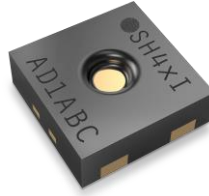
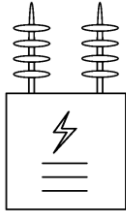


Water Activity Measurement a_W



Highlights

- Water activity (a_W) accuracy: up to ± 0.02
- a_W operating range: 0...1
- a_W long term drift 0.005
- Temperature accuracy: up to $\pm 0.2^\circ\text{C}$
- Operating range in oil: 15...60°C
- Supply voltage VDD: 2.3 V ... 5.5 V

Moisture contamination, and in extreme cases water droplet formation, in transformer, hydraulic, and lubricant oils can lead to a variety of problems and impact their performance. Monitoring water activity in oil can provide valuable insights into the degree of degradation and thus prevent the formation of free water. In critical processes that rely on flawless oil performance, online monitoring of water activity is crucial. The SHT4xI-Digital sensor allows for monitoring dissolved water in oil to avoid reaching the saturation point and formation of free water, and therefore enables damage prevention, lifespan extension of machinery, and optimal performance throughout the lifecycle.

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1 Water activity

Water activity a_w is a measure of absorbed water in a material. It is defined as the ratio of vapor pressure of water in a material p , and the saturation vapor pressure of pure water at the same temperature p_0 in the same material. Water activity is typically measured on a scale from 0 ... 1, with 0 representing a completely dry material and 1 indicating that the saturation point is reached and free water starts to form, see formula (Eq. 1) below. The saturation point in a material is the equivalent to the dew point in air when measuring %RH.

$$a_w = \frac{p}{p_0} \quad (\text{Eq. 1})$$

Note that water activity does not specify absolute moisture content. Absolute moisture content is the water present in a sample divided by the sample's weight, expressed as a percentage or in parts per million (ppm), while water activity reflects the amount of absorbed water. This difference is significant for evaluating stability. Measuring water activity allows for better understanding of material purity and ensures the quality and safety of systems before the material functionality is impaired.

1.1 Water activity in oil

In oil, water can appear in three different forms; absorbed, emulsified, and free. Absorbed water only interacts with the oil molecules on the atomic level, and is measured by water activity. Emulsified water is present as stabilized droplets, while free water is visible in the form of a separate phase. Each type of water presents different risks to product stability. Absorbed water can cause hydrolysis, oxidation, and other types of chemical degradation, while emulsified and free water can additionally promote microbial growth and strongly affect electrical properties of the overall system. By measuring water activity, it is possible to understand the risk of hydrolysis and oxidation in oil and mitigate the risk of phase separation.

Water can infiltrate an oil system through different channels, such as absorption from the atmosphere during handling and storage or the decomposition of oil additives and chemicals in the system. Such infiltration can lead to corrosion or other types of damage that can affect the oil's ability to lubricate or insulate. In addition water activity is an early proxy that precedes acid formation. Particularly synthetic oils exhibit a propensity to react with water and deteriorate, often forming acidic compounds. These act as strong oxidizing agents and oxidation leads to the formation of deposits, sludge, and varnish in the oil. This reduces the oil's performance and can potentially cause equipment failure. The formation of acidic compounds increases the corrosiveness of the oil, which can lead to damage to metal surfaces and other materials in the system.

The water saturation point of oil is influenced by several factors, including the type of oil (mineral or synthetic), the presence of water-soluble additives, and the temperature of the oil. Mineral oils often have a lower saturation point than synthetic oils. Mainly due to the addition of additives who allow to tune the oils saturation point. Hygroscopic additives can raise the saturation point of oil by dissolving and retaining water in the solution. Conversely, added surfactants can decrease the saturation point by improving emulsification and promoting phase separation.

Synthetic oils in particular tend to react with water and break down under acid evolution.

| Oil type | Typical saturation levels |
|------------------|--------------------------------------|
| Synthetic oil | Saturation levels up to 10'000 ppm |
| Mineral oil | Saturation level around 100 ppm |
| Transformer oils | Saturation level around 10-100 ppm |
| Hydraulic oils | Saturation level around 100-1000 ppm |
| Lubricating oils | Saturation level around 500-5000 ppm |

Table 1. Summary of how different parameters affect the water saturation point of an oil.

To show the effect of temperature on the saturation point of an oil refer to **Table 2** below. Generally, higher temperatures lead to increased water absorption capabilities of oil.

| Temperature | 0 °C | 20 °C | 80 °C |
|--------------------------|--------------|---------|---------|
| Saturation point | 150 ppm | 300 ppm | 500 ppm |
| Actual amount of water | 200 ppm | 200 ppm | 200 ppm |
| Water activity a_w | 1 | 0.63 | 0.4 |
| Formation of free water? | Yes, ~50 ppm | no | no |

Table 2. Example calculations showing the effect of temperature on water activity.

Lubricant Oils and Hydraulic Oils

As mentioned above, water activity plays a direct role in the aging rate of lubricating and hydraulic oils which has a direct effect on the durability of machine components relying on oil. Lubricant and hydraulic oils are designed to sustain high pressures while maintaining low compressibility and remaining chemically inert and unreactive. Water molecules in oil will be adsorbed mostly by hygroscopic additives or hydrophilic surfaces. These hygroscopic additives can lose their intended functionality through hydrolysis, resulting in the formation of acidic byproducts, while the hydrophilic surfaces can oxidize in the presence of water, which is further enhanced by the aforementioned acidic byproducts.

This increase of oxidizing agents in the system enhances the process of oxidation, particularly in the presence of catalytic metals such as copper, lead and tin. Consequently, rust is formed, compressibility is reduced, and increased friction leads to worn out parts.

Transformer Oil

Oil serves several important purposes in a transformer: It helps to dissipate heat from the winding by transferring it to the surrounding air or water, acts as an insulator to prevent electrical discharge and breakdown, and lubricates moving parts within the transformer to reduce wear and extend the lifespan of the transformer. However, once the water activity in the oil increases and free water starts to form, it can lead to conductive creeping partial discharges, and even total failure of the transformer.

There are several ways in which oil can enter a transformer, including through faulty gaskets, decomposition of the insulation paper or through ambient humidity during production and operation.

2 Sensirion Solution

To allow on-line monitoring of crucial oil systems as found in large hydraulic systems, gearboxes, transformers, and many others, Sensirion offers the SHT4xl-Digital humidity and temperature sensor. Tailored to industrial applications and with elevated supply-voltage and enhanced ESD protection, this model of our newest temperature and humidity sensor generation is perfectly suited for your built-in water activity monitoring. The sensors dielectric absorbs water molecules until the water vapor pressure is in equilibrium with the surrounding oil. This changes the capacitance of the sensor and from that the water activity of the oil can be concluded. This relative measurement principle allows generation of a more complete picture of the dissolved water content in an oil than absolute measurement techniques, making it perfect for on-line monitoring. Furthermore, it allows for direct comparison of different oils as a_w renders useful values regardless of physical parameters or chemical composition.

To get started and test the suitability of the capacitive sensing solution in your application, order the SHT4xl Evaluation kit (see section 4) and check first for the suitability of you oil. Should you need any assistance in defining a suitable measurement protocol please do not hesitate to reach out to us info@sensirion.com.

3 Sensor Specifications

The SHT4xl Digital is suitable for use in hydraulic, lubricating, and transformer oils. While it may be challenging to make general statements about compatibility due to the vast array of oils and additives available, we have successfully tested the sensor with a mineral transformer oil that has a low saturation point.

| Parameter | Conditions | Value | Units |
|------------------------------|------------|------------|---------|
| SHT4xl-Digital a_w acc. | typ. | ± 0.02 | a_w |
| Resolution ¹ | - | 0.0001 | a_w |
| Specified a_w range | - | 0 to 1 | a_w |
| Long-term drift ² | max. | 0.005 | a_w/y |

Table 3. Water activity measurement specifications from 15 °C to 60 °C specified for J10 transformer oil (DIN57370-VDE 0370).

¹Resolution of A/D converter

²Typical value for operation in normal a_w operating range in mineral oils. Value may be higher in environments with higher additive concentration.

4 Ordering Information

| Material Description | Material Number | Details | Quantity (pcs) |
|-------------------------|-----------------|--|----------------|
| SHT40I-AD1B-R2 | 3.000.553 | Base a_w & T accuracy. 0x44 I2C addr. | 2500 |
| SHT40I-AD1B-R3 | 3.000.664 | Base a_w & T accuracy. 0x44 I2C addr. | 10000 |
| SHT40I-AD1P-R2 | tbd | Base a_w & T accuracy. 0x44 I2C addr. With protective cover | 2500 |
| SEK-SHT40I-AD1B-Sensors | 3.000.639 | Base a_w & T accuracy. 0x44 I2C addr Sensirion Evaluation Kit | 1 |

Table 4. SHT4xl-Digital ordering options for a_w Measurements³.

5 Bibliography

[1] R. Garvey, "Estimating Water Content in Oils: Moisture in Solution, Emulsified Water, and Free Water," p. 15, 1996.

6 Revision History

| Date | Version | Pages | Changes |
|--------------|---------|-------|---------------------|
| January 2023 | 0 | All | Preliminary release |
| April 2023 | 1 | All | Initial release |

³ Please note that the filter membrane option is not suited for measurements in oil.

Important Notices

Warning, Personal Injury

Do not use this product as safety or emergency stop devices or in any other application where failure of the product could result in personal injury. Do not use this product for applications other than its intended and authorized use. Before installing, handling, using or servicing this product, please consult the data sheet and application notes. Failure to comply with these instructions could result in death or serious injury.

If the Buyer shall purchase or use SENSIRION products for any unintended or unauthorized application, Buyer shall defend, indemnify and hold harmless SENSIRION and its officers, employees, subsidiaries, affiliates and distributors against all claims, costs, damages and expenses, and reasonable attorney fees arising out of, directly or indirectly, any claim of personal injury or death associated with such unintended or unauthorized use, even if SENSIRION shall be allegedly negligent with respect to the design or the manufacture of the product.

ESD Precautions

The inherent design of this component causes it to be sensitive to electrostatic discharge (ESD). To prevent ESD-induced damage and/or degradation, take customary and statutory ESD precautions when handling this product. See application note "ESD, Latchup and EMC" for more information.

Warranty

SENSIRION warrants solely to the original purchaser of this product for a period of 12 months (one year) from the date of delivery that this product shall be of the quality, material and workmanship defined in SENSIRION's published specifications of the product. Within such period, if proven to be defective, SENSIRION shall repair and/or replace this product, in SENSIRION's discretion, free of charge to the Buyer, provided that:

- notice in writing describing the defects shall be given to SENSIRION within fourteen (14) days after their appearance;
- such defects shall be found, to SENSIRION's reasonable satisfaction, to have arisen from SENSIRION's faulty design, material, or workmanship;
- the defective product shall be returned to SENSIRION's factory at the Buyer's expense; and
- the warranty period for any repaired or replaced product shall be limited to the unexpired portion of the original period.

This warranty does not apply to any equipment which has not been installed and used within the specifications recommended by SENSIRION for the intended and proper use of the equipment. EXCEPT FOR THE WARRANTIES EXPRESSLY SET FORTH HEREIN, SENSIRION MAKES NO WARRANTIES, EITHER EXPRESS OR IMPLIED, WITH RESPECT TO THE PRODUCT. ANY AND ALL WARRANTIES, INCLUDING WITHOUT LIMITATION, WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE, ARE EXPRESSLY EXCLUDED AND DECLINED.

SENSIRION is only liable for defects of this product arising under the conditions of operation provided for in the data sheet and proper use of the goods. SENSIRION explicitly disclaims all warranties, express or implied, for any period during which the goods are operated or stored not in accordance with the technical specifications.

SENSIRION does not assume any liability arising out of any application or use of any product or circuit and specifically disclaims any and all liability, including without limitation consequential or incidental damages. All operating parameters, including without limitation recommended parameters, must be validated for each customer's applications by customer's technical experts. Recommended parameters can and do vary in different applications.

SENSIRION reserves the right, without further notice, (i) to change the product specifications and/or the information in this document and (ii) to improve reliability, functions and design of this product.

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