

## On-line free-chlorine/total-chlorine monitors' evaluation – a step towards a correct choice of residual disinfectant monitor

Alexander Badalyan, Joachim Buff, Mike Holmes, Christopher W. K. Chow and Dammika Vitanage

### ABSTRACT

A number of commercially available on-line disinfection residual analysers were evaluated using a test rig under laboratory conditions. The methodology used for this trial was based on the following two standards: ISO Standard 15839 (2003), "Water Quality – On-line sensors/analysing equipment for water – Specifications and performance tests" and ISO 8466-1 (1990), and "Water Quality – Calibration and evaluation of analytical methods and estimation of performance characteristics. Part 1: Statistical evaluation of the linear calibration function".

The assessment of each analyser involved the determination of a set of performance characteristics including response delay, rise and fall times, linearity, limit of quantification and day-to-day repeatability. The effects of likely interferences were also covered. Results obtained from this trial for two total chlorine monitors were compared with the technical specifications as supplied by their respective manufacturers. This study concludes that persons responsible for instrument procurement should be cautious when relying only on manufacturers' technical specification claims. A more informed selection can be made by undertaking an evaluation study similar to the one described in this paper, as this will confirm the performance of a monitor under particular operating conditions. In general, residual disinfectant monitors utilising the colorimetric measurement method showed better performance than those employing amperometric/polarographic methods.

**Key words** | on-line disinfectant monitors' performance evaluation, on-line free chlorine monitors, on-line monochloramine monitors

**Alexander Badalyan**  
**Joachim Buff**  
**Mike Holmes**  
**Christopher W. K. Chow** (corresponding author)  
**Dammika Vitanage**  
CRC for Water Quality and Treatment,  
Hodgson Road, Bolivar, SA, Australia

**Alexander Badalyan**  
Sansom Institute, University of South Australia,  
City East Campus, Adelaide 5095,  
South Australia, Australia

**Joachim Buff**  
Department of Process Engineering,  
Georg-Simon-Ohm-Fachhochschule Nürnberg,  
Wassertorstrasse 10, Nurnberg D-90489,  
Germany

**Mike Holmes**  
United Water International Pty. Ltd.,  
180 Greenhill Road, Parkside 5061,  
South Australia, Australia

**Christopher W. K. Chow** (corresponding author)  
Australian Water Quality Centre, PMB 3,  
Salisbury 5110, South Australia,  
Australia  
E-mail: [Chris.Chow@sawater.com.au](mailto:Chris.Chow@sawater.com.au)

**Dammika Vitanage**  
Sydney Water Corporation,  
115-123 Bathurst Street, Sydney 2000, NSW,  
Australia

### INTRODUCTION

Selection of a disinfectant residual monitor should take into account both performance or technical characteristics and the whole of life cost. In many cases, the initial purchase cost may be considerably less than the installation cost, particularly if analysers are located in distribution systems without access to facilities readily available at most water treatment plants. These are power supply, easy access to water samples, sample and chemical disposal drains, environmental protection, and operator attention and

servicing. Cost of ownership is also important and calibration or maintenance requirements including chemicals and replacement parts require consideration. The monitor should be accurate and reliable; it should be robust to interference when subjected to changes in water quality, and output data should be delivered in a convenient reading format that can be integrated into a supervisory control and data acquisition (SCADA) system. The performance of an analyser in the field may differ from the performance

claimed by the instrument manufacturer. Environmental and water quality conditions used during factory trials can differ markedly from those found at water treatment plants and in distribution systems. Therefore, the choice of an appropriate monitor should be made based on the careful analysis of the monitor's performance characteristics with respect to the customer's operational conditions.

This paper describes the methodologies involved in setting up an on-line instrument evaluation trial and it provides guidance in interpreting evaluation trial results to assist in the selection of an instrument.

## EXPERIMENTAL

### Experimental apparatus

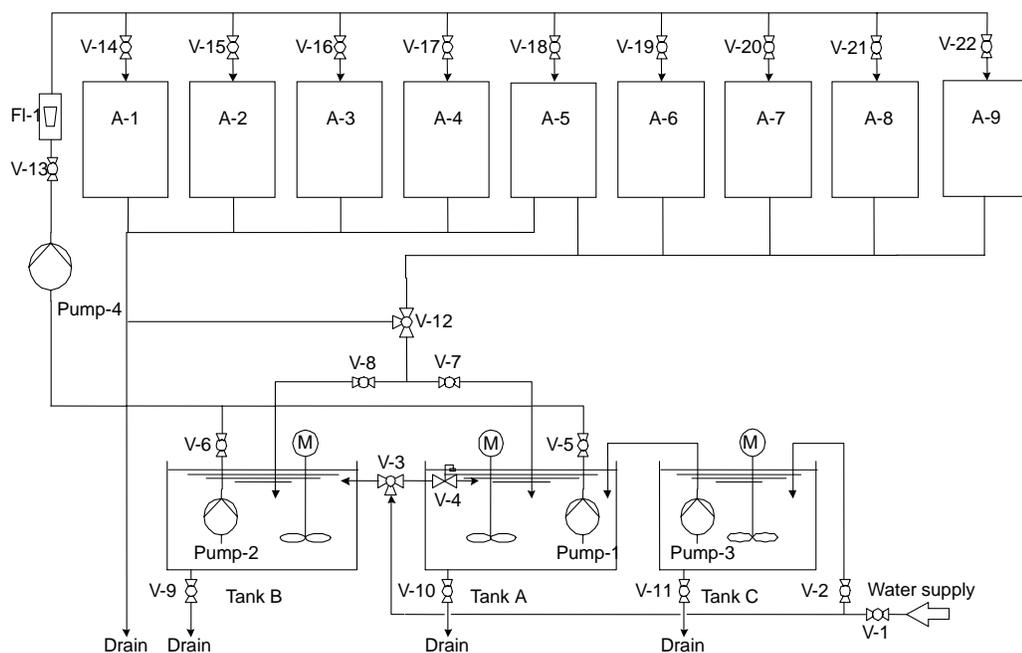
Six free-chlorine analysers, three total-chlorine/monochloramine analysers and three combined free-chlorine/total-chlorine/monochloramine analysers were evaluated. Hence, free-chlorine measurements were delivered by nine on-line monitors (labelled as A-1 to A-9) and total-chlorine/monochloramine by six monitors (labelled as A-1 to A-6). All analysers are commercially available and utilize either colorimetric or amperometric/polarographic measuring methods. In most cases, instrument suppliers installed and commissioned the monitors in the test rig. The residual disinfectant concentration ranges evaluated in this study were from 0 to 2 mg/L for free and total and monochloramine. Residual disinfectant concentrations in this paper are expressed as a percentage of the upper maximum range: 20% and 80% monitor spans correspond to free-chlorine and monochloramine concentrations of 0.4 and 1.6 mg/L, respectively.

According to Lynggaard-Jensen (2002), many key on-line water quality analyser performance characteristics must be determined in controlled laboratory conditions. These include *response time*, *linearity*, *coefficient of variation (COV)*, *limit of detection (LOD)*, *limit of quantification (LOQ)*, *repeatability*, *lowest detectable change (LDC)*, *short-term drift (ShTD)*, *day-to-day repeatability*, *memory effect* and *interference*. However, the above author indicated that response time and long-term drift can be determined in the field. As a result, a test rig was constructed to enable individual residual disinfectant residual analysers to be

performance-tested under simulated operational conditions. The test rig was flexible in design to accommodate individual monitor installation and operational requirements and to enable their optimal performance. The test rig employed three water tanks (A, B and C) as indicated in Figure 1. Tanks A and B were used to batch high and low concentration test solutions, respectively, while tank C contained chlorine- and/or ammonia-free water. Water was pumped from a selected tank to the analysers and the flow rate controlled using a diaphragm valve and rotameter. The design and operation of the rig ensured that all analysers received a common water supply, i.e. water of identical quality. Water discharged from the electrochemical analysers was not adulterated with chemicals and was recycled back to the feed tank, otherwise it was disposed to drain. The valving arrangements incorporated in the rig design minimised mixing of feed waters when supply tanks were rapidly switched. Mains water, supplied from a local water treatment plant (South Australia), was the feed to the analysers. Chemicals were manually dosed to, and mains water mixed in, the A and B tanks, enabling standard concentrations of chlorine, chloramine, ammonia and alkalinity to be prepared. Chemical interference tests were undertaken involving the controlled addition or modification of pH, DOC, conductivity, iron and manganese. The outputs from the on-line instruments, as well as sample temperature and pH, were logged using a 16-channel datalogger (Prologger 7001, MEA, Australia).

### Experimental procedure

The experimental procedure for all monitors was carried out in accordance with International Standard ISO 15839:2003(E) (2003). Following installation, commissioning and calibration of the analysers in the test rig, a preliminary response test (PRT) was conducted to determine the required data logging frequency for each analyser. The data logger was programmed to log readings at an interval equivalent to 10% of the PRT. The disinfectant residual concentration in the analyser feed stream was varied between 20% in tank A and 80% in tank B. Analyser feed water was batch-prepared by adding a concentrated stock solution of either sodium hypochlorite, pre-prepared monochloramine solution (1000 mg/L as



**Figure 1** | Experimental set-up and layout of the custom-built test rig.

chlorine) or ammonia solution to achieve the required disinfectant residual concentration for free chlorine, monochloramine/total chlorine or ammonia, respectively. Residual disinfectant concentrations were determined using standard laboratory methods (4500-Cl, APHA *et al.* 1998). Free-chlorine, chloramine (monochloramine and dichloramine) and total-chlorine concentrations were determined by titration (APHA *et al.* 1998). Total chlorine was determined as the sum of the free-chlorine and chloramine concentrations. Ammonia was determined in grab samples using a commercial test kit (Hach DR890, CO, USA).

Dechlorinated mains water was used to prepare zero residual concentration solutions. Test rig tanks were filled using mains water and stirred continuously for 24 h after which the free-chlorine concentration decayed to  $<0.05$  mg/L. Analyser feed solution was spiked with stock solution to achieve a 35% and 65% disinfectant residual and daily comparison was made of the analyser measurements and the relevant laboratory-method-determined residuals. Daily measurement of analyser feedwater temperature, pH and flowrate were also performed. Weekly chemical analyses were undertaken to determine analyser feedwater quality for a range of anions and cations.

## RESULTS AND DISCUSSION

### Analyser performance characteristics

Experimental data obtained from the analyser performance trials were used for the evaluation of analyser performance characteristics according to International Standard ISO 15839:2003(E) (2003) and these are discussed below.

### Response, delay, rise and fall time

These parameters were determined by allowing the analysers to achieve stable readings in response to a feedwater disinfection residual concentration equivalent to 20% of measuring span. Once readings were stable, the analyser feed tank was switched as rapidly as possible by valve adjustment to deliver feedwater with a disinfectant residual concentration equivalent to 80% of maximum. Once analyser readings had stabilised, the feed disinfectant residual concentration was decreased back to 20% of the measuring range as rapidly as possible by resetting the valve arrangements. The data logger recorded analyser responses to changes in feed concentration.

Monitors possessing a quick response performance are well suited to functioning as measuring devices in

chlorination or chloramination disinfection process control employing chemical dosing. Less responsive monitors may be suitable only for residual monitoring purposes. Figure 2 presents the theoretical response of an analyser to an abrupt change in a measured parameter such as chlorine or monochloramine concentration. Free-chlorine monitors A-6 and A-9 and monochloramine monitors A-2 and A-3 have reasonably short response times, indicating that they are appropriate for controlling chlorination or chloramination (see Tables 1 and 2).

### Linearity

Linearity indicates how closely monitor readings match the results of laboratory calibration tests performed on calibrating solutions. The test for *linearity*, according to ISO 8466-1:1990, can be determined by “graphical representation of the calibration data with the calculated regression line” (International Standard ISO 8466-1:1990 1990). Data obtained from these experiments were subjected to linear regression tests with mean-least squares approximation used to find the best fit of the linear equation to the experimental data. The criterion for the best fit is

the value of the square of regression coefficient ( $R^2$ ). The closer this coefficient is to unity, the closer the data points are arranged in relation to the ideal straight line. Tables 1 and 2 show that free-chlorine monitors A-2, A-6, A-7 and all monochloramine monitors pose  $R^2$  values  $>0.9$ , indicating good correlation with titration results (see Tables 1 and 2). *Linearity* evaluation (as well as other performance characteristics) for all analysers was carried out during six-day tests (SDT), when no adjustments of calibrations were made to the analysers. These analysers were calibrated only before and after the SDT. The linearity results are the reflection of the poor performance of analysers A-5, A-8 and A-9. We may conclude that their calibration failed after three days of SDT. As the recommendation, these three analysers should undergo more frequent calibration.

### Covariance

The *COV* is defined as the “ratio of the standard deviation of the on-line sensor/analysing equipment to the mean of the working range of the equipment” (International Standard ISO 15839:2003(E) 2003). The *COV* value is often used to

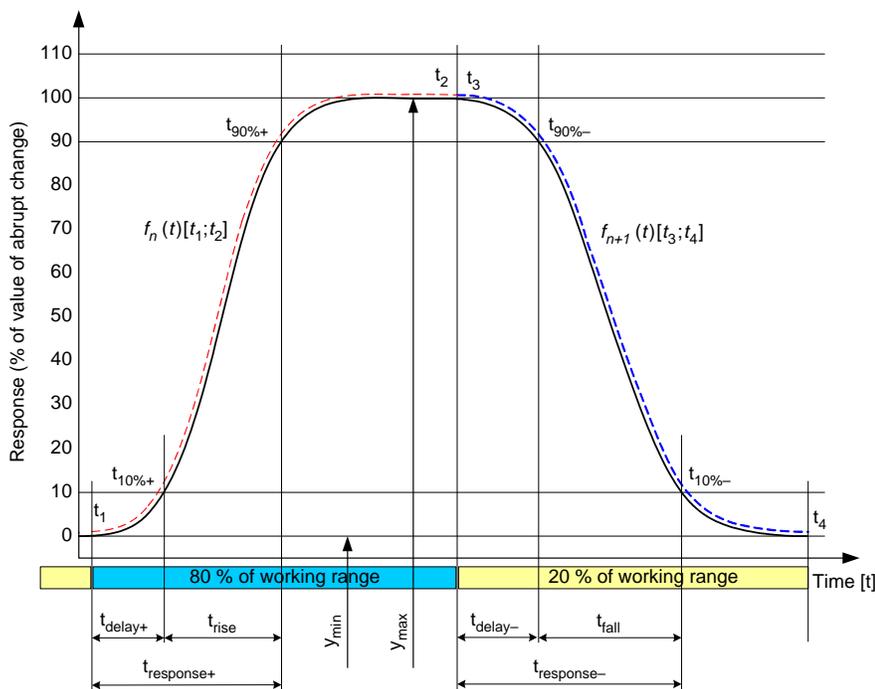


Figure 2 | Typical on-line analyser response to an abrupt change in chlorine/monochloramine concentration.

**Table 1** | Summary of selected free-chlorine analyser key performance characteristics

Parameter	Unit	Analyser								
		A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8	A-9
Measuring technique		Ampero metric	Ampero metric	Polarographic	Ampero metric	Ampero metric	Polarographic	Colori metric	Ampero metric	Ampero metric
+ ve/-ve	S	81.2	202.2	55.2	109.7	82.3	59.9	128.8	89.6	41.5
Response time		91.6	145.8	75.6	84.0	104.3	48.4	124.4	100.0	47.2
Linearity – $R^2$		0.8730	0.9716	0.8829	0.8971	0.7967	0.9599	0.9554	0.6425	0.6794
COV	%	17	8	14	11	14	7	7	32	28
LOD	mg/L	0.07	0.08	0.10	0.07	0.10	0.06	0.06	0.03	0.02
LOQ	mg/L	0.23	0.27	0.32	0.22	0.32	0.22	0.19	0.10	0.05
Repeatability, 20% test solution	mg/L	0.05	0.01	0.05	0.04	0.06	0.03	0.02	0.02	0.03
Repeatability, 80% test solution	mg/L	0.03	0.08	0.03	0.02	0.03	0.01	0.04	0.01	0.02
Day-to-day repeatability, 35% test solution	mg/L	0.09	0.06	0.20	0.06	0.12	0.21	0.07	0.19	0.23
Day-to-day repeatability, 65% test solution	mg/L	0.20	0.11	0.38	0.11	0.12	0.31	0.09	0.40	0.46
LDC, 20% test solution	mg/L	0.15	0.04	0.14	0.12	0.19	0.08	0.06	0.06	0.08
LDC, 80% test solution	mg/L	0.08	0.23	0.10	0.06	0.08	0.02	0.13	0.02	0.05
Short-term drift	%	0.55	0.00	1.07	1.22	1.39	1.47	1.50	1.81	1.09
Memory effect	mg/L	0.02-No	0.04-No	0.00-No	0.16-Yes	0.04-No	0.06-No	0.05-No	0.06-No	– 0.05-No
PH dependence	%	100.2	33.1	83.4	46.1	96.1	11.8	3.3	44.6	186.3
Conductivity dependence	%	1.5	2.7	3.0	2.3	2.5	14.1	4.1	2.8	4.8

**Table 2** | Summary of total-chlorine/monochloramine analyser selected key performance characteristics

Parameter	Unit	Analyser A-1	A-2	A-3	A-4	A-5	A-6
Measuring technique		Polarographic	Amperometric	Amperometric	Colorimetric	Colorimetric	Colorimetric
Chemicals required		No	No	No	Yes	Yes	Yes
+ ve/-ve Response time	S	361/155	244/269	152/146	1020/860	910/715	1365/1111
Linearity – $R^2$		0.9335	0.9064	0.9907	0.9973	0.9262	0.9518
COV	%	28	32	11	7	21	16
LOD	mg/L	0.023	0.016	0.015	0.090	0.092	0.256
LOQ	mg/L	0.077	0.055	0.052	0.302	0.308	0.854
Repeatability, 20% test solution	mg/L	0.03	0.01	0.02	0.01	0.09	0.10
Repeatability, 80% test solution	mg/L	0.09	0.09	0.02	0.04	0.09	0.18
Day-to-day repeatability, 35% test solution	mg/L	0.11	0.16	0.04	0.02	0.06	0.11
Day-to-day repeatability, 65% test solution	mg/L	0.34	0.45	0.13	0.13	0.25	0.12
LDC, 20% test solution	mg/L	0.09	0.03	0.07	0.04	0.26	0.29
LDC, 80% test solution	mg/L	0.26	0.27	0.07	0.12	0.26	0.00
Short-term drift	%	7.77	–8.91	–3.14	–0.97	8.06	10.92
Memory effect	mg/L	0.02-No	0.01-No	–0.03-No	–0.07-Yes	0.15-No	0.07-No
pH dependence	%	44	57	42	6	15	ND
Conductivity dependence	%	0.9	2.0	1.5	1.0	3.5	12.4

compare the variation of different analysers. The *COV* combines the value for the  $R^2$  and the slope of the linearity test in one parameter, expressed as percent variation of the analyser measuring range. Results are summarised in Tables 1 and 2.

### Limit of detection

The *LOD* is the lowest value of a measured parameter that can be distinguished from the background noise in the absence of that parameter. However, distinguishing a result does not mean it can be measured, since one is still not certain what the value is. Free-chlorine monitors A-8 and A-9, as well as total-chlorine/monochloramine monitors A-1 to A-3, showed the lowest *LOD* (see Tables 1 and 2).

### Limit of quantification

ISO 15839:2003(E) (2003) states that *LOQ* is the “lowest concentration of determinand that can be measured with an acceptable level of *accuracy* and *precision*, and is equal to 10 times the standard deviation” (International Standard ISO 15839:2003(E) 2003). This characteristic requires measurements of very low disinfectant residual concentration solutions within the accuracy and precision claimed by the manufacturer for each analyser. Once again, free-chlorine monitors A-8 and A-9 and total-chlorine/monochloramine monitors A-1 to A-3 showed the best performance in regards to *LOQ* (see Tables 1 and 2).

### Day-to-day repeatability

*Day-to-day repeatability* is defined as “precision under day-to-day repeatability conditions” (International Standard ISO 15839:2003(E) 2003). *Day-to-day repeatability* conditions are “conditions where independent test results are obtained with the same method on identical test items in the same laboratory by the same operator using the same equipment and reagents over several days” (International Standard ISO 15839:2003(E) 2003). *Day-to-day repeatability* is reported for 35% and 65% of the monitor's working range. Free-chlorine monitors A-2, A-4 and A-7, and monochloramine monitors A-3 and A-4, showed the best performance (see Tables 1 and 2).

### Interference

The quality of an analyser's performance is determined not only by how accurately it responds to variations of disinfectant residual concentration in water, but by how *insensitive* and robust its readings are to water quality changes such as temperature, pH and conductivity. The response of a monitor's readings should be unchanged within its experimental uncertainty. Not all analysers perform well in this regard. Some may be very sensitive to interference. For that reason, analysers can develop an “undesired output signal caused by a property(ies)/substance(s) other than the one being measured” (International Standard ISO 15839:2003(E) 2003), which is called *interference*. In this trial, the effect of changes in pH from 5 to 10, electrolytic conductivity, temperature, dissolved organic carbon (DOC), and concentrations of iron and manganese on each monitor's output, expressed as a percentage of its span, was investigated. Free-chlorine monitor A-7 and total-chlorine/monochloramine monitor A-4 exhibited the lowest sensitivity to interference as compared to the other analysers to pH variations (see Tables 1 and 2). These monitors should be preferred over others when the pH of the water in the field may vary significantly. All analysers, except free-chlorine monitor A-6 and total-chlorine/monochloramine monitor A-6, showed good stability with respect to variation of electrolytic conductivity.

### Interpretation of testing results

A number of technical factors that require consideration when selecting an on-line disinfectant residual analyser for a particular application are discussed below.

Most water utilities do not undertake the comprehensive testing procedure presented in this paper before purchasing a disinfectant residual monitor. Many rely on the technical information supplied by the instrument manufacturers. However, as shown in our findings, a potential purchaser should undertake several tests under simulated or actual field operational conditions, in order to compare test results with those claimed by the analyser manufacturer. In addition, many technical documentations/specifications produced by manufacturers use metrological characteristics that may be quite different from those presented in the ISO Standards used in this paper.

The conditions used to determine performance characteristics may also differ from one manufacturer to another, thus making a correct choice even more difficult. As an example, information from two arbitrarily chosen manufacturers of free-chlorine monitors, monitors A-7 and A-9, is presented in Table 3. This allows a comparison to be made with performance indicator parameters determined using ISO methodology as presented in Table 1.

As the first step, a buyer should check that the *measuring range* of an analyser covers all the possible disinfectant concentrations in their water supply. This seemingly simple technical parameter is very important, since overexposure of the measured variable (free chlorine, total chlorine/monochloramine or ammonia) may cause an analyser to take a long time to return to normal operation (recovery) at best, whereas in the worst case scenario the monitor may require recalibration. In our testing program, we identified the key performance parameter called “*memory effect*” which deals with such variable overshooting. However, neither of the aforementioned two manufacturers supplied information about this key performance parameter. Therefore, some degree of caution should be exercised when making a choice of a monitor based solely upon manufacturer technical specifications.

Almost all manufacturers include values of *accuracy* in their technical documentation. This value may be expressed

as a percentage of full scale or as a concentration in mg/L. It is important to select a monitor possessing a low absolute value as this indicates high accuracy. As an example, monitor A-7 in Table 3 purports to be more accurate than monitor A-9, but this difference is operationally negligible. However, it is not clear if the accuracy of  $\pm 5\%$  refers to a full scale or to the reading of the monitor. We can only assume that the accuracy of monitors A-7 and A-9 is determined as a percentage of the full scale of the monitor. This is an example of how ambiguity in reporting technical specifications creates difficulties when assessing a monitor's performance and/or choosing an appropriate monitor. Values of *COV* (see Table 1) can also be regarded as experimental uncertainties in the readings of on-line monitors. For monitors A-7 and A-9, *COVs* were determined as 7 and 28%, respectively. So both monitors failed to comply with the claimed accuracy as per Table 3: however, monitor A-7 may be considered as having performed satisfactorily. We should stress again, however, that failure to meet the claimed performance is not necessarily disadvantageous, but rather that the monitor demonstrated different performance in the local testing conditions.

*Precision* is regarded as a standard deviation of measurements. In other words, it is a measure of the proximity of results to each other produced by several measurements of the same parameter under constant

**Table 3** | Manufacturers' sourced technical characteristics of free-chlorine analysers

Parameter	Monitor A-7	Monitor A-9
Measuring range	0–5 mg/L	0–5 mg/L
Accuracy	0.035 mg/L as Cl <sub>2</sub> or $\pm 5\%$ , whichever is greater	0.05 mg/L as Cl <sub>2</sub> or $\pm 6\%$ of full scale, whichever is greater
Repeatability	N/A	0.02 mg/L as Cl <sub>2</sub> or $\pm 3\%$ of full scale, whichever is greater
Precision	0.005 mg/L as Cl <sub>2</sub> or $\pm 5\%$ , whichever is greater	N/A
Sensitivity	N/A	0.01 mg/L as Cl <sub>2</sub> or $\pm 1\%$ of full scale, whichever is greater
Minimum detection limit	0.035 mg/L	N/A
Stability	N/A	3% of full scale
Drift	<1.5% per month	N/A
Response time	90% < 2 minutes 99% < 5 min	90% change < 5 min
Conductivity range	N/A	> 10 $\mu\text{S/cm}$ up to 2500 $\mu\text{S/cm}$
pH range	4–8	4–10
Output signal	4–20 mA	4–20 mA

measuring conditions. In Table 3, both manufacturers referred to the same parameter, but gave them different names: *repeatability* and *precision*. According to International Standard ISO 5725-1:1994(E) (1994), *repeatability* is determined as *precision* under repeatability conditions (“conditions where independent test results are obtained with the same method on identical test items in the same laboratory by the same operator using the same equipment within short intervals of time”). In our testing program, either “*Repeatability using 20 and 80% test solutions*” or “*day-to-day repeatability using 35 and 65% test solutions*” could be applied to this term. As follows from Table 1, monitors A-7 and A-9 demonstrated the following values of these parameters as “*day-to-day repeatability as determined using 35 and 65% test solutions*”: 3.5% (0.07 mg/L) and 4.5% (0.09 mg/L) for monitor A-7, and 11.5% (0.23 mg/L) and 23.0% (0.46 mg/L) for monitor A-9, respectively. Values demonstrated as “*day-to-day repeatability as determined using 20 and 80% test solutions*” were equivalent to 1.0% (0.02 mg/L) and 2.0% (0.04 mg/L) for monitor A-7, and 1.5% (0.03 mg/L) and 1.0% (0.02 mg/L) for monitor A-9, respectively. According to Table 3, these values should be less than or equal to 5 and 3%, respectively, if they are to agree with manufacturers' specifications. Therefore, only monitor A-7 performed within the claimed value of precision. However, if the manufacturer were more precise in identifying this performance characteristic (it may be “*Repeatability using 20 and 80% test solution*”), then both monitors would have demonstrated excellent compliance with the *repeatability* values claimed by the manufacturers. However, the reliance only on precision is not correct. *Repeatability* and *precision* should always be considered together with *accuracy*, as it is not particularly useful to have an analyser that is highly precise if the result is consistently incorrect.

*Sensitivity* and *minimum detection limit (MDL)* have the same meanings in the view of these two manufacturers, which is essentially correct. Sensitivity of an instrument is its “ability to distinguish a true analytical signal from a background noise”, according to Guenther et al. (1996). Therefore, *LOD*, sensitivity and *MDL* are interchangeable, but note, however, that these three parameters should not be used instead of *LOQ*. According to the data presented in Table 1, monitor A-7 did not perform well since its *LOD*

(0.06 mg/L) is less than its *MDL* from Table 3 (0.035 mg/L). At the same time, monitor A-9 (*LOD* = 0.02 mg/L) was able to perform within the claimed sensitivity of 1% of full scale (which corresponds to 0.05 mg/L). Overall, monitor A-9 is more sensitive than monitor A-7, which follows from their technical specifications in Table 3.

Similar to the discussion in the previous paragraph, these two manufacturers use two different names for the same technical specification, in this case, *stability* and *drift*. In our testing program, *ShTD* was determined within the percentage of the measuring range over a 24 h period on the same calibration solution under stable conditions. It is not clear from Table 3 what time periods have been used by the respective instrument manufacturers to determine the values reported for stability and drift. Our results for *ShTD* fall within the manufacturers' claimed ranges for *stability* and *drift*: however, for monitor A-7, our results were obtained over a 24 h period, whereas the manufacturer unusually reports in percentage drift per month, making comparison difficult.

Although data in Table 3 referring to *response times* were different for manufacturers' claims (90 and 95% change) and in our testing (20 and 80% change), by interpolation we get very similar numbers, confirming that these two monitors perform well within the manufacturers' claimed characteristics.

As a result of interference, readings of a monitor may vary even when the concentration of disinfectant residual remains constant. According to International Standard ISO 15839:2003(E) (2003), *interference* “is an undesired output signal of a monitor caused by a property(ies)/substance(s) other than the one being measured”. Examples of such properties are water electrolytic conductivity and pH. In field conditions, they may vary and affect a particular analyser's output. For this reason, manufacturers frequently report on tests in which analysers have been exposed to feedwater containing potential interfering chemicals. Tests may be undertaken under a range of electrolytic conductivity and pH conditions, as indicated in Table 3. Exposure of monitors A-7 and A-9 to various ranges of electrolytic conductivity (286, 572 and 819  $\mu\text{S}/\text{cm}$ ) caused relatively minimal change in the monitors' readings, 4.1 and 4.8% of the measuring range, respectively. These electrolytic conductivity variations are within the manufacturers'

acceptable range for accuracy as indicated in Table 3 ( $\pm 5\%$  and  $\pm 6\%$  accuracy). However, analyser A-9 performed poorly when subjected to feedwater with low and high pH (pH 5 and pH 10, respectively).

Finally, disinfectant residual monitors should deliver an output signal proportional to disinfectant residual concentration in a format allowing integration into SCADA or telemetry systems. The current standard method of communication used by most analysers employs a 4 to 20 mA output signal as provided by monitors A-7 and A-9. The development of "smart analysers" which incorporate onboard performance and condition assessment such as temperature, flow, power supply voltage and sensor condition requires more advanced communication protocols such as PROFIBUS and DeviceNet.

## CONCLUSIONS

A constructed test rig was successfully applied to assess the performance of on-line disinfectant monitors according to ISO Standards 15839:2003 and 8466-1:1990. All tested monitors were evaluated against their claimed performance characteristics. In general, colorimetric systems performed better compared to amperometric/polarographic systems. This is probably due to the fact that amperometric/polarographic systems suffer from the notoriously known dependence of the sensor's response from pH of water. The data acquisition system in the present testing programme measured pH of feedwater on a daily basis, giving variations in pH readings from 7.3 to 7.6. Taking into the account that pH of feedwater was not adjusted in the present testing programme, but used "as received", and significant values of pH interferences presented in Tables 1 and 2 (from 11.8 to 186.3%), the less than perfect performance of amperometric/polarographic residual disinfectant monitors is understandable. The conclusions on residual disinfectant monitor performance and, consequently, its selection for a specific application depend on the interpretation of the

above discussed results with respect to a monitor's technical characteristics.

It is therefore recommended that the performance of residual disinfectant monitors be evaluated using the protocols discussed in this paper. This is particularly important when considering a new monitor, application or environment.

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