Seven arsenic field test kits were evaluated for their ability to detect arsenic III, V, and a combination of species, and their performance was compared with that of graphite furnace atomic absorption spectrophotometry. Performance was evaluated for precision, accuracy, matrix effects, linearity, operator bias, and ease of use. Precision, determined by standard deviation, was relatively good for all test kits. However, accuracy, as calculated using percent recoveries, varied greatly among the test kits. Matrix effects were evaluated using known additions of sulfide and antimony in reagent water. Field samples were also tested at various arsenic concentrations to determine performance throughout the working range (linearity) of the test kits. Results indicated that two of the seven field test kits met acceptable criteria of accuracy, precision, linearity, expense, and ease of use as defined by the authors. Given the varied performance among the testing kits, the authors concluded that water professionals should be cautious in choosing field test kits for noncompliance analyses.

Evaluation of arsenic field test kits for drinking water analysis

BY J. MITCHELL SPEAR, YOU "MARK" ZHOU, CHARLES A. COLE, AND YUEFENG F. XIE

On Jan. 22, 2001, the US Environmental Protection Agency (USEPA) published the final Arsenic Rule, which specified an effective compliance date of Jan. 23, 2006 (USEPA, 2001). This rule lowers the maximum contaminant level (MCL) for arsenic from 50 to 10 µg/L. It is estimated that nearly 4,000 water utilities in the United States are affected, and about 97% of them are small public drinking water systems serving fewer than 10,000 people (Kommineni et al, 2002; Frey & Edwards, 1997). The USEPA also published best available technologies and small system compliance technologies (SSCT) to aid small water systems in complying with the new arsenic MCL of 10 µg/L. Under the SSCT, small water systems may choose point-of-use (POU) devices, including activated alumina, ion exchange, iron-based sorption media, or reverse osmosis. POU devices are often the most cost-effective systems for arsenic removal, especially for very small systems serving fewer than 200 connections (Kommineni et al, 2002). Although many POU devices have low capital costs and require little maintenance, monitoring their treatment effectiveness is a major obstacle.

Monitoring the treatment effectiveness of every customer's POU device with USEPA-approved analytical methods is cost-prohibitive and therefore unrealistic for small water systems. Commercial arsenic sample analysis generally costs between $15 and $50 per sample (Ray, 2002). USEPA-approved analytical methods require using instruments such as graphite furnace atomic absorption (GFAA), inductively coupled plasma–mass spectroscopy (ICP–MS), inductively coupled plasma–emissions spectroscopy (ICP–ES), or hydride generation atomic adsorption (HGAA; USEPA, 2001). Any water system that decides to purchase the ana-

TABLE 1 Groundwater characteristics

Constituent or Contaminant	Concentration
pH	8.4
Alkalinity	230 mg/L as $CaCO_3$
Calcium hardness	74 mg/L as $CaCO_3$
Total dissolved solids	448 mg/L
Fluoride	0.11 mg/L
Barium	0.0289 mg/L
Nitrate	3.6–5.1 mg/L
Arsenic	Nondetect
All other inorganic chemicals tested*	Nondetect

$CaCO_3$—calcium carbonate

*Cyanide, mercury, antimony, beryllium, cadmium, chromium, nickel, selenium, and thallium

lytical equipment and do its own in-house sample analysis rather than pay for external analysis will find that these instruments are expensive (between $30,000 and $150,000) and require a trained technician (McNeill et al, 2004). In addition to the greater cost of using a contracted laboratory, the lag time between sending the sample for analysis and receiving the results often makes it difficult for the water utility to test different arsenic removal strategies or determine the removal efficiencies of POU devices in a timely manner.

In response to the need for affordable, "quick, easy, and reliable" testing of arsenic, several field test kits have recently become commercially available for arsenic analysis. Many of these field kits are simple to use and do not require a skilled technician; several are relatively inexpensive (less than $5 per analysis). Because they are easy to use, relatively inexpensive, and portable for field use, test kits seem to be a probable alternative to expensive commercial analyses for routine operational (noncompliance) testing. However, most kits provide only discrete (noncontinuous) concentration values, and recently, the reliability of field test kits has been questioned. Many previously evaluated field kits produced weak correlations with approved analytical methods (Rahman et al, 2002). The objectives of this project were to evaluate seven commercially available field test kits and determine their reliability and applicability to water utilities currently using POU devices, utilities testing potential treatment strategies, or utilities simply interested in conducting noncompliance arsenic analysis on their raw and treated waters.

Point-of-use devices are often the most cost-effective systems for arsenic removal, especially for very small systems serving fewer than 200 connections.

EXPERIMENTAL METHODS

Test kits. This study evaluated seven commercially available field test kits: evaluated were the BVC,[1] ECO,[2] Hach,[3] LaMotte,[4] Merck,[5] Quick II,[6] and TraceDetect.[7] Two to four kits with different lot numbers were chosen for each product evaluated. The exception was the TraceDetect kit that uses anode stripping voltammetry (ASV), in which the same electrodes were used for the duration of the study.

Except for the TraceDetect kit, the six other test kits use similar chemistries of hydride generation as described in method 3114B (*Standard Methods*, 1998). These test kits reacted zinc dust in an acidified reaction vessel by addition of tartaric acid, sulfamic acid, or hydrochloric acid. This reaction converts the inorganic arsenic to arsine gas. The arsine gas reacts with a mercuric bromide test strip to form a yellow- to brown-colored mercury halogenated compound—AsH_2HgBr. The amount of arsine gas (AsH_3) generated increases with the concentration of arsenic in the sample. The mercuric bromide strip intensifies in color with increases of arsine gas, thereby quantifying the arsenic concentration in the sample. To determine the arsenic concentration, the color of the reacted test strips is compared against the specific incremental chart provided with each test kit. Test kit quantification was limited by the resolution of the comparative color chart and therefore provided semiquantitative concentrations. Variations among field test kits include possible chemical additions for catalytic properties and minimization of effects by potential interferences.

The TraceDetect kit used ASV in conjunction with microelectrodes. ASV has been tested by several researchers (Feeney & Kounaves, 2000; Huang & Dasgupta, 1999). The arsenic is reduced and collected on the working electrode and then stripped off (oxidized) and measured in a way similar to method 3130B (*Standard Methods*, 1998). ASV in conjunction with microelectrodes provides continuous data, although it requires a higher degree of analytical training.

Analyses. All analyses were conducted following test procedures provided with each test kit (i.e., reagent amounts,

TABLE 2 Major characteristics of the field test kits evaluated

Test Kit	Concentration Intervals *µg/L*	Number of Reagents	Test Time *min*	Sample Size Required *mL*	Unit Price* per Kit	Number of Samples per Kit (Cost* per Test)
BVC	10, 25, 50, 100, 500	2	13	10	$30.00	100 ($0.30)
ECO	25, 50, 100, 150, 200, 300, 500, 750	4	35	10	$36.00	100 ($0.36)
Hach	0, 10, 30, 50, 70, 300, 500	5	40	50	$106	100 ($1.06)
LaMotte	4, 6, 8, 10, 12, 14, 16, 18, 20, 30, 40, 50, 60, 70, 80, 100, 140, 160	3	16	250	$153.00	50 ($3.06)
Merck	0, 10, 25, 50, 100, 500	2	32	10	$69.60	100 ($0.70)
Quick II	1, 2, 2.5, 3, 4, 5, 6, 7, 10, 12, 14, 20, 30, >30, >40, >60, >80, >100	3	16	100	$219.99	50 ($4.40)
TraceDetect	Continuous	3	>10†	50	$12,500.00	5,000‡ ($2.50)

*Based on purchase in 2003–04.
†It takes approximately 45 min to build a calibration curve.
‡Assumes that with proper electrode usage and maintenance, 5,000 samples can be analyzed

time requirements, and temperature). However, no sample dilutions were performed on the waters tested. Additionally, all results were reported to the nearest concentration interval; no attempt was made to estimate a value between two of the provided concentration intervals. Any sample resulting in a color formation less than the lowest concentration interval was reported as zero. Results obtained from all test kits were compared with those obtained using method 7060A (GFAA; USEPA, 1994). This method was performed using GFAA spectroscopy.[8]

The method detection limit (MDL) for method 7060A and the TraceDetect kit using ASV was calculated using the following equation:

$$\text{MDL} = t_{(n-1,\ 1-\alpha=0.99)} \times \text{SD} \qquad (1)$$

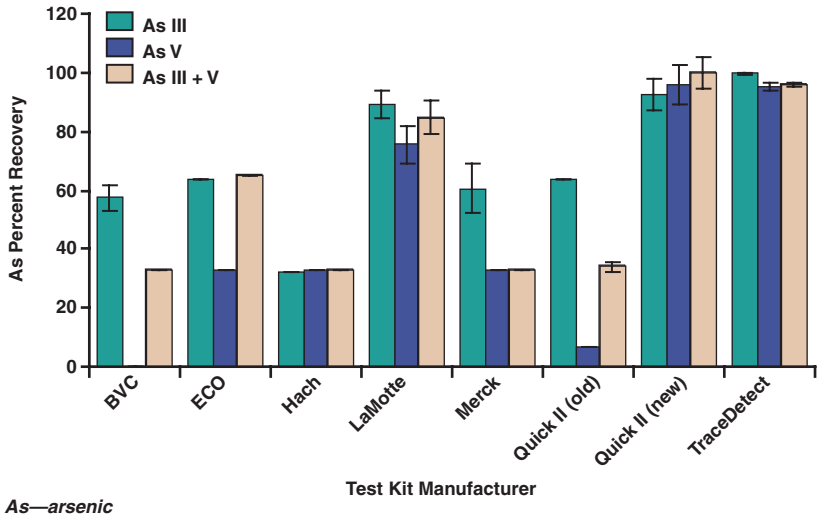
in which t is equal to the Student's t statistic for n–1 degrees of freedom at 99% confidence level and SD is equal to the standard deviation. For seven replicates, the t value was equal to 3.14.

Laboratory performance. Laboratory tests were conducted to determine the accuracy and precision of the test kits compared with known standard arsenic solutions in reagent water. A concentration of ~30 µg/L of arsenic was added to 18 megaohms of deionized reagent water.[9] The concentration of 30 µg/L was chosen on the basis of the following criteria: the value was near one of the incremental values provided by each of the kits and was greater than the 2006 enforceable MCL of 10 µg/L but less than the previous MCL of 50 µg/L. These criteria should provide information that will assist water utilities that are most affected by the current regulation. Additions of arsenic III, arsenic V, and a 1:1 combination of arsenic III and V were used to evaluate all test kits. Five to seven replicate tests were used to calculate accuracy (percent recoveries) and precision (standard deviation).

The objectives of this project were to evaluate seven commercially available field test kits and determine their reliability and applicability to water utilities currently using point-of-use devices, testing potential treatment strategies, or simply interested in conducting noncompliance arsenic analysis on their raw and treated waters.

Matrix interference and field performance. Matrix interference testing was determined by additions of known interference agents (antimony and sulfide). Antimony was evaluated at three concentrations (0.25, 1.0, and 5.0 mg/L) spiked into the reagent water using standard antimony solution (1,000 µg/mL in 2% nitric acid) containing approximately 30 µg/L of arsenic. Effects of 0.5, 5.0, and 10 mg/L of sulfide on arsenic analysis were evaluated by adding sodium sulfide. In addition, controls (no antimony or sulfide additions) were used for comparison. All levels were tested in duplicate at least. Performance was determined by measuring percent recoveries. In addi-

FIGURE 1 Percent recoveries of arsenic field test kits in reagent water



As—arsenic

Standard deviations are indicated by error bars.

tion, field performance testing consisted of spiking arsenic III and V (1:1) at concentrations of 5, 10, 25, 50, and 75 µg/L into a local groundwater sample. Water quality characteristics are listed in Table 1. Linear regression was used to compare test kit results with those obtained using method 7060A (USEPA, 1994).

Operator performance and ease of use. Operator bias was determined by comparing the results obtained by four operators. The results of one operator were compared against the results of the other operators, using a protocol similar to that described by Schock and George (1993). Each operator was given a large sample of known concentration. Smaller aliquots were taken from these samples and analyzed by each operator. The first operator, designated operator 1, was experienced in the use of the test kits, having performed many analyses using them before the comparison. Operators 2, 3, and 4 had not used the test kits before the comparison. Ease of use was calculated by having each operator rate the test kit on a scale of 1–10. The operators determined the score of the test kits using the following criteria: ease of following the instructions provided, method of chemical additions, operation of the testing apparatus (i.e., sample bottles and caps), and ease of interpreting the results (comparison of test sample to the color chart). A score of 10 indicated the test kit had a high ease of use, and a score of 1 indicated difficulty and the need for additional training. Because no interpretation was required in the method using ASV, no attempt was made to determine operator bias for the TraceDetect kit. Ease of interpreting the results was excluded from the calculation of the ease-of-use score.

RESULTS AND DISCUSSION

General characteristics. Concentration intervals provided by each test kit ranged from five intervals to continuous data (Table 2). Sample sizes ranged from 10 to 250 mL, and the number of chemical reagents required ranged from two to five additions among field test kits (Table 2). Analysis time varied from 13 to 40 min (Table 2). The number of samples each test kit could perform was 50 or 100 for five of the seven test kits evaluated. However, the TraceDetect kit using ASV was dependent on the life of the electrodes, which determines the total number of samples that can be analyzed. Costs ranged from $0.30 to $4.40 per analysis (Table 2).

Laboratory performance. The relative standard deviation was <3% for all measurements obtained by method 7060A, and the standard deviation was calculated at 0.49 µg/L. The calculated MDL was equal to 1.9 µg/L. Because six of the testing kits being evaluated provided discrete (noncontinuous) concentration values, standard deviations and MDLs could not be determined in the traditional sense; however, standard deviation was calculated using the incremental data. Limited conclusions should be based on this calculation, because the value

TABLE 3 Operator bias

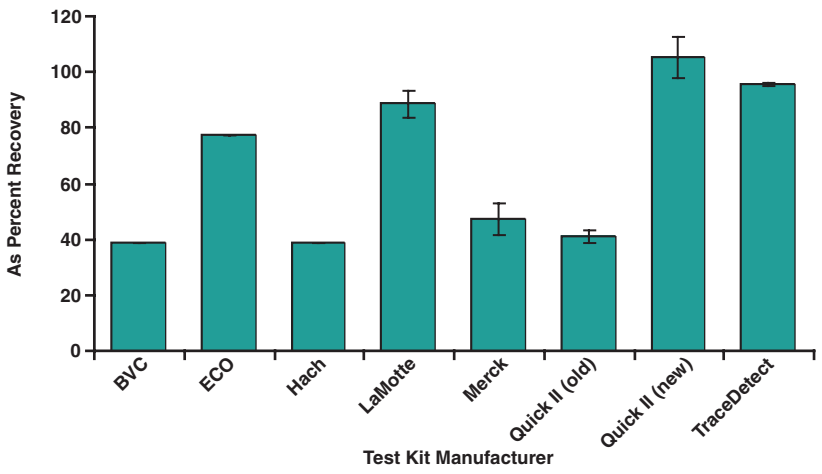
Test Kit	Operator Number	Slope (Intercept)	Correlation Coefficient*
BVC	Operator 4	0.87 (0.0)	0.897
ECO	Operator 4	0.99 (–1.6)	0.905
Hach	Operator 2	0.84 (2.44)	0.829
LaMotte	Operator 3	1.0 (0.77)	0.890
Merck	Operator 3	0.47 (4.9)	0.689
Quick II	Operator 2	0.90 (1.0)	0.873

*Significant to the 0.01 α level

is largely dependent on how close in concentration the next greater or lower value appears on each test kit's comparison chart. No attempt was made to calculate the MDL.

Percent differences obtained between the test kits and method 7060A were chosen to indicate the accuracy of the test kits (Figure 1). Standard deviation calculated for each test kit was chosen to signify the overall precision. Because the TraceDetect kit using ASV provided continuous data, the authors were able to calculate the MDL. The relative standard deviation was <5% for all measurements, and standard deviation was equal to 0.65 µg/L, corresponding to an MDL value of 2.1 µg/L. This value was similar to the calculated MDL using GFAA.

FIGURE 2 Recovery of arsenic using field test kits and a field water source



As—arsenic

Standard deviations are indicated by error bars.

Percent recoveries on test kits ranged from 33.3 to 105% for arsenic III spiked into reagent water at a level of 31.4 µg/L (Figure 1). Percent recoveries ranged from 33.3 to 97.3% for arsenic V spiked at a level of 30.7 µg/L (Figure 1). Similar recoveries (33.3 to 100%) were achieved using a combination of arsenic III and V (1:1; Figure 1). No determination was made for the arsenic V for the BVC field kit because the method is for determination of arsenic III only. Determination for the combination of arsenic III and V was approximately half the recovery for the arsenic III addition alone (Figure 1). This seemed to verify that the BVC kit was measuring only the arsenic III, which was half the amount in the arsenic III and V combination addition as in the arsenic III addition alone.

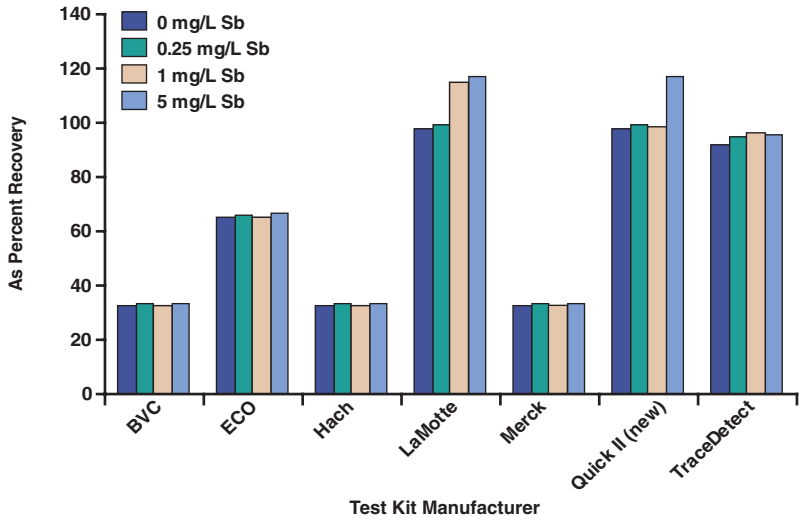
All test kits had a standard deviation of <10 µg/L, with many having a standard deviation of zero, thus indicating a high level of precision. This also suggests the five to seven replicates chosen in this study were sufficient to determine the percent recovery values. It has been suggested that to obtain the most accurate results, samples be determined in triplicate whenever possible (Schock & George, 1993). When few replicates are used, the median value that can eliminate either extremely high or low values is often the better predictor of the actual concentration when compared with the arithmetic mean (Dean & Dixon, 1951). However, mean values were used in this study's calculations because no extremely low or high values were obtained, as indicated by the low standard deviations.

As shown in Figure 1, the Quick II field kits designated "old" and "new" demonstrated significant differences in recoveries. After the authors communicated the poor testing results to the manufacturer, the manufacturer recalled the test strips of mercuric bromide. The old packaging had an inadequate polyethylene lining that permitted a reaction between the mercuric bromide and the aluminum foil packaging, causing poor recoveries. The new strips dramatically improved the performance of the product. Percent recoveries increased from 64 to 94% for arsenic III, from 7 to 96% for arsenic V, and from 34 to 100% for the arsenic III and V addition (Figure 1).

One item not addressed was the waste generated and the health concerns associated with conducting these analyses.

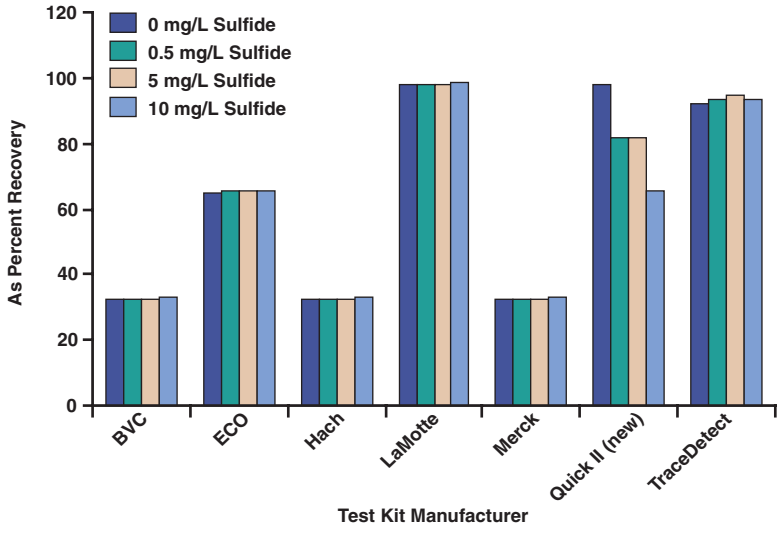
Matrix interference and field performance. Figure 2 shows the results of the field testing. Percent recoveries and standard deviations were similar to those using reagent water, with recoveries ranging from 38.8 to 105% (Figure 2) compared with 33.3 to 105% for the reagent water (Figure 1). Standard deviation ranged from 0 to 7.2 µg/L for seven replicates on each test kit. As in the laboratory testing, similar improvement was observed in the field testing for the old Quick II field kit versus the new one, with recovery increasing from 41 to 105% for this test (Figure 2).

FIGURE 3 Arsenic recovery with several concentrations of interference agent antimony



As—arsenic, Sb—antimony

FIGURE 4 Arsenic recovery with several concentration levels of interference agent sulfide



As—arsenic

Matrix interference results are shown in Figures 3 and 4. Antimony would rarely be found in the levels tested, given that antimony concentrations in the majority of US drinking waters have been found to be <1.5 µg/L (Frey & Edwards, 1997); nonetheless this research evaluated levels up to 5.0 mg/L.

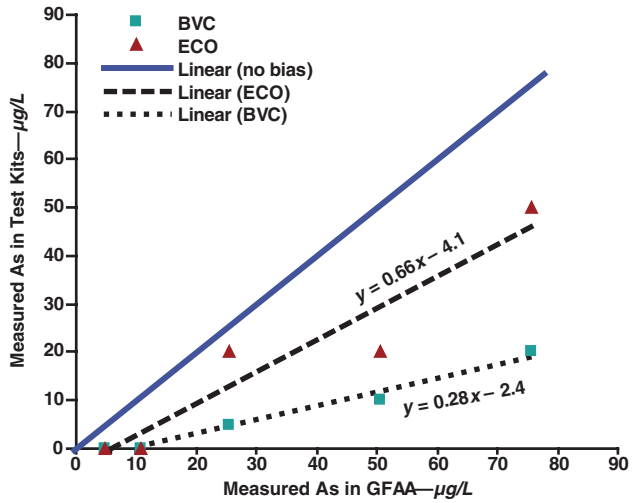
Recoveries did not seem to be additionally compromised in the presence of antimony in the concentration range of 0.0 to 5.0 mg/L (Figure 3). For all but the LaMotte and Quick II test kits, percent recoveries were less than ±5% different in the control sample (0.0 mg/L of antimony) compared with the highest concentration addition (5.0 mg/L) (Figure 3). The LaMotte test kit results indicated a positive interference (approximately 16 to 20% higher recovery) in the levels of 1.0- and 5.0-mg/L antimony additions. The Quick II test kit results indicated a positive interference (approximately 20%) in the 5.0-mg/L antimony addition. Sulfides did not appear to influence the percent recoveries for six of the seven test kits in the range of 0.0 to 10.0 mg/L (Figure 4). Increase in sulfide concentrations, however, did seem to reduce the percent recovery in the Quick II test kit from 98% in the 0.0-mg/L sulfide addition to 66% in the 10.0-mg/L sulfide addition. However, concentrations of hydrogen sulfides at the levels tested would not be common for drinking waters (McNeill et al, 2004).

In addition to the interference study and the 30-µg/L spiked field samples, test kits were evaluated at several additional concentrations. A combination of arsenic III and V (1:1) was spiked into finished groundwater (Table 1) at 5, 10, 25, 50, and 75 µg/L to determine the performance of the test kits through the working range of their calibration (linearity). The values obtained by the test kits were plotted against the actual values, as determined by method 7060A (Figures 5–8). Test kit response curves were plotted with the following equation:

$$y = mx + b \qquad (2)$$

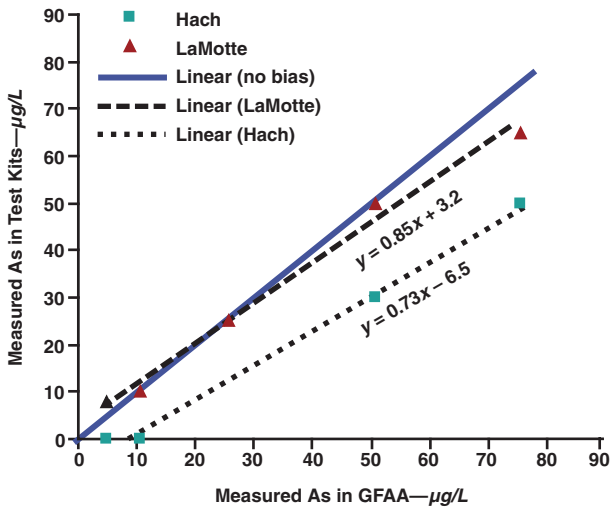
in which m is the slope or test kit response and b is the y-intercept. Slopes close to 1.0 with a zero intercept indicate no bias, whereas slopes much less than 1.0 with an intercept of zero indicate the potential of a negative bias (sample results lower than the actual concentration) in the higher range of the test kit. Slopes greater than 1.0 with a zero intercept indicate the potential of a positive bias in the higher concentrations. A slope equal to or near 1.0 and with a negative y-intercept indicates an equal negative bias throughout the range of the test kit. Therefore, a positive intercept and slope near 1.0 indicates a positive

FIGURE 5 Comparison of analytical results from the BVC and ECO test kit with GFAA results



As—arsenic, GFAA—graphite furnace atomic absorption

FIGURE 6 Comparison of analytical results from the Hach and LaMotte test kit with GFAA results



As—arsenic, GFAA—graphite furnace atomic absorption

bias throughout the range of the test kit. Only three test kits demonstrated both a slope near 1.0 and an intercept close to zero (Figures 5–8). The TraceDetect, LaMotte, and Quick II kits had calculated slopes near 1.0 (0.900, 0.848, and 0.770, respectively) and intercepts less than ±2.0.

Two manufacturers suggest making sample dilutions if the arsenic is above a certain concentration. Ideally, the sample dilution would achieve an arsenic concentration in a portion of the color comparison chart that has the most intervals per change in concentration. Had the authors followed this suggestion, the difference between the tested and the actual concentration might have been closer in the higher concentration portions of the curves for these two field test kits. However, in order to achieve consistency in the evaluation among field test kits, no dilutions were performed.

Operator performance and ease of use. As explained previously, no attempt was made to determine operator bias for the TraceDetect kit. The other six kits showed strong correlations among operators (Table 3). Correlation coefficients ranged from 0.69 to 0.91. Slopes among operators ranged from 1.0 to 0.47 (Table 3). Five of the six field kits had slopes and correlation coefficients > 0.80. Only the Merck kit—with a value of 0.47—had a slope that deviated greatly from 1.0. However, this likely was caused by the relatively low recoveries found throughout the range of samples tested. The number of samples ranged from 11 to 21.

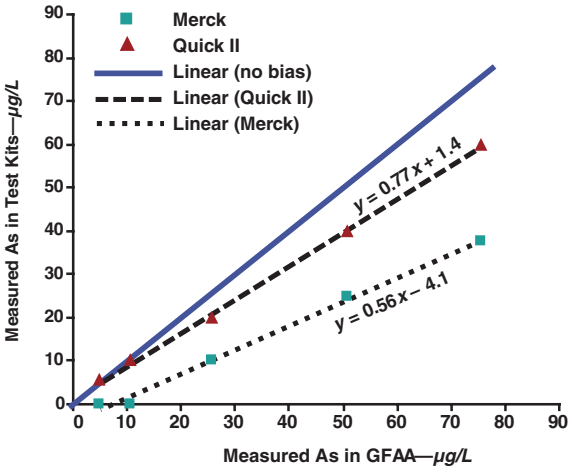
On a 1–10 scale, with 10 being the easiest to use, ease-of-use scores ranged from 2.3 to 8.4, and standard deviation was < 1.0 for all kits (Figure 9). The Hach, LaMotte, Merck, and Quick II kits all scored significantly higher (α < 5%) than the other three kits (Figure 9), indicating that they were easier to use relative to the other field test kits evaluated. Significant differences are indicated by different letters. For example, test kits with a letter "b" are significantly different from test kits with either a letter "a" or "c."

OTHER CONSIDERATIONS

Comparison with previous studies. Results of previous studies have shown poor correlations of arsenic test kits with USEPA-approved methods (McNeill et al, 2004; Rahman et al, 2002). One study evaluated three field test kits; however none of the kits provided a concentration interval below the 10-µg/L level. The second study evaluated three field kits. However, one of the test kits was eliminated in the evaluation because the lowest color interval was 100 µg/L. Only one of the remaining two test kits had arsenic concentrations < 10 µg/L. This kit produced most of the results with 5 µg/L of the actual sample concentration, the lowest concentration value provided with the field test kit color chart (McNeill et al, 2004). The results of the current study appear consistent with these previous studies evaluating field test kits with higher detection levels (above 10 µg/ L) and a limited number of intervals on the color charts. However, those field test kits that have generated color charts with more resolution (more color intervals) and lower detection limits seem to provide accurate results.

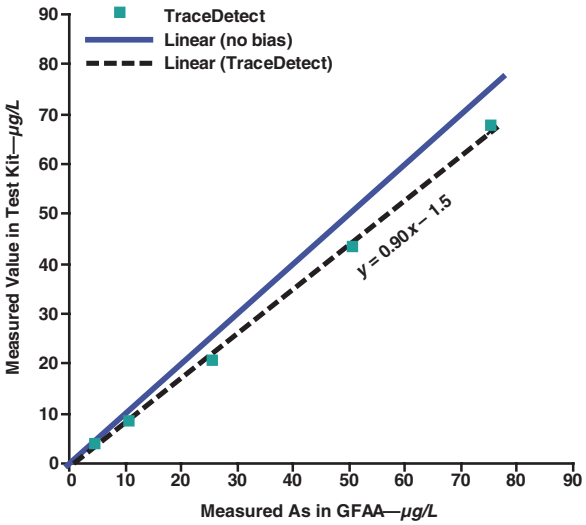
For the purpose of noncompliance testing of arsenic in water systems, the authors suggest that kits must be able to test below the 10-µg/L level and have several concentration intervals (at least eight) between 20 and 0 µg/L. This is particularly useful in testing the removal efficiencies of dif-

FIGURE 7 Comparison of analytical results from the Merck and Quick II test kit with GFAA results



As—arsenic, GFAA—graphite furnace atomic absorption

FIGURE 8 Comparison of analytical results from the TraceDetect test kit with GFAA results



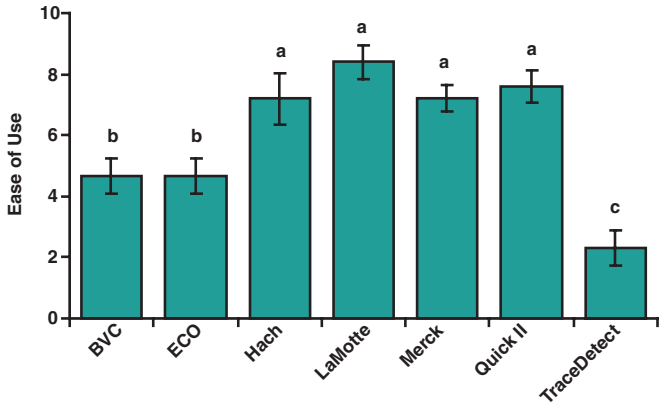
As—arsenic, GFAA—graphite furnace atomic absorption

ferent POU devices on raw water. It may also be useful for developing correlations between arsenic concentrations in the treated water and a reliable surrogate. One such surrogate is the use of monitoring conductivity to determine removal efficiency in reverse osmosis devices. On the basis of results from the current evaluation, the LaMotte test kit was used to test the effluent from an arsenic adsorption media POU study and compared with GFAA. All 115 effluent samples measured by the test kit were lower than the lowest color interval provided (4 µg/L) and reported as "nondetectable," consistent with the results from the GFAA.

One item not addressed was the waste generated and the health concerns associated with conducting these analyses. Most of these field test kits generate wastes of the following chemicals: hydrochloric acid, zinc, potassium iodide, stannous chloride, and mercuric bromide. Of these wastes, the mercuric bromide test strips are the most difficult to address because they cannot be disposed of in general waste. Of possible greater concern for those test kits that use chemistries similar to standard method 3114B is the gas that is generated during the analysis. This gas may be dangerous to the analyst if a large number of samples are performed in a poorly ventilated area (Rahman et al, 2002; Hussam et al, 1999).

Despite these concerns, field test kits seem to be a likely choice for many water utilities conducting noncompliance sampling. If the correct field kit is chosen and properly used, it can offer a low-cost approach to providing the water utility and operator with useful information on arsenic concentration.

FIGURE 9 Results for field test kit ease of use



10 indicates greatest ease, zero indicates greatest difficulty.

Letters within the figure indicate significant differences among the types of test kits.

CONCLUSIONS

Results from this study suggest that three of the seven field test kits assessed produce reliable results and could be used for noncompliance sampling in drinking water. The water utility should first evaluate the expected range of arsenic concentration of the system before determining which test kit is best suited to its needs. The authors suggest that the LaMotte and the Quick II kits will be most applicable for water utilities having a raw water arsenic concentration < 100 µg/L. The TraceDetect kit performed very well, but

because of the high initial cost, it is most applicable in medium-to-large water utilities that have both the capital to purchase the instrument and a greater number of samples to analyze (which would reduce the cost per sample). Additionally, this field kit is also appropriate for contracted vendors responsible for monitoring the influent and effluent arsenic concentrations of POU devices.

The results obtained in this study can help water systems make educated decisions in choosing the appropriate field test kit for conducting routine (noncompliance) arsenic analysis. This in turn will aid them in complying with the Arsenic Rule. Study results may also be used by the test kit manufacturers to improve their products. One manufacturer changed the packaging of its test strips during the study, which significantly improved the test kit's results.

ACKNOWLEDGMENT

The authors acknowledge the US Environmental Protection Agency's Small Public Water Systems Technology Assistance Center Grant for funding this project. The authors also thank TraceDetect (Seattle, Wash.) for loan of the Nano-Band™ Explorer and Industrial Test Systems Inc. (Rock Hill, S.C.) for donation of one of the Quick II field test kits evaluated. This article represents the view of the authors and does not constitute endorsement or recommendation for use by the funding agency.

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FOOTNOTES

[1]BVC-100, Asian Arsenic Network, Fukuoka, Japan
[2]ECO-W100, Asian Arsenic Network, Fukuoka, Japan
[3]Hach Co., Loveland, Colo.
[4]LaMotte, Chestertown, Md.
[5]Merck and Company Inc., Whitehouse Station, N.J.
[6]Quick II, Industrial Test Systems, Inc., Rock Hill, S.C.
[7]TraceDetect Nano-Band™ Explorer, TraceDetect, Seattle, Wash.
[8]5100 PC/HGA 600, PerkinElmer, Shelton, Conn.
[9]Barnstead Nanopure™, Barnstead International, Dubuque, Iowa

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