New Water Turbidity Measurement Technology – the US Experience

Introduction

The amount of insoluble matter present in drinking water is an essential quality indicator. Silt, sand, bacteria, spores, and chemical precipitates all contribute to the cloudiness or turbidity of water. Drinking water (DW) which is highly turbid can be unpalatable and unsafe. Consumption of even low concentrations of certain bacteria and other microorganisms can cause serious health effects. Consequently, an accurate and sensitive measurement of turbidity is vital for ensuring that drinking water is free of these contaminants. Public health and safety organizations throughout the world have recognized the importance of measuring drinking water quality through turbidity. The US EPA requires turbidity monitoring for all produced drinking waters[1]. The EU Drinking Water Directive identifies turbidity as one of several fixed monitoring parameters which must be measured for all water intended for human consumption[2]. The WHO recommends monitoring turbidity frequently and at multiple points throughout the treatment process[3]. While regulatory limits vary across national borders, there is widespread agreement that reliable turbidity monitoring is an essential component of drinking water production.

As with any analytical procedure, turbidity should be measured in a fast and accurate manner. Both these characteristics of analytical instrumentation, especially designed for process analysis, are important. Drinking water operations look for fast response of their instrumentation and want to have confidence in results in order to be able to react to potential filter breakthroughs. New turbidity measurement technology has been developed by Hach® that specifically addresses these characteristics. From these two standpoints the new technology provides unprecedented benefits measuring not a single reflection of the light beam at 90°, but collecting an array of results at 90° all the way around the sample cell, as depicted in Figure 1.

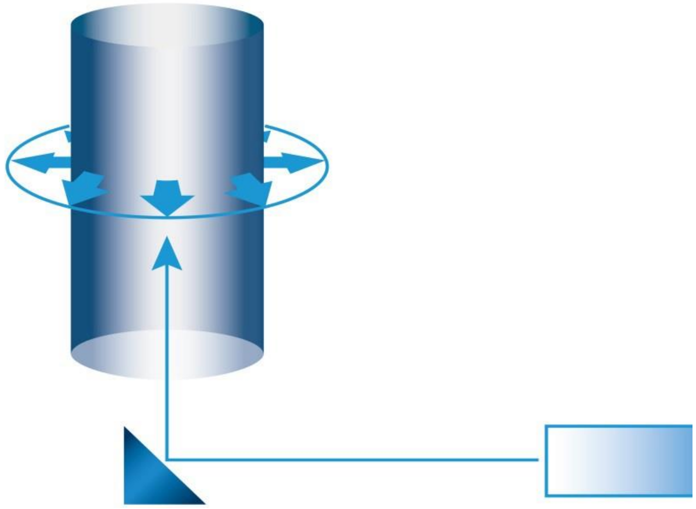


Figure 1: Schematics of the 360° by 90° turbidity measurement system

Collecting the light reflected at 90° in the full circle (360° x 90°) allows a significantly increased signal-to-noise (S/N) ratio, which measurement, especially at low end of the range.

General specifications defined for the new process turbidity instrumentation based on the 360° x 90° patented technologies are summarized and presented in Table 1 below.

[1] *Environmental Protection Agency (2009) - National Primary Drinking Water Regulations (EPA Publication No. 816-F-09-004) Rockville, MD: U.S. Environmental Protection Agency.*

[2] *EU Drinking Water Directive - Council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption [1998] OJ L330*

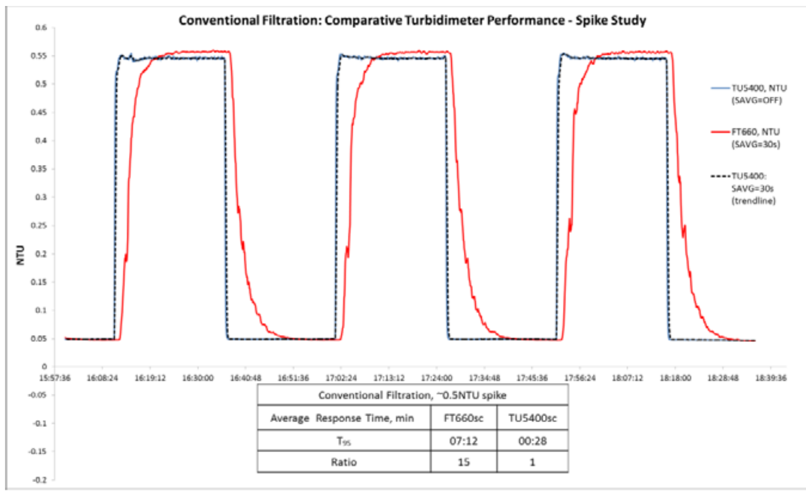
[3] *World Health Organization (2011) - Guidelines for Drinking-water Quality, 4th Ed. Geneva, Switzerland*

Table 1: TU5 series process turbidimeters major specifications:

Parameter	Specification
Range	0 to 700 NTU, FNU, TE/F and FTU; 0 to 175 EBC
Detection	0.0002 NTU at 25°C (77°F)
Precision	TU5300 sc: 0.006 NTU or 1% (the larger value) at 25°C (77°F) TU5400 sc: 0.0006 NTU or 1% (the larger value) at 25°C (77°F)
Accuracy	0 to 40 NTU: ± 2% or ± 0.01 NTU (the larger value) 40 to 700 NTU: ± 10% of reading based on formazin primary standard at 25°C
Linearity	Better than 1% for 0 to 40 NTU based on formazin primary standard at 25°C
Response Time	T_{90} < 30 seconds (at 100 mL/min)

In addition, this technology uses a much smaller sample vial and therefore allows for significantly decreased event detection time as was determined during a round of tests at several DW facilities employing either membrane or conventional filtration. These studies were conducted with a set of most representative existing FT660 sc and new TU5400 sc turbidimeters to evaluate the performance of the instruments built on the new technology against a well-known laser nephelometer.

The data presented in Figure 2 illustrate the performance of process turbidimeters built on existing and new technologies and allow comparing the time these instruments take to detect a turbidity spike. This test setup ensured that an extremely accurate amount of Formazin standard was added to the real filter effluent sample stream. The tested instruments measured the same sample with tightly controlled flow rate to eliminate known uncertainties. Data logging was set to 5 second intervals for each tested analyzer. The only difference in the data acquisition was in signal averaging; however, it was easily mitigated by available MS Excel functions to provide an equal comparison. A post-factum signal averaging for the TU5400 readings revealed no significant difference in its response time (Figure 2, trendline).



Conventional Filtration, ~0.5NTU spike		
Average Response Time, min	FT660sc	TU5400sc
T_{95}	07:12	00:28
Ratio	15	1

Figure 2: A representative graph and calculations averaging three consecutive spikes to illustrate the response of two turbidimeters measuring conventional filter effluent before and after spiking with Formazin standard

Studies conducted at several conventional and membrane filtration DW facilities involved spiking at three levels: ~1.5 mNTU, ~100 mNTU, and ~500 mNTU with tight controls over all potentially interfering test conditions. These studies involved hundreds of such standard addition experiments at each spike level. Membrane filtration study results showed the time to reach 90% of the spike concentration (T90) for the TU5400 was ~26 times faster (at the lowest spike level) than for the existing laser turbidimeter. The graph in Figure 2 represents a higher level standard addition test being part of a full scale three-level spiking study conducted at two conventional filtration DW plants (US). As follows from the results (Figure 2, table), the time to reach 95% of the spike concentration (T95) for the new technology was ~15 times faster (ratio, Figure 2).

Another important aspect of customer expectations is the comparison between laboratory and process instrumentation results. This is an important part of day to day DW facility operation and it may cause a lot of pain for operators and management due to current US EPA requirements[4]. To briefly illustrate advantages of the new system it may be enough to say that both new process and lab turbidity analyzers are built with identical measurement systems. Therefore, given the 360° x 90° technology with an extremely stable laser light source, the same cell design provides assurance that the readings between lab and process are going to match within normal experimental error. The identical measurement technology provides additional means to troubleshoot potential discrepancies and peace of mind for the end users.

[4] *US EPA – Guidance Manual for Compliance with the Interim Enhanced Surface Water Treatment Rule: Turbidity Provisions (TURBIDITY METHODS & MEASUREMENT), EPA-815-R-99-010, April 1999*

To summarize, new technology employing a much smaller measurement cell, laser light source, and the 360° x 90° detection technique has demonstrated several tangible benefits over existing instrumentation: significantly faster response time, better accuracy, and designed-in agreement between process and lab measurements of the same sample. Such benefits come with a tradeoff that needs to be understood and taken into account – a potential for more frequent cleaning of the process analyzer's measuring cell. There are options and accessories available to mitigate the tradeoff, such as an automated cleaning module. However, given the new design, even manual cleaning and calibration of the process turbidimeter (as required) takes significantly less time for the user. This and other aspects of new instrumentation performance were evaluated during an expansive field test program encompassing five countries, 18 DW facilities, various test conditions, and applications.

Field Test

A field test of the new TU5 series turbidimeters was conducted in various applications (from raw to finished water) and environmental conditions (from Michigan to California and Puerto Rico in the US, as well as in China, Canada, Germany, France and the UK) to address all major concerns. One of the most representative field studies was conducted at a drinking water facility in Pennsylvania managed by the Western Berks Water Authority (WBWA), which has been an early adopter of new technologies for many years. The short and long-term testing was focused on the new lab and process turbidimeters' performance, their ability to fit expectations, usefulness of the features, and overall comparison with the existing commercially available instrumentation. WBWA received a set of instruments including lab turbidimeter (TU5200) and process unit (TU5300 sc) and was asked to install and test the instrumentation without Hach supervision. The installation was conducted in January of 2015 (Figure 3) and customer impressions and feedback were collected after the first set of testing, which included the match between lab and process, calibration and maintenance exercises.

Figure 3: TU5300 sc process turbidimeter with flow sensor (optional) and sc200 controller installed at Western Berks DWTP

John Ruth, Plant Operator/Instrumentation Technician who was one of several users testing the equipment offered initial feedback regarding each analyzer, its features, and available options:

Laboratory unit: "I am impressed with the accuracy especially at the lower turbidity levels."

Comparison between the process and lab measurements: "The lab and process turbs are very close to each other. We are using our finished water and turbs have been very much closer than our other benchtop unit."

Process unit: "We liked the flow sensor a lot. We liked having the indicator light let us know when the flow was insufficient."

After the TU5300 sc was moved from finished water to a pre-filter application considered by the user more important, Ruth characterized the performance of both analyzers: "The benchtop is consistent with the process turb. We are now on pre-filter water and the comparisons are still good."

Ruth also gave some initial impression on some key functions and features of the new instrumentation: "The calibration of the process turbidimeter went well using the 20NTU Stablcal® vials. We also calibrated the benchtop unit with the Stablcal vials (20 and 600NTU). The use of the Stablcal vials with the RFID capability made the calibrations quick and easy, with less chance of operator error."

Lastly, Ruth responded on the use of the RFID feature: "The RFID system works well and will be useful when using several different turbidimeters and samples."

To illustrate one of the most important features determining the match between process and lab results, the data derived from the Comparison Log recorded by the TU5200 when RFID tags were used, are presented in Table 2.

Table 2: Comparison between process (TU5300) and laboratory (TU5200) turbidity readings for the same samples – the data is recorded by the TU5200 with use of the RFID technology

Sampling Date/Time	Sensor Name	TU5300, NTU	Analysis Date/Time	TU5200, NTU	Difference, %	Evaluation
1/16/15 9:23:10	TU5300 sc	0.448	1/16/15 9:23:37	0.52	16.8	Measurement values do not match.
1/16/15 9:23:10	TU5300 sc	0.448	1/16/15 9:24:32	0.49	8.6	Measurement values match.
1/16/15 9:26:53	TU5300 sc	0.418	1/16/15 9:26:48*	0.44	4.4	Measurement values match.
1/16/15 9:31:52	TU5300 sc	0.435	1/16/15 9:31:20*	0.46	4.9	Measurement values match.
1/21/15 10:23:26	TU5300 sc	0.372	1/21/15 10:23:00*	0.40	6.1	Measurement values match.
1/23/15 8:37:03	TU5300 sc	0.377	1/23/15 8:36:29*	0.42	10.5	Measurement values do not match.
1/23/15 8:37:03	TU5300 sc	0.377	1/23/15 8:37:00*	0.35	6.5	Measurement values match.

** - Clock on the TU5200 was not adjusted to display correct time.*

It can be seen from the table that it may require more than one attempt to read the same sample collected at the process instrument to pass the evaluation criteria – usually it is an indication that either process or lab measurement vial needs to be cleaned. However, when the readings are within 10% from each other, the TU5200 will display the "match" message (Evaluation column, Table 2). It is necessary to point out that only the same sample readings are suitable for such comparison and the best way to ensure it is with the use of the RFID tags read by both process and lab units. The laboratory instrument is recording every reading and calibration in a separate log to maintain the data for historical analysis. Similar to this, the TU5300 sc records all readings during its operation, as well as additional information such as flow (if the flow sensor option is installed), temperature and humidity inside the analyzer, and other parameters vital to automatically evaluate the system health. System health can be monitored by PROGNOSYSTM predictive diagnostics software (with use of a SC1000 controller) which is also available in other modern Hach process analyzers.

As it was mentioned above, initial short-term testing of the new process analyzer was conducted on finished water – the main target application for low range turbidimeters, and the test showed very good performance of the TU5300 sc turbidimeter. The WBWA is a 2013 winner of the rarely achieved Phase IV "Presidents Award" recognition from the Partnership for Safe Water, and its personnel strive to achieve the best possible control of their water treatment processes.

Therefore, the process unit was placed at the most challenging application before the filter (Figure 4) to evaluate its performance against the current analyzer. This application allows the user to see changes in settled water quality quickly and react appropriately – thus the fast and accurate response with minimum maintenance is the key for providing robust process control.

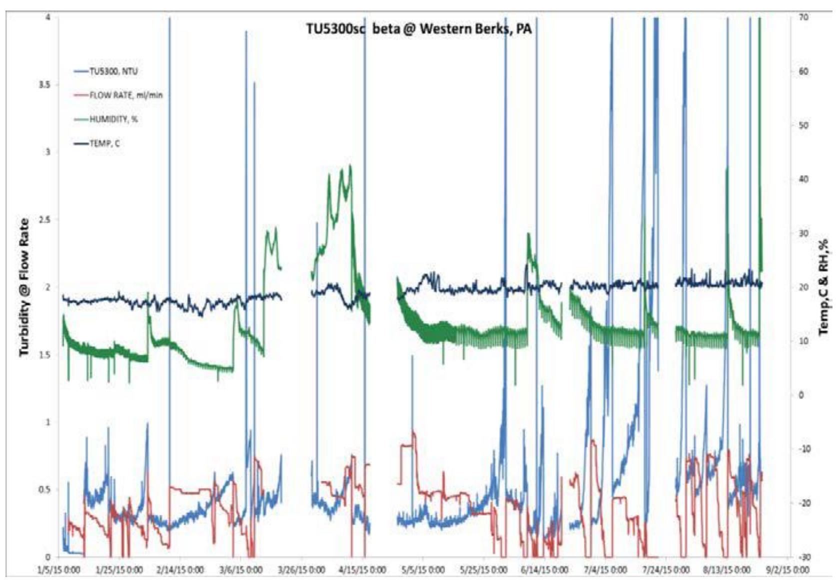


Figure 4: Process analyzer data recorded during the pre-filter application test

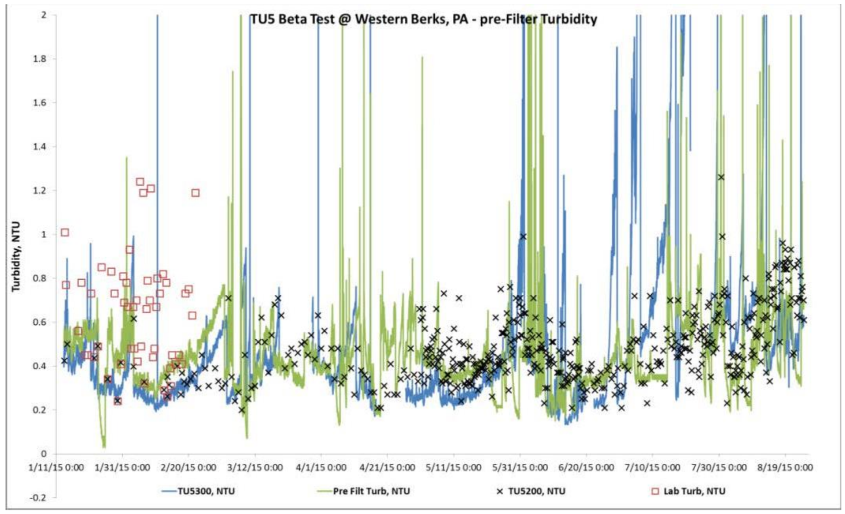


Figure 5: Comparison between turbidity readings from two process and two lab instruments

As seen from the graphs in Figure 4, the analyzer was operating on challenging pre-filter water without major interruption for almost nine months and the personnel conducted routine calibrations with 20NTU standard quarterly, based on their schedule. The gaps in the data occurred due to natural delays in data collection, because the analyzer was not connected to their SCADA system. The spikes in turbidity readings were either related to natural water quality events or to insufficient flow to the analyzer as was recorded by the flow sensor. The temperature and humidity constantly monitored inside the unit were quite stable which shows a steady state of the major system health indicators. Sample vial cleaning was conducted on an "as needed" basis depending on water quality changes and usually corresponded with the loss of the sample flow. The need for vial cleaning was usually indicated by a warning provided by the software and displayed on the controller. Manual vial cleaning takes very little personnel time and puts the instrument back into normal operation mode within about 1-2 minutes of total down time, which is significantly less than the regulatory 15-min data recording interval.

An important part of the test was the comparison between readings received from another process turbidimeter as well as multiple grab sample analysis conducted with a benchtop unit during every shift. Ruth said, "We do bench top QA/QC test on our Raw, Pre-treatment, Pre-filter, Filter effluent, Clearwell, and Finished water samples four times per day." The data illustrating the performance of both tested turbidimeters are presented in Figure 5, where we can see all turbidity readings plotted against time and each other. Since this application is equally challenging for any process turbidimeter, it seems more valuable to compare process and lab data as presented in the chart (Figure 5). As can be seen from Figure 5, the plant operators were using two process turbidimeters and, originally, two benchtop units for the test. Ruth said, "On 2/25 we switched from the 2100Q [existing benchtop] to using the [TU5200] for our QA/QC tests. You can see that with the [TU5200] readings are much lower and much closer to what they should be."

The result of the switch is self-explanatory and can be clearly seen in the chart (Figure 5). As also seen from this figure, all process and lab turbidity readings correlated well during relatively calm water conditions in winter and spring time, however, once the conditions changed, per John's reference to "busy summer", the value of online monitoring increased dramatically. Close analysis of the charts presented in Figure 5 demonstrated that on several occasions the new process turbidimeter reacted to water changes quicker than the reference analyzer, let alone laboratory analysis.

Conclusions

- The thorough testing of the new laser technology embodied in TU5 series turbidimeters, featuring the 360^{o} x 90^{o} measurement with a smaller cell, demonstrated its superior performance in terms of faster response time.
- The same design of the analytical system between new process and lab turbidimeters allowed achievement of a consistent match between the readings of the same sample.
- The TU5 series instruments demonstrated robust performance across various applications and environmental conditions. There was no excessive maintenance required even in the most challenging water conditions.

Acknowledgement

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