WP1.: Sensors

# D1.3: Sensor requirements and needs

Brief review of available sensor technology.

CHAIN

Smart Water Networks

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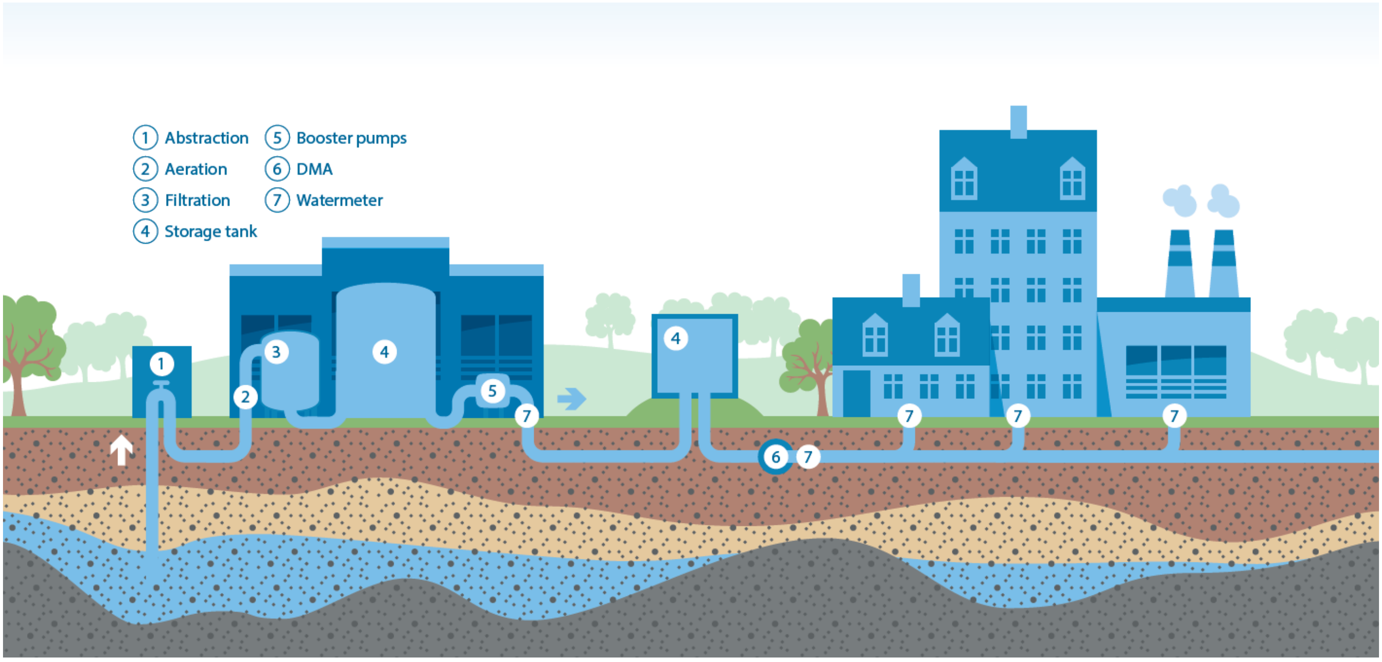
# 1 Introduction

As part of Innovation Fond project CHAIN Smart Water Networks, project number 7076-00043B, work package one represents an evaluation of sensors. The work package consists of two parts:

- description of sensors installed and planned for the two utilities.
- brief review of commercially available sensors

This report constitutes the second part and has been made in the project's working group 1 consisting of the 2 utilities together with Kamstrup. Sensors included cover the system from source to tab as illustrated below.




## 1.1 Methodology

The sensors included in the brief review are selected in order present an overview and to bring as much value as possible for water utilities of sensors suitable for online monitoring.

The selected sensors are listed in the first table below. This table is followed by fact sheets for each of the described sensors including information concerning:

- Short description of parameter
- Technical features and concept
- Customer need and benefits
- Advantage, potential and target market
- Risks and concerns

The fact sheets contain examples of commonly used sensors or the sensors the CHAIN group has decided to focus on. The selection of sensors and the choice of information presented here, is decided on by the group, in the aim to present an overview and to bring as much value as possible for water utilities. In order to establish a link to current legislation about water quality, reference to the European Drinking Water Directive and the Danish legislation has been included for many of the parameters. The sensors presented in this document are expected to be of relevance worldwide, with different source of the raw water (surface or ground water) as well as different treatment principles used at the specific site.

The report is from the CHAIN project, mainly with inputs from the two Utilities. Contact information for the content of the report: Astrid Søe, ars@kamstrup.com

# 2 Overview of available sensor technologies

This chapter focuses on chemical and physical parameters for water quality evaluation and distribution network optimization.

The selection of sensors listed in this chapter, is made by the CHAIN group. The sensors have been chosen to represent commonly used sensors and sensors of special interest with focus on the application for the water utilities. Information about the sensors is described with the aim to give an overview and to bring as much value as possible for water utilities.

The sensors are presented in the table below and described in more detail in the appendix. If new findings occur during the course of the CHAIN project, this document will be updated accordingly in case the findings are found of high importance for the project.

## 2.1 Parameters and considerations concerning sensors

Many different parameters can be measured at the water utilities and in the distribution net. In this study, the focus is on parameters, which are used for evaluation of water quality and distribution net optimization and which can be measured on an online basis in real time with no or little maintenance. Real time sensors are evaluated as relevant for the scope of this project with potential for incorporation into Machine Learning processes. Many physical and chemical parameters are suited for real time data collection; thus, these parameters are the main focus of this report.

In the description of the parameters, a distinction is drawn between 1) sensors, generally measurering with no or little maintenance and 2) analyzers (or cabinet analyzers), which are in principle wet chemistry methods made compact and suitable for field use. For analyzers you generally need several reagents, which have to be changed at regular intervals, you may also have a pump and membranes[4]. The measurement principle could be titration, sometimes detected photometric in a coloration process [4]. Example of typical analyzers used for water measurements are Nitrate, Ammonium and Dissolved Organic Carbon (DOC). Analyzers are less suited for measurements on an online basis in the distribution net, due to the relative high amount of maintenance. In contrast, typical sensors such as Conductivity, Oxygen and Turbidity are more suited as online distribution network parameters. The tendency is to a lesser degree to use analyzers and substitute these with other sensors. Optical sensors have become more stable and cheaper and smaller during the last years with the introduction of LED-diodes. However, optical sensors still have an issue with fouling, as the lamp as well as the receiver are prone to biofilm growth. Biofilm reduces the signal in the optical sensors, where cleaning maintenance is needed to restore the sensitivity of the sensor. Some developments are on the market to create an automated cleaning process, e.g. mechanical or with compressed air. Measurement methods even more suited for sensors in the distribution net, are sensors using a principle less influenced by fouling, such as electrodes with an electrical current or sensors using ultrasound.

The number of commercial sensors/analyzers has increased considerably. The sensors presented in this document are expected to be of relevance worldwide. In order to establish a link to current legislation about water quality, reference to the European Drinking Water Directive has been included for many of the parameters. The European Drinking Water Directive is incorporated (and in some cases further specified) to local Member State legislation [7]. However, it is here important to notice that in recent years many countries have experienced a change in paradigm towards recognition of online sensors to acknowledge the operational advantages to be gained from continuously measuring dynamic values in contrast to the values obtained according to the Directive on a very sparse frequency scale. The sensor market reflects a new big business in consolidation. The buyers now have many options, and, consequently, must try to find the sensors with the characteristics desired. The comparison of sensors may be challenging. For laboratory methods, validation procedures have been consolidated. Whereas for field sensors the performance of the sensor may be difficult to evaluate based on the producer data sheets. In order to accommodate this, a common standard (ISO15839, 2003) has been developed to increase the transparency within this area in a way that sensors can be validated in a comparable and defined way [1, 4].

When online data are collected, it is important to consider which data collection frequency is needed. For parameters changing fast, a fast data collection is needed, which is more challenging concerning data transmission (radio package size) and battery consumption. Lower data frequency is more feasible for sensor applications in the distribution network, with low or no maintenance. For the collected sensor data, the data evaluation is essential. The large amount of data must be processed to give value for the utilities. Thus, suited analytical tools are needed to avoid the data ending as unused “data-cemetery”. Data validation is essential as basis for the practical data usage. Data validation can be used on a short time and a long-time horizon. Short time changes can give the possibility to react on immediate changes in water quality. Long-time changes often indicate drift of the sensor signal (e.g. growth of biofilm on the sensor). The data validation does not differentiate between the sensor itself and the processes the sensor is measuring. For that reason, a complex data validation with more sensors (cross validation) is often recommended. The data validation methods are based on the confidence to the data ranging from reliable data, to measured values, which are unexpected/physically impossible. In the confidence calculations weights can be attached to the results. Data validation is essential in order to minimize false positive warnings about changes in water quality [3, 6] .

This report presents a selection of chemical and physical parameters evaluated as interesting as online sensors for water utilities for optimizing and monitoring operations and water quality. For sensors, such as pH, conductivity and turbidity, products from many producers are available. For these general sensor parameters, no specific producers (or no specific data sheets) have been mentioned in order to treat the producers in a fair way. Prices of sensors are not included as they may vary and a “cheap” sensor, which brings little information to the water utility may be more “expensive” as an “expensive” sensor bringing more value for the operation of the water network.

### 2.1.1 Key drivers and economic considerations

The key drivers for the water sector are increased efficiency of operations, compliance with legislation as well as risk-based ways to secure water quality for consumers and ensuring that the consumers have trust in the safety of their local water. The total cost of ownership (TCO) for water quality systems can be split down into a) cost of the sensor itself b) installation costs (building the installation, project costs, expenses to skilled personnel, connecting to communication and power supply) and c) maintenance (time for calibration, cleaning, spare parts and service at site). Installation costs can be reduced if sensors are designed to install in an easy way or the pipes already have suited fittings. Preferably the installation could be carried out at a time with pipe replacement or repair. Maintenance cost can be reduced if the sensor can perform a self-cleaning and calibration or if, due to sensor design, cleaning and calibration is not necessary. The cost is reduced if the sensor is made of materials that prevent fouling making the cleaning intervals longer or if the measurement principle is not influenced by fouling. Costs can further be reduced if the sensor works without any chemicals or moving parts and if power consumption can be at a minimum [5].

Some challengers for the water sector are to keep a low cost for sensors placed in remote locations. During the time of operation, the sensor should preferably maintain itself for the lifetime (e.g. some years) so no access to the unit shall be necessary. It is essential for an extensive sensor grid to have a suited system for communication. Water networks are mostly buried beneath the street or pavement. Access to the water installations are often valve and meter chambers, which may be covered with cast iron lids, making the radiocommunication difficult. Many different standards for communication are available, such as M-Bus, GSM, Sigfox, NB-IoT and Lora-Wan. For the choice of communication, the battery consumption is essential to consider as the various communication ways may consume more or less battery power, have the possibility to transmit larger or smaller packages of information and with various time frequencies. For the remote sensors, enough battery capacity is essential for the sensor lifetime and the sensor should be able to operate without the need for drain, as this is most often not available at all the potential sensor grid locations. Some designs of sensors allow installation directly into pipes, in other words submerged (InSitu), while others work in a flow through setup (by-pass) and need drain for installation. In contrast to sensors in the distribution net, the sensors at the water works normally can be plucked up to wired communication, mains power and drain. Furthermore, sensors in the distribution net will be placed in a difficult environment (presence of chlorine, hydrogen sulfide, electromagnetic noise etc.), which of course is wet, but also may be corrosive. IP 68 is necessary as well as inert materials, resistant to the environment and not influencing the water in a negative way (drinking water approved materials) [5].

Some economical scenarios for the use of sensors have been put forward over the years. One example is a scenario, where a French city of 100,000 inhabitants typically has 600 km of distribution network, an annual consumption of 6 million $m^3$ of water (60$m^3$/person). The water price (production and distribution) is 1€/$m^3$ giving a total price for consumed water of 6 million €. Assuming the city can only increase the price of the water by 1%, the money available will be 60,000 €/year, and with an estimated lifetime of the units of 5 years the TCO of the units will be 300,000 €. Installation costs can be estimated at 2,500 €/unit (digging a hole, integration of the unit on the network and clean up afterwards). If the price for the unit is set to 2,000 € and the annual operating cost (maintenance, energy, communication, etc.) to 15% of the price = 300 €, then the TCO will be 6,000 €/unit. With the available money the city can install 50 units (one every 12 km). On a European scale this will give approximately 580,000 units with a value of 3,500 million € [5].

### 2.1.2 Microbial parameters

Microbial activity is described for some of the sensors presented in this report, where physical or chemical parameters can give useful indications. In the absence of reliable real-time pathogen detection methodologies, continuous turbidity monitoring is often considered as the best available surrogate [3] .

Directly microbial parameters (microbial analyzers) are generally connected with a certain lag time, which makes the method less suitable for covering the distribution network. Furthermore, the microbial analyzers generally need drain, electricity mains, maintenance and frequent change of test solutions. Some prework is generally also needed to make a baseline value for the measurement site.

However, some microbial methods and analyzers are mentioned below to give an insight into this measurement area. For microbial parameters the analyzers are generally more company specific.

Traditional methods include E.coli/Coliforms (IDEXX) and Heterotrophic plate count at 22°C (ISO 6222) - are time consuming laboratory methods.

Some methods (microbial analytical equipment) have shorter lag time such as:

BACMON (from Grundfos) based on a specialized photo evaluation, measuring number of particles and number of bacteria  - the method was tested at e.g. Aarhus Vand.

Bactiquant (from Mycometer used e.g. at Aarhus Vand, Brønderslev and HOFOR) based on flourescence measurements from an enzyme-substrate reaction. Measures microbial presence and can be semiautomated.

ATP-methods are quick methods, where the cells energy processes are quantified, which gives a certain measure of microbiological activity. Can be semiautomated.

Colifast is a Norwegian product where the technology is based on a substrate reaction with an enzyme from coliform bacteria. The method has a lag time of 2 to 12 hours and is tested in several utilities.

Flow cytometry (for example from the company OnCyt AG) is detecting bacterial cells with down to 15 min lag time by cell staining. The method is used routinely at an array of Swiss water utilities.

PCR methods are be used to identify microorganisms from DNA or RNA analyses. These methods can be semiautomated (for example from the company GNAcode).

## 2.2 References


- ISO 15839:2003 - Water quality — On-line sensors/analysing equipment for water — Specifications and performance tests, ISO standard, 2003, Geneva
- Guideline about collection and use of water quality data for utilities (SVGW Regelwerk W1014, Empfehlung für die Datenfassung und -auswertung bei Wasserversorgungen), 2018, Zürich
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- In-situ nutrient sensors for real-time control of biological nutrient removal. Proceedings of the Water Environment Federation, WEFTEC 2003, 255-276(22)
- Sensor Grid for Water Distribution Networks & Wastewater Collection Systems. ACQUEAU The Eureka Cluster for Water, Water and Information/communication Technologies working group, Final report 2011
- Realtids procesmålinger og modellering af vandkvalitet i forsyningssystemer (data håndtering og modellering), VTUF projekt 7319, 2011
- European Drinking Water Directive COUNCIL DIRECTIVE 98/83/EC, of 3 November 1998, on the quality of water intended for human consumption, Official Journal of the European Communities, 1998

# 3 Table of available sensor technologies

Physical and chemical parameters suited for online and real time data collection

| Parameter | Unit | Measurement principle | Fact sheet # |
|---|---|---|---|
| **Pressure** | Bar, water column | A force per unit area | 3.1 |
| **Water level** | Meters (or cm) | Sonic, mechanical or manual reading | 3.2 |
| **Flow** | $m^3$/h, L/sec, L/min or others | Magnetic inductive or mechanical methods | 3.3 |
| **Temperature** | ˚C (or Fahrenheit) | Thermometer (thermocouples). | 3.4 |
| **Acoustic sensors for leakage detection** | Sound signal | Microphone or other sound catching device (e.g. vibration) | 3.5 |
| **pH** | pH-unit | Potentiometric (electrodes, electrolyte and membrane) | 3.6 |
| **Dissolved oxygen** | mg/L | Optical method (fluorescence) | 3.7 |
| **Turbidity** | FNU, FTU or NTU | Optical method (a measure of particles per volume) | 3.8 |
| **Ultrasonic particle measurement** | Unit (not yet defined) | Ultrasound method (a measure of particles per volume) | 3.9 |
| **Conductivity** | µS/cm | Electrical conductance | 3.10 |
| **UV254** | UV absorption at 254 nm | Optical method | 3.11 |
| **Coloration** | Light absorption by 436 nm | Optical method | 3.12 |
| **Absorbance spectra** | UV-visible absorption (200 nm to 700 nm) | Optical method | 3.13 |
| **Free chlorine/total chlorine/Chlorine dioxide** | mg/L | Amperometric (electrodes and electrolyte membrane covered – several sensor units) | 3.14 |
| **Oxidation Reduction Potential (ORP, Redox)** | mV | Electrochemical | 3.15 |
| **Ammonium** | mg/L | Ion selective electrode (or an analyzer) | 3.16 |
| **Nitrate/nitrite** | mg/L | Optical method, ion selective electrode (or an analyzer) | 3.17 |
| **Refractive Index** | Change in signal | Measurement of the refraction of light from water | 3.18 |

## 3.1 Pressure

**1. Short description of parameter**

**Pressure measurements are highly widespread to ensure sufficient pressure when the water is leaving the water treatment plant and in some cases at selected places in the distribution net. Together with hydraulic models this can be used to control the right pressure level in the entire distribution system. A pressure of 2 bar is often regarded as desirable at the site of the consumers.**

**2. Technical features and concept**

**Pressure is a force per unit area. There are many different units for pressure. In water distribution networks, commonly units are Bar, PSI and Pascal. Various principles are used (e.g. piezoelectric or strain gauge). The measurement does not need drain and can generally run on battery. Not much maintenance is needed and the sensor can generally run for years without inspection. The accuracy and repeatability is generally good. The data collection frequency depends on the brand and model, some models measure background pressure, while others have intervals with high frequency measurements allowing to pick short events of water hammers.**

**3. Customer need and benefits**

! **Pressure is used for many purposes in water distribution systems: Securing sufficient pressure for the customers; Avoiding high pressure (constant or in transients) that can damage pipes by bursts in the system; Monitoring low pressure, which could pose a risk to water intrusion (microbial pollution) and pipe collapse (including drop in pressure after a high pressure event).**

**The use of pressure sensors are highly widespread.**

**4. Advantage, potential and target markets**

! **Addition of more pressure measurements at selected locations in the distribution network will be of advantage for operations and lifetime of pipes as well as for securing water quality.**

**All utilities all over the world might have good use of pressure measurements in order to optimize their operations.**

**5. Risks and concerns**

**There is low risk and concern with pressure measurements. However, as much data is collected, data handling has to be considered. The data collection frequency and method as well as the pressure transducer response time should be considered for what is needed for the actual application.**

## 3.2 Water level

**1. Short description of parameter**

Water level sensors are used to measure the height of the water level in water tanks. The tanks could be the raw water tank before water treatment, the clean water tank at the utility or high level tanks (e.g. water towers) in the distribution network. For the last two examples the water level helps determining the pressure in the distribution network.

**2. Technical features and concept**

Water level is generally measured by sonic, mechanical or manual readings. By sonic measurements, a sensor, placed above the water, measures the distance from the sensor to the surface of the water. This measurement is calculated in to the height of water in the tank and thereby water pressure. In a mechanical reading, a mechanical part is moved by the water surface (e.g. a ball or a floating stick). This mechanical part may result in an activation of a switch that may open or close a valve. In a manual reading the height of the water is read on a scale. The level of maintenance is varying, where sonic systems often are very robust, mechanical systems can be stuck and manual reading is very labor consuming.

**3. Customer need and benefits**

Water level readings are vital for water utilities. Applications may include: activation of a switch that may open or close a valve or a pump to ensure the correct water level in a tank, pressure management, volume calculations of reservoirs or other operational tasks.

**4. Advantage, potential and target markets**

It is advantageous to have automated sonic, reliable water level sensors in the water tanks. It is also advantageous that the level sensors send the level reading automatically into the SCADA system to ensure correct operations and potentially warnings (for low or high water levels).

All utilities all over the world will generally need water level sensors/readings.

**5. Risks and concerns**

If the systems break down and no/wrong water level reading is obtained, this can have large negative consequence for the water distribution. Manual read measurement may take considerable time for the utilities.

## 3.3 Flow

**1. Short description of parameter**

**Flow is measured in order to determine rate of water production at the water utility. It may also be used for calculating water balance and water loss in the water distribution systems. Flow is measured at the water leaving the treatment plant. Flow is also often measured at the entrance point of a district and should fit the demand of the consumers in the district.**

**2. Technical features and concept**

**Flow is often measured by magnetic inductive or mechanical methods. Not much maintenance is needed and the meter can generally run for years without inspection. The accuracy and repeatability is generally good, but varies with design and technology.**

**3. Customer need and benefits**

**It is beneficial to measure flow at the utility at central points in the distribution net (at production site and DMA nodes, e.g. valve and meter chambers) and to measure consumption at consumers. The measurements are used for measurering water balance in the system, to calculate the demand for water production at the water utility and help to find areas with leakage. In most countries measurements of water loss are compulsory, thus the flow from the utility and measurements of water consumption is very widespread (often at each household).**

**4. Advantage, potential and target markets**

**There is a potential to expand the use of data from flow measurements and combine them with consumption measurements. In some countries more than half of the produced water is lost in the distribution network often due to leaks. A well measured water balance helps identify where problems have to be solved.**

**5. Risks and concerns**

**Drawbacks by mechanical methods is that there are moving parts which can be worn or stuck over time. Drawbacks by magnetic inductive methods is that they may in some cases be influenced by poor installation influencing the accuracy.**

## 3.4 Temperature

**1. Short description of parameter**

Temperature is often measured in several places in the distribution net and during water treatment. The water temperature reflects the movement of the water in the distribution network. The temperature is influenced by weather conditions and hydrology. The expectation to water temperature vary from country to country. In Denmark a desirable temperature at the site of the consumers is 12°C or below.

**2. Technical features and concept**

Temperature is measured with a thermometer (thermocouples). The measurement does not need drain and can generally run on battery. Not much maintenance is needed, and the component generally can run for years without inspection. The accuracy and repeatability are generally good.

**3. Customer need and benefits**

! Temperature is a quality parameter for the consumers as the drinking water should not be too warm in summer and should not freeze in winter. The temperature is also an indication of stagnating water in the distribution net. Indication of possible change in water quality (e.g. intrusion of surface water such as rivers or rain). Water temperature is influenced by installation depth of the piping; a shallow installation poses a risk of water heating in summer and freezing in winter. Temperature measurements of the water is often quite widespread.

**4. Advantage, potential and target markets**

There is a potential to use temperature measurements to a larger degree. Often temperature is measured at central locations and in some cases measured in the water meters at all consumers. With data analytics the temperature results can add valuable knowledge about water quality and be used to calibrate hydrological models.  When temperature measurements are combined with consumption data the value of the data increases.

All markets could make use of temperature measurements – especially areas where hot or cold weather may be a problem for the distribution.

**5. Risks and concerns**

There is low risk and concern with temperature measurements. However, as much data is collected, data handling has to be considered.

## 3.5 Acoustic sensors for leakage detection

**1. Short description of parameter**

**Acoustic sensors are often used to detect leaks in water pipes (noise logger systems). The utility might have microphone equipment themselves or they hire a consultant company to drive around and listen to the water pipes to identify leaks.**

**2. Technical features and concept**

**Microphone or other sound catching device (e.g. vibration) is used. The listening is often done in events to find a specific leak/broken water pipe. In some cases, sound catching instruments can be attached to pipes on a more permanents basis. However, traditional microphones drain a battery quickly. Thus, for a permanent installation, mains power or a non microphone technique is preferable. There is a medium level of maintenance of the equipment.**

**3. Customer need and benefits**

**Acoustic sensors are used to find/detect leaks in water pipes by the change in sound when water is floating out of a leaking pipe. They may also be used in the detection of systems with cavitation - bobbles in the water stream are problematic to the life time of pumps and pipes. It is relatively widespread to use acoustics to detect leaks.**

**4. Advantage, potential and target markets**

**Acoustic sensors are advantageous in order to reduce water loss. This saves the water resources and the costs of the utilities to cleaning and pumping of water. It can in some circumstances be advantageours to have noise loggers installed permanently to find leaks in an automated way in order to reduce costs from water loss and manual tasks.**

**All water utilities can benefit from reducing loss of water.**

**5. Risks and concerns**

**The concerns about noise logging is that the leak finding events sometimes can be difficult and labor intensive.**

## 3.6 pH

**1. Short description of parameter**

!

pH is measured to ensure that the water has a pleasant (neutral) pH for drinking water when it leaves the water utility. pH may vary according to the source of the raw water and may have to be adjusted. If softening has taken place in the water preparation, pH adjustment is necessary. The parameter is an unspecific indication of water quality, a measure of dissolved acids and bases

**2. Technical features and concept**

pH is a potentiometric method, which measures the hydrogen-ion activity, indicating the acidity or alkalinity. These is a high frequency of maintenance due to solution/electrolyte change and calibration. For exact measurements (process control) it is our experience that calibration every week is needed and for indicative measurements, calibration every month is needed. Real time data collection is possible. The method is run on battery or mains electricity input. The measurement may be possible without drain - depending on materials

**3. Customer need and benefits**

The customers make use of the data for control/documentation of water quality. The parameter is an indication for change in the origin of water and a parameter in water processing control. The method is relatively widespread, for some utilities the parameter has only little use, as for others the processes in the water treatment are highly dependent on the pH values.

**4. Advantage, potential and target markets**

The parameter is a compulsory quality parameter of drinking water and thus, necessary to measure. The parameter also gives valuable process evaluation.

pH of drinking water is measured in most countries. The water should not be aggressive. pH is part of the EU water quality parameters and has to be measured. In EU the limit is 6,5-9,5 pH-units. In Denmark the water is expected to be 7,0-8,5 pH-units.

**5. Risks and concerns**

The concerns about pH measurements is that the instrument has to be calibrated and maintained very frequently in order to deliver a correct result.

## 3.7 Dissolved oxygen

**1. Short description of parameter**

**Oxygen is measured in drinking water and oxygen is added to groundwater in order to enhance the taste. Furthermore, oxygen is added as part of the water treatment process.**

**2. Technical features and concept**

**Oxygen is generally measured optically (by fluorescence). It can be a real time measurement without need for drain. The sensor is measuring inorganic dissolved oxygen. Some maintenance is needed as the measurement principle is an optical sensor with risk of fouling. Traditionally dissolved oxygen was measured by an electrochemical sensor (with use of electrolytes in a clark cell).**

**3. Customer need and benefits**

**Oxygen can be used for process control. The parameter gives an indication of microbial activity (e.g. by stagnating water there is a decrease in oxygen). Indication for change in the origin of water (note that this parameter may change over time – the parameter is not always conservative). A certain oxygen content of the water is aimed for in order to give the water a good taste. Oxygen depleted water taste old or flat. A good taste is reached at minimum 5 mg/l. A very high oxygen content makes the water more aggressive toward components in the distribution system. The method is relatively widespread. For some utilities the parameter has only little use, as for others the processes in the water treatment are highly dependent on the oxygen values.**

**4. Advantage, potential and target markets**

**The parameter is useful in combination with other parameters for process control, water quality estimation (stagnating water with risk of microbial growth) and for calibration of hydrological models. If the water, for example, has an oxygen content of 10 mg/L as it leaves the utility and has a content of 0 mg/L by the consumer, this indicates that there might be organic material and microbial growth.**

**The parameter is important to monitor for several markets – depending on their source water, treatment principles and state of distribution system. The oxygen content should be monitored at intervals at the water intake locations (according to Danish legislation).**

**5. Risks and concerns**

**Some maintenance is needed. Some interpretation in combination with other parameters is also needed.**

## 3.8 Tubidity

**1. Short description of parameter**

**Turbidity in water is an important measure for water quality. In the distribution network the sensor may, for example, indicate intrusion of water from the surrounding soil or turbulence in the water stream due to leakage where pipe sediments are stirred up into the water stream. Effectiveness of cleaning steps can be monitored at the water treatment plant.**

**2. Technical features and concept**

**Turbidity is measured with light. FNU is referencing to the ISO 7027 (European) turbidity method. NTU is referencing to the USEPA Method 180.1. FNU is measured using near infrared light and NTU is using white light – both standards measure the light scattering at 90° angle. FTU is another unit, which does not specify how the instrument measures the sample. The methods are based on calibrations using the same formazin primary standards. If turbidity is measured with light directly straight through the water (low precision), a low maintenance frequency is needed (our experience about every 2$^{nd}$ year). If a measurement at a 90° angle is used, a higher precision is obtained (down to 3$^{rd}$ decimal with 4 times calibration per year).**

**3. Customer need and benefits**

**Turbidity is a useful measure for utilities in order to detect polluted in the network by intrusion of water from surrounding soil (where surrounding ground water pressure is higher than network pressure or the pressure in the piping is low due to leaks or mountains). Piping is prone to intrusion of turbid water if there is a pressure event followed by decreased pressure (where soil is sucked into the water stream). The parameter can also be used as a quality parameter in order to open a network after a maintenance flushing. The parameter can further be used to manage or optimize filter back flush cleaning times, to adjust cleaning processes when incoming water quality changes and as a parameter influencing chlorination disinfection efficiency.**

**4. Advantage, potential and target markets**

**The parameter brings useful information about water treatment and piping status to water utilities all over the world. Turbidity impact the efficiency of disinfection processes. A turbidity not higher than 0.2 NTU is desirable for optimal disinfection. If turbidity exceeds 1 NTU, disinfection with chlorine may not work properly (as microbes may be protected in the particles, where particles from some sources have higher potential human risk than others). Thus, monitoring of turbidity of water is beneficial for securing water quality/disinfection efficiency and for saving money by making processes more efficient.**

**Turbidity is an aesthetic parameter for the consumers. According to EU legislation turbidity should be monitored, should be acceptable to consumers and should preferably not exceed 1,0 NTU for treated surface water ex treatment plant. According to Danish legislation turbidity should not exceed 1 FTU at the site of the consumers. A useful limit to fulfill the latter is to use an indicative limit of 0,3 FTU ex treatment plant.**

**5. Risks and concerns**

**The results depend on particle size distribution and the optical properties of the particles. Calibration is done with a specific size distribution whereas the conditions in real life have different distribution patterns – often with more variation than in calibration solutions. The results in FNU and NTU are comparable but not identical. Some maintenance is needed due to fouling or high battery consumption (of battery powered instruments) if automated cleaning processes are carried out of the lamp or the light receiver. The presence of air bubbles in the water disturbs the measurement of turbidity using inline turbidity sensors.**

## 3.9 Ultrasonic particle measurement

**1. Short description of parameter**

**Particles suspended in water is an important measure for water quality. In the distribution network the sensor may indicate intrusion of water from the surrounding soil. Effectiveness of cleaning steps can be monitored at the water plant. The ultrasonic particle measurement method an alternative method for measuring particles or cloudiness compared to a traditional tubidity measurement. The method is different as the traditional light base method of turbidity and tend to have less fouling problems and energy consumption, thus, sensors can be operated on battery.**

**2. Technical features and concept**

**Particles are measured with ultrasound signal in the water stream. The sensor is running on battery, the signal can be transmitted with radio or wired. This technology is being developed as part of the Danish Innovation Fond project "TURBUS – Turbidity Ultrasonic Sensor for Water Quality". It is expected that the sensor will be highly robust and the aim is that the sensor can run many/several year without maintenance.**

**3. Customer need and benefits**

**The ultrasound particle measurement is useful for utilities in order to detect polluted in the network by intrusion of water from surrounding soil (where surrounding ground water pressure is higher than network pressure or the pressure in the piping is low due to leaks or mountains). Piping is prone to intrusion of turbid water if there is a pressure event followed by decreased pressure (where soil is sucked into the water stream). The parameter can also be used as a quality parameter in order to open a network after a maintenance flushing. The parameter can further be used to manage or optimize filter back flush cleaning times, to adjust cleaning processes when incoming water quality changes and as a parameter influencing chlorination disinfection efficiency.**

**4. Advantage, potential and target markets**

**The parameter brings useful information about water treatment and piping status to water utilities all over the world. The ultrasound particle measurement is expected to be better suited for field deployment compared to the optical products measuring particles or turbidity. The traditional optical methods tend to be more prone to fouling, the optical sensors are energy consuming (where the ultrasound can run on battery) and the optical sensors have expensive optics and a diode, where the ultrasound sensor is expected to be more simple. The ultrasound technology is highly sensitive in order to measure larger particles in the water – particles which are often expected to be related with intrusion or turbulence of water. The online sensor data can be combined with water consumption data and with analytical models. The combination of data can be of good use for the utilities. The ultrasound sensor data can go into an IoT network or alternatively with a stronger battery/mains power, go into a GSM network.**

**5. Risks and concerns**

**This technology is under development, thus, not a mature technology. More field tests are needed in order to prove its usability for utilities.**

## 3.10 Concuctivity

**1. Short description of parameter**

Conductivity is a measure of salts in the water. This can be used to indicate, water quality, intrusion of water and the origin of water when two different water sources are mixed.

**2. Technical features and concept**

Conductivity is a measure of electrical conductance in the water. The method has low to no maintenance and the method is relatively widespread.

**3. Customer need and benefits**

Conductivity can be used to monitor drinking water quality to give a warning if, for example, river or sea water intrudes into a clean water source. The parameter can reveal if ground water piping is leaking/worn out, which may allow water from higher soil layers to intrude into ground water during pumping. The parameter can give an indication of mixing water if the sources have different conductivity values. The parameter can be used for control during steps of water preparation. The parameter can also be used to test of lag time, mixing efficiency and water age in a system (e.g. a tank) where salt is used as indicator substance.

**4. Advantage, potential and target markets**

Conductivity is part of the EU drinking water directive and is compulsory to measure. The parameter is an indicator value with a limit of 2500 µS/cm at 20°C. According to Danish legislation conductivity should be between 300 and 2500 µS/cm at 20°C. It is a parameter, which is easy to measure because the method is not prone for fouling. The parameter is often used and has particular value where the source water has a risk of pollution/intrusion from salt sources – such as sea water intrusion into ground water at coastal areas or where surface water basins is in risk of pollution from run of from streets or mixing with river water.

The parameter is relevant for all markets – especially where there is risk of pollution/intrusion of salt water to the raw water source.

**5. Risks and concerns**

The results from the measurement have to be interpreted, as the measure only gives indications about water quality issues.

## 3.11 UV254

**1. Short description of parameter**

UV-254 is an optical method where the absorption at 254 nm is measured. The method is commonly used and has been used for relatively long time as an indication of dissolved organic carbon.

**2. Technical features and concept**

UV absorption at 254 nm is an optical method. This measures unspecific, organic dissolved substances. The method has some correlation to the traditional wet chemistry method for dissolved organic carbon (DOC). At 254 nm there is a good absorption of most organic carbon compounds. Aromatic carbon molecules (e.g. PAH's) absorb at this wavelength. However, other compounds absorbing at this wavelength (which are not organic carbon compounds) may disturb the detection. The UV absorption at 254 nm has historically often been used as 254 nm is the wavelength of a mercury lamp. The detection of organic compounds is enhanced if a wider spectrum of wavelength is used (e.g. 240-270 nm). The sensor has some maintenance due to fouling of the lamp or the receiver.

**3. Customer need and benefits**

The parameter is beneficial in order to control of raw water - indication for organic materials (Dissolved organic carbon) or test of water preparation steps that remove carbon in the water. The method is quite widely used.

**4. Advantage, potential and target markets**

This optical method has been used for many years and has good potential for further use. It is advantageous to use optical methods compared to the traditional wet chemistry methods (analyzers), because the optical methods require less maintenance than the traditional analyzers.

Most markets and utilities can use this sensor for quality and optimization work.

**5. Risks and concerns**

Some maintenance is needed due to fouling. A high battery consumption (of battery powered instruments) is needed if automated cleaning processes are carried out of the lamp or the light receiver.

## 3.12 Coloration

**1. Short description of parameter**

**Light absorption at 436 nm indicates a yellow coloration of water. This can be used for identifying the quality if the raw water – either peat/humus coloration of ground water or changes in the quality of surface water.**

**2. Technical features and concept**

**Light absorption by 436 nm is an optical method.**

**3. Customer need and benefits**

**The parameter is an indication of dissolved colored material such as humus. Also iron or manganese may influence the measurement. The need is mainly to evaluate raw water. It is an unspecific method indicating dissolved colored substances. The method is used in some areas, where there are issues with water coloration.**

**4. Advantage, potential and target markets**

**Mainly an advantage in countries where surface water is used as source water and where this parameter can be used to indicate changes in the incoming water quality, which may influence the water treatment process.**

**The method is used in some countries/areas where coloration is problematic – especially in areas where surface water is used as raw water source and the water is influenced by colored substances, for example, peat.**

**5. Risks and concerns**

**Some maintenance is needed due to fouling. A high battery consumption (of battery powered instruments) is needed if automated cleaning processes are carried out of the lamp or the light receiver.**

## 3.13 Absorbance spectra

**1. Short description of parameter**

**The total UV-visible light spectrum can give a good description of the compounds in the water. The method can be used to monitor many kinds of chemical changes in water quality on a fingerprint level.**

**2. Technical features and concept**

**UV-VIS spectrum is measured by an optical method (diode array light sensor). Traditionally these sensors have been quite expensive, bulky and energy consuming, but light measurements are becoming smaller and cheaper (due to LED technology). For the evaluation of the results can be used: 1) comparison (subtraction) spectra between two locations. 2) comparison to a reference spectrum. 3) the change in spectrum over time (e.g. to detect if there is a difference between the current spectrum and the spectrum 15 minutes earlier).**

**3. Customer need and benefits**

**The parameter can be useful for water quality evaluation. The measurement technique is not very widely used, but several sensors are emerging on the market.**

**4. Advantage, potential and target markets**

**It is an advantage for the optical methods that they become cheaper and smaller due to new developments. The method has potential for further use in water quality work.**

**Most markets and utilities can with benefit use this sensor.**

**5. Risks and concerns**

**Some maintenance is needed due to fouling. A high battery consumption (of battery powered instruments) is needed if automated cleaning processes are carried out of the lamp or the light receiver. By a whole spectrum a large amount of data is collected that must be interpreted, which may be challenging.**

## 3.14 Free chlorine/total chlorine/Chlorine dioxide

**1. Short description of parameter**

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**Chlorination of water is essential for disinfection and water quality in many countries and, thus, of great value to measure in the distribution network. Under-dosing pose a risk to the consumers because of lack of disinfection and thereby risk of potentially pathogenic bacteria. Over-dosing pose an adverse effect due to the negative effect on health by high chloride concentrations and disinfection by products (trihalomethane (THM, such as chloroform, a methane with 3 halogens) and haloacetic acids (HAAS)) - as well as high corrosion on pipes and equipment (the WHO guideline suggests a level of 0,2 mg/L to ensure sufficient disinfection, distribution net levels are generally 0,2 - 1,0 mg/L).**

**2. Technical features and concept**

**Chlorination level is generally measured using an amperometric principle (membrane covered) to measure free chlorine (Cl2 + HOCl + OCl-) and total chlorine (free chlorine + combined chlorine) and possibly chlorine dioxide. Several chemical compounds are used for disinfection, such as hypochloride (an ion in combination with e.g. Na), chlorine as gas form, chlorine dioxide and chloramines. Chlorine is traditionally measured with lab analyzer methods using either colorimetric or amperometric titration. In all cases a reduxion-oxidation process is carried out, where solvents are added resulting in a change in color or a change detected over a set of electrodes. The sensor using the amperometric principle works slightly different, but has a much narrower interval, where chorine can be measured accurately.**

**3. Customer need and benefits**

**Customer need for these measurements, are in areas, where chlorination is used for disinfection. The parameters can be used to check disinfection after water preparation at the utility. The parameter is valuable to check district chlorination, where the efficiency is difficult to calculate, as this depends on distance, flow speed, temperature, amount of organic material, turbidity, pH and other factors. In systems, where secondary dosing is carried out (district spike chlorination, chlorination in the distribution net after the initial disinfection source), the level of spike chlorination should preferably be determined based on measurements.**

**4. Advantage, potential and target markets**

**The chlorine sensors are highly useful in markets where chlorination is used for disinfection of drinking water.**

**5. Risks and concerns**

**For the sensors at the market, you generally need a high level of maintenance. The membrane of the amperometric sensor normally has to be changed at least once a year (or for the more precise lab methods, solvents have to be changed once a month). There are many disturbing factors, which have to be taken into account. It is a complex system where the operator needs to have a good knowledge of the system (pH, organic material, maganese etc) in order to evaluate the chlorination, especially focus is put on keeping a good disinfection without decomposition products (THM and HAAS) and to avoid infections with e.g. Giardia and Chryptosporidium. A good chemical knowledge is needed to run the titration systems. In order to make this parameter of real value for the distribution net you need a sensor without maintenance, a sensor with a solid phase technology - in order to get total cost of ownership and maintenance frequencies down to a relevant level.**

## 3.15 Oxidation Reduction Potential (ORP, Redox-potential)

**1. Short description of parameter**

**Redox-potential can be used to indicate microbial growth. The parameter can also be used to indicate level of chloride in water. Since Oxidation Reduction Potential (ORP) can be measured with electrodes, which are small, simple, cheap and probably last for years without maintenance, this parameter is expected to be of great value to evaluate water quality in distribution networks.**

**2. Technical features and concept**

**The measurement is electrochemical (generally a gel filled epoxy electrode). The measurement principle may be developed to a simple electrode with low maintenance and low cost (suitable for extensive distribution net application). The absolute value is of less interest, whereas changes in signals can give indication of critical changes in the composition of the water.**

**3. Customer need and benefits**

**The customers have benefits in monitoring of changes in Redox value in raw water or in distribution net - a decrease in redox-value can indicate bacterial growth (as also decrease in oxygen happens by bacterial growth). By bacterial growth, organic material is decomposed. Redox value can further be used to check water process steps (removal of iron, manganese or nitrate). The parameter is also used for control of disinfection with chlorine or chlorine dioxide.**

**4. Advantage, potential and target markets**

**Redox measurements are more applicable from a measurement point of view compared to chlorine sensors because redox can be based on a solid phase technology and, thus, is not expected to require maintenance. Redox is a valuable measure of microbial activity. If the measurements are carried out in a dense pattern in the distribution network with data communication and analytics together with consumption data (and possibly temperature data) this can be a strong tool for evaluating microbial risk in systems. Redox potential can, furthermore, be used to evaluate the source of the water for a ground water well field. The top of the water column is positive while the reduced ground water is negative. Thus, if shallow water (by mistake) is extracted, the redox value will be positive.**

**Redox potential is useful for many customers who want to monitor indication of microbial pollution, depletion in chlorination or optimize water treatment processes.**

**5. Risks and concerns**

**The parameter is highly unspecific, which creates a challenge for interpretation of the value, as there is no balance between reduced and oxidized compounds in the soil (the sources for oxidation in a profile down the soil are generally, $O_2$ in the top, then nitrite/nitrate and finally sulphate). The instruments experience a large drift, and, thus, the absolute values or comparison of sensors are not useful (poor repeatability from day to day and from sensor to sensor). Redox potential is influenced by pH, oxygen, which makes the data interpretation complicated.**

## 3.16 Ammonium

**1. Short description of parameter**

**Ammonium is important for evaluation of raw water quality, indication of level of treatment needed and evaluation of effectiveness of treatment procedure.**

**2. Technical features and concept**

**By high content of ammonium a potentiometric sensor (with an ion selective electrode) can be used. By low ammonium content an analyzer is used (with chemical reactions).**

**3. Customer need and benefits**

**The parameter is a compulsory quality parameter of drinking water and, thus, necessary to measure. According to EU legislation, there is a limit of 0,50 mg/L for drinking water (with the exception that the parameter may be exceeded when chlorination with chloramine is used). The parameter may indicate pollution with fertilizer or wastewater. The parameter is, furthermore, a control of steps of nitrification - parameter for raw water or water preparation.**

**4. Advantage, potential and target markets**

**Ammonium is an important parameter for raw water and water preparation. The parameter us useful for most markets – especially when the water source is influenced by agriculture.**

**5. Risks and concerns**

**By low ammonium concentrations (below 1 mg/L), only analyzers can be used and the manual work (maintenance, change of solutions etc.) is quite high.**

## 3.17 Nitrate/Nitrate

**1. Short description of parameter**

**Evaluation of raw water quality – indication of level of treatment needed. Evaluation of effectiveness of treatment procedure.**

**2. Technical features and concept**

**Optical procedure, where concentrations are calculated by using different short wavelengths (close to 200 nm).**

**3. Customer need and benefits**

**The parameter is used for test of pollution of raw water from fertilizer. The parameter is also important for testing raw water and water preparation.**

**4. Advantage, potential and target markets**

**The parameters are compulsory quality parameter of drinking water and, thus, necessary to measure. There is an EU limit of 50 mg/L for nitrate and 0,10 mg/L for nitrite ex treatment plant (with limits to the relation between nitrate and nitrite and with the exceptions if chlorination with chloramine is used).**

**The parameters are important for most markets – especially when the water source is influenced by agriculture.**

**5. Risks and concerns**

**Large variation in short wavelengths and interference of other compounds may be seen. These wavelengths are not easy to quantify because of background water light absorption. A bias of 100% may be found. Some maintenance is needed due to fouling of lamp or receiver.**

## 3.18 Refractive Index

**1. Short description of parameter**

! **Refractive index changes when the composition of water changes. All kinds of dissolved chemicals in water will change the refraction (bending) of light beams.**

**2. Technical features and concept**

! **Light refraction a change of the angle (bending) of a light beam going through the water (or could be reflected by the water surface). All kinds of chemicals dissolved in water will change the refraction of light, and the result is a sum changes in refraction. In a Mach-Zehnder interferometer (like in the Optiqua sensor) Refractive index (RI) changes result is phase shift in laser light; light beam is split in two paths; inference between sensing beam and reference beam reveals RI-induced phase difference, which is used to calculate the RI change. Another use of the techniques is to use a coated cell, where specific compounds attach to the surface and only few chemicals are detected, but at much lower levels (better sensitivity).**

**3. Customer need and benefits**

! **It is an interesting measurement, because it is possible to monitor all kinds of chemical change in the water quality. Most other methods only detect few or some kinds of chemicals.**

**The alternative method with a specific coated cell could also be interesting because it would be much more sensitive.**

**4. Advantage, potential and target markets**

! **The method is not very widely used but has some potential for water quality evaluation. An instrument was tested by Aarhus water.**

**As almost all compounds can be detected, the potential for the use of this parameter is good. However, the sensitivity is low. The markets interested in the parameter, is most likely countries, where there is a large fear of intentional pollution. The sum of a large number of compounds in a pollution event might be of interest.**

**5. Risks and concerns**

! **The method is not very sensitive to changes; thus, large changes must occur before a signal is measured – about 5 mg/L. For some substances 1 mg/L. The method needs some maintenance.**