 | 0.883 | 0.875 | 0.867 | 0.859 | 0.851 | 0.844 | 0.836 |
| 16 | 1.002 | 0.993 | 0.984 | 0.975 | 0.966 | 0.957 | 0.948 | 0.940 | 0.931 | 0.923 | 0.915 | 0.906 | 0.898 | 0.890 | 0.882 | 0.874 | 0.866 | 0.858 | 0.850 | 0.843 | 0.835 |
| 17 | 1.002 | 0.993 | 0.983 | 0.975 | 0.966 | 0.957 | 0.948 | 0.940 | 0.931 | 0.922 | 0.914 | 0.906 | 0.897 | 0.889 | 0.881 | 0.873 | 0.865 | 0.857 | 0.850 | 0.842 | 0.834 |
| 18 | 1.002 | 0.992 | 0.983 | 0.974 | 0.965 | 0.957 | 0.948 | 0.939 | 0.930 | 0.922 | 0.914 | 0.905 | 0.897 | 0.889 | 0.880 | 0.872 | 0.864 | 0.856 | 0.849 | 0.841 | 0.833 |
| 19 | 1.002 | 0.992 | 0.983 | 0.974 | 0.965 | 0.956 | 0.947 | 0.939 | 0.930 | 0.921 | 0.913 | 0.905 | 0.896 | 0.888 | 0.880 | 0.872 | 0.864 | 0.856 | 0.848 | 0.840 | 0.832 |
| 20 | 1.002 | 0.992 | 0.983 | 0.974 | 0.965 | 0.956 | 0.947 | 0.938 | 0.930 | 0.921 | 0.912 | 0.904 | 0.896 | 0.887 | 0.879 | 0.871 | 0.863 | 0.855 | 0.847 | 0.839 | 0.831 |
| 21 | 1.002 | 0.992 | 0.983 | 0.974 | 0.965 | 0.956 | 0.947 | 0.938 | 0.929 | 0.920 | 0.912 | 0.903 | 0.895 | 0.886 | 0.878 | 0.870 | 0.862 | 0.854 | 0.846 | 0.838 | 0.830 |
| 22 | 1.002 | 0.992 | 0.983 | 0.974 | 0.964 | 0.955 | 0.946 | 0.937 | 0.929 | 0.920 | 0.911 | 0.903 | 0.894 | 0.886 | 0.877 | 0.869 | 0.861 | 0.853 | 0.845 | 0.837 | 0.829 |
| 23 | 1.002 | 0.992 | 0.983 | 0.973 | 0.964 | 0.955 | 0.946 | 0.937 | 0.928 | 0.919 | 0.911 | 0.902 | 0.893 | 0.885 | 0.877 | 0.868 | 0.860 | 0.852 | 0.844 | 0.836 | 0.828 |
| 24 | 1.002 | 0.992 | 0.983 | 0.973 | 0.964 | 0.955 | 0.946 | 0.937 | 0.928 | 0.919 | 0.910 | 0.901 | 0.893 | 0.884 | 0.876 | 0.867 | 0.859 | 0.851 | 0.843 | 0.835 | 0.827 |
| 25 | 1.002 | 0.992 | 0.983 | 0.973 | 0.964 | 0.955 | 0.945 | 0.936 | 0.927 | 0.918 | 0.910 | 0.901 | 0.892 | 0.884 | 0.875 | 0.867 | 0.858 | 0.850 | 0.842 | 0.834 | 0.826 |
| 26 | 1.002 | 0.992 | 0.982 | 0.973 | 0.964 | 0.954 | 0.945 | 0.936 | 0.927 | 0.918 | 0.909 | 0.900 | 0.891 | 0.883 | 0.874 | 0.866 | 0.857 | 0.849 | 0.841 | 0.833 | 0.825 |
| 27 | 1.002 | 0.992 | 0.982 | 0.973 | 0.963 | 0.954 | 0.945 | 0.935 | 0.926 | 0.917 | 0.908 | 0.900 | 0.891 | 0.882 | 0.874 | 0.865 | 0.857 | 0.848 | 0.840 | 0.832 | 0.824 |
| 28 | 1.002 | 0.992 | 0.982 | 0.973 | 0.963 | 0.954 | 0.944 | 0.935 | 0.926 | 0.917 | 0.908 | 0.899 | 0.890 | 0.881 | 0.873 | 0.864 | 0.856 | 0.847 | 0.839 | 0.831 | 0.823 |
| 29 | 1.002 | 0.992 | 0.982 | 0.972 | 0.963 | 0.953 | 0.944 | 0.935 | 0.925 | 0.916 | 0.907 | 0.898 | 0.889 | 0.881 | 0.872 | 0.863 | 0.855 | 0.846 | 0.838 | 0.830 | 0.822 |
| 30 | 1.002 | 0.992 | 0.982 | 0.972 | 0.963 | 0.953 | 0.944 | 0.934 | 0.925 | 0.916 | 0.907 | 0.898 | 0.889 | 0.880 | 0.871 | 0.863 | 0.854 | 0.845 | 0.837 | 0.829 | 0.821 |

Calculated from: Morse, J. W., F. J. Millero, J. C. Cornwell, and D. Rickard. 1987. The chemistry of the hydrogen sulfide and iron sulfide systems in natural waters. Earth-Science Rev. 24: 1–42. [https://doi.org/10.1016/0012-8252\(87\)90046-8](https://doi.org/10.1016/0012-8252(87)90046-8)