

Evaluation of digital camera as a portable colorimetric sensor for low-cost determination of inorganic arsenic (III) in industrial wastewaters by chemical hydride generation assisted-Fe(III) – 1, 10-phenanthroline as a green color agent

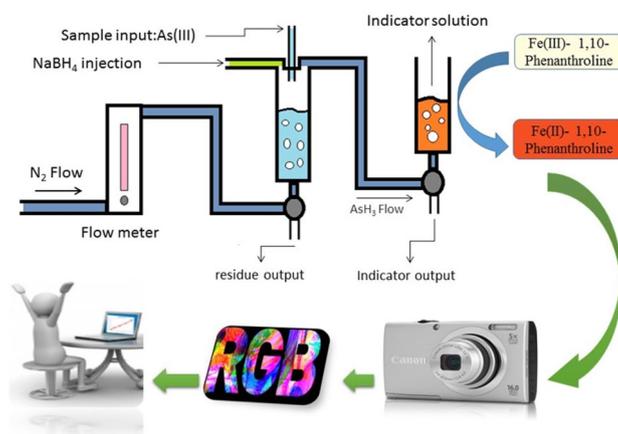
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Abstract

This research presents a novel, simple and green method for colorimetric determination of As(III) using a digital camera as the colorimeter. It is based on chemical hydride generation of arsine (AsH_3) from acidic solution of As(III) by NaBH_4 as well as the sequential reaction of arsine with Fe(III)-1,10-phenanthroline solution that produces red complex of Fe(II)-1,10-phenanthroline. The intensity of color red is related to the concentration of As(III) and acquired by image processing—Image J—software. To achieve the best sensitivity, we investigated the changes of RGB value in terms of red color intensity of the complex. Blue was the best as it showed the highest sensitivity. Under optimized conditions, the calibration curve was linear in the range of $1\text{--}25\ \mu\text{g mL}^{-1}$ for As(III) and detection limit was $0.392\ \mu\text{g mL}^{-1}$. The relative standard deviation (RSD) for five replicate measurements of $10, 15, 20\ \mu\text{g mL}^{-1}$ of As(III) were 0.89, 2.43 and 3.08%, respectively. The proposed method was successfully used to determine As(III) in the industrial wastewater using standard addition method. The desirable recovery values (96–109%) indicate applicability of the proposed method for determination of As(III) in a complex matrix, such as industrial samples, in the presence of several unknown interferences without the need for any sample preparation.

Graphical abstract



Keywords Compact digital camera · Colorimetry · As(III) · Hydride generation · Industrial waste waters

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Introduction

Arsenic is a highly toxic element found in ground or industrial wastewaters, which has adverse effect on human health leading to disease such as bladder illness, lung and skin cancer, skin hyperkeratosis, skin pigmentation, etc [1, 2]. Arsenic is found in several chemical forms which its mobility and toxicity depending on its oxidation states [1, 3]. As(III) and As(V) are common forms of inorganic arsenic in the natural environments and As(III) is reported to be 25–60 times more toxic than As(V) [4]. It indicates the vital importance of As(III) determination. Hydride generation (HG) is a well-known technique for determination of As in a wide range of samples [5–8]. There are a number of analytical techniques based on the HG for As determination, such as atomic absorption spectrometry [9, 10], atomic emission spectrometry [11], atomic fluorescence spectrometry [12, 13], ICP—mass spectrometry [14], gas diffusion flow injection with electrochemical detection [15] and spectrophotometric method [1, 5]. There are several combinations of classical spectrophotometric methods and HG for determination of As. Most of these methods are based on the reaction of arsine (AsH_3) with silver diethyldithiocarbamate (SDDC) in an organic base—chloroform (or CCl_4) solution [16–19]. These colorimetric methods have a number of advantages such as desirable detection limit, common reagents and lack of any important challenges, but have some main disadvantages including expensive tools, need for an expert operator and use of toxic materials like chloroform, SDDC, pyridine and so forth as indicator and solvent that can cause disease in operators and leave negative effect on the environment.

In recent years, popular communications and IT equipment (mobile phones, digital cameras, scanners, webcams, etc.) have been developed as detection devices for colorimetric analysis [20–28]. A digital image consists of many pixels with each pixel being formed by three basic colors (red, green, and blue), which are abbreviated as “RGB”. In camera-based colorimetric analysis, can apply color intensity instead of absorbance as the analytical signal using image processing tools. Image processing software such as Image J and Matlab integrated with image processing tool box—software [29, 30] can easily extract the intensity of basic color (RGB) for desired pixels.

This study explains a novel, simple and green method for colorimetric determination of As(III) in a complex matrix using a digital camera as the colorimeter. It is based on chemical hydride generation of arsine (AsH_3) from acidic solution of As(III) by NaBH_4 and sequential reaction of arsine with Fe(III)-1,10-phenanthroline solution that produces red complex of Fe(II)-1,10-phenanthroline. The intensity of the red color is related to the

concentration of As(III) and extracted by image processing—Image J—software. To the best of our knowledge, it is the first study to apply Fe(III)-1,10-phenanthroline solution for determination of As(III) using a combination of colorimetric method and hydride generation technique.

The proposed method was successfully applied for determination of As(III) in industrial wastewaters.

Experimental

Apparatus

Analytical system

A schematic diagram of the analytical system is shown in Fig. 1 [5]. This system consists of a hydride generator and a simple arsine trapping tube. Arsine gas generated in the hydride generator is carried into the indicator solution along with nitrogen gas flow. All colorimetric measurements were performed with a Canon A2400 IS compact digital camera in the colorimetric analyzer box. Image J—software was used for image processing.

Colorimetric analyzer box

The colorimetric analyzer box (Fig. 2) was made from a polystyrene foam box. Dimensions of the box (width \times length \times height) are as follow: outside $18 \times 28 \times 23$ cm and inside $17 \times 27.5 \times 22.5$ cm.

The box interior was covered with two layers of white paper to enhance image quality and reduce noise. Three blue LEDs, as the light sources, were mounted on the box wall on the top of camera. A digital camera was installed in front of the near the center position of the box.

Reagents and solutions

All chemicals used in the experiments were of the analytical grade and used without further purification. All solutions were prepared by doubly distilled water. Stock solution (1000 g/L) of As(III) was prepared by dissolving 0.1320 g of As_2O_3 (Merck) in 10 mL of 1 mol L^{-1} NaOH (Merck) and diluting to 100 mL with doubly distilled water. Fe(III) stock solution (0.025 mol L^{-1}) was prepared by dissolving 1.2100 g of $\text{NH}_4\text{Fe}(\text{SO}_4)_2 \cdot 12 \text{ H}_2\text{O}$ in 2 mL of concentrated sulfuric acid and diluting to 100 mL with doubly distilled water. 1,10-phenanthroline stock solution (0.1 mol L^{-1}) was prepared by dissolving 0.1982 g of 1,10-phenanthroline monohydrate in 10 mL absolute ethanol. This solution must be stored in refrigerator at 8°C . The NaBH_4 solution was prepared daily as 0.5% (m/v)

Fig. 1 The schematic diagram of the analytical system: **a** flow meter; **b** hydride generator flask; **c** three-way valve; **d** absorber tube; **e** three-way valve; **f** indicator input; **g** washing water input

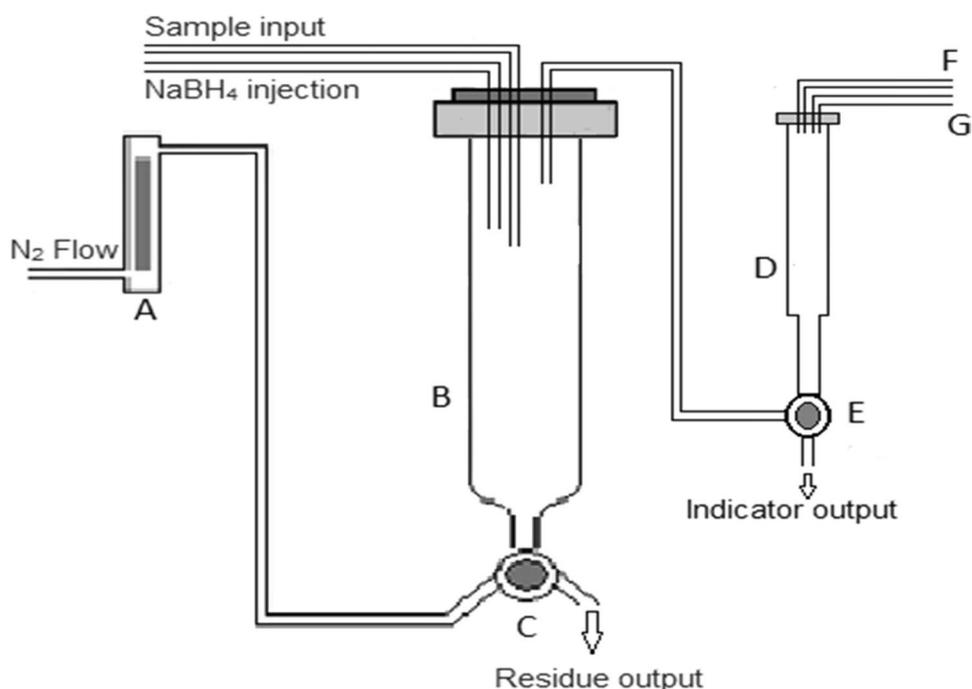
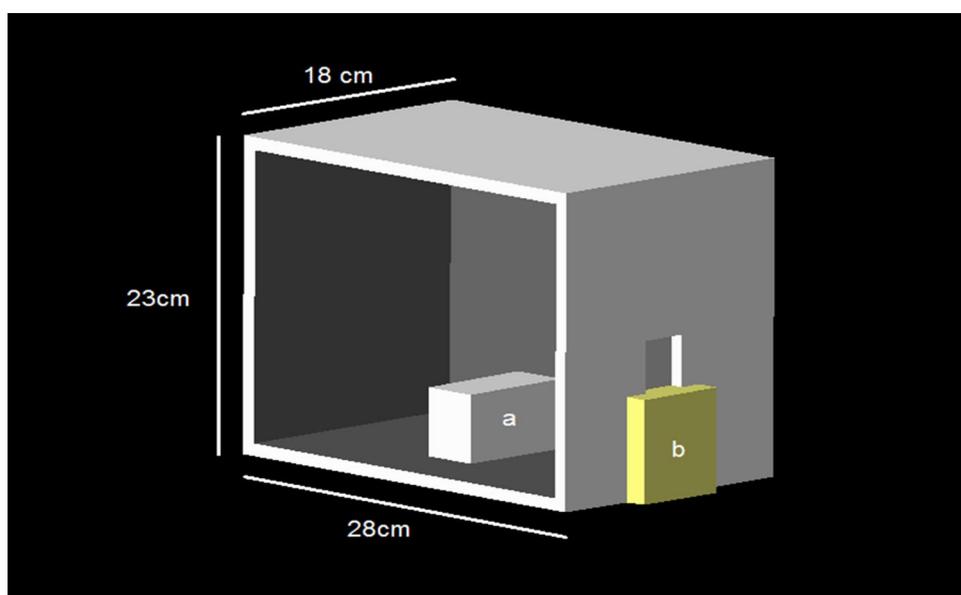


Fig. 2 The schematic diagram of the colorimetric analyzer box: **a** sample location; **b** camera location



solution in 0.05 mol L^{-1} NaOH. The working solutions were prepared freshly by appropriate dilution of the stock solutions.

Indicator solution was prepared daily by mixing 15 mL absolute ethanol, 2 mL Fe(III) stock solution, 1.6 mL 1,10-phenanthroline stock solution and 5 mL water in a 50 mL volumetric flask, which was diluted to 50 mL by doubly distilled water after 15 min. This indicator solution should be used after 2 h to achieve stable condition.

Procedure

10 mL of sample or standard solution of As(III) containing sulfuric acid (1.5 mol L^{-1}) was transferred to the hydride generator flask. The absorber tube was filled with 4 mL of indicator solution. Then, 4 mL of 0.5% (m/v) NaBH_4 was injected into the hydride generator. The arsine derived from As(III) was purged by a stream of N_2 gas at a flow rate of 20 mL/min and transferred to the absorber tube, in which

arsine reacted with Fe(III)-1,10-phenanthroline complex which produced red complex of Fe(II)-1,10-phenanthroline. After 15 min, the indicator solution was transferred to the crystal glass bottle (diameter 2 cm) which was then placed carefully in the colorimetric analyzer box beside the glass bottle containing the blank (4 mL of indicator solution without arsine reaction). Images were taken and quantitative changes of blue color intensity between the sample and the blank were monitored using Image J-software.

Preparation of real sample

A wide range of disturbance can be eliminated with the application of hydride generation (HG) technique, but for achieve optimum results in analysis of real sample (industrial wastewater), following technique is suggested by authors.

A simple paper filtration can be used to remove particulate matter and sludge, and Chelex 100 resin can be applied to remove transition metal ions [5].

Results and discussion

Chemical hydride generation (HG) technique is widely used for determination of As(III) in a variety of matrices, especially in water samples [18, 31]. Professional instruments such as atomic absorption spectrometry, atomic emission spectrometry and atomic fluorescence spectrometry are usually employed as detector, but spectrophotometer followed reaction of AsH₃ with proper coloring agent provides an appropriate and convenient means for colorimetric analysis of Arsenic. This study is based on chemical hydride generation of arsine (AsH₃) from acidic solution of As(III) by NaBH₄ and subsequent reaction of arsine with Fe(III)-1,10-phenanthroline solution, which produces red complex of Fe(II)-1,10-phenanthroline. The

intensity of colored reagent was measured by a colorimetric analyzer applied to the compact digital camera. The RGB color system of an image was then investigated for colorimetric determination of As(III). Image J-software was employed to extract four parameters of R, G, B and RGB_{average} from each image.

The effect of various experimental conditions including the proposed colorimetric system and hydride generation process were studied and optimized.

Evaluation of the basic colors (red or green or blue) as analytical signal

For achieve to the best analytical signal with the aim of monitoring indicator color conversion, we investigated changes of RGB value in terms of red color intensity of Fe(II)-1,10-phenanthroline complex under different ambient lights where white, red, green, and blue LEDs were used as the source of light. As shown in Fig. 3, blue color in the blue ambient light reveals the highest response. Additionally, as depicted in Fig. 4, blue color yielded the sensitive signal.

Thus, we used three blue LEDs as the source of light in subsequent investigations. Three LEDs caused adequate intensity of the light in the light box.

Analytical response selection

To obtain the suitable analytical response, some method was investigated. The best analytical response (highest and most sensitive) was difference between *B* value derived from indicator solution of sample [containing As(III)] and *B* value derived from indicator solution of control sample (blank).

Response (AU) = $\Delta B = \text{blue intensity}_{(\text{blank})} - \text{blue intensity}_{(\text{sample})}$.

Fig. 3 Monitoring of the indicator color conversion with different ambient light. Blue signal in the blue ambient light, indicates highest response. Conditions: As(III), 20 $\mu\text{g mL}^{-1}$; all other conditions are as in Table 1

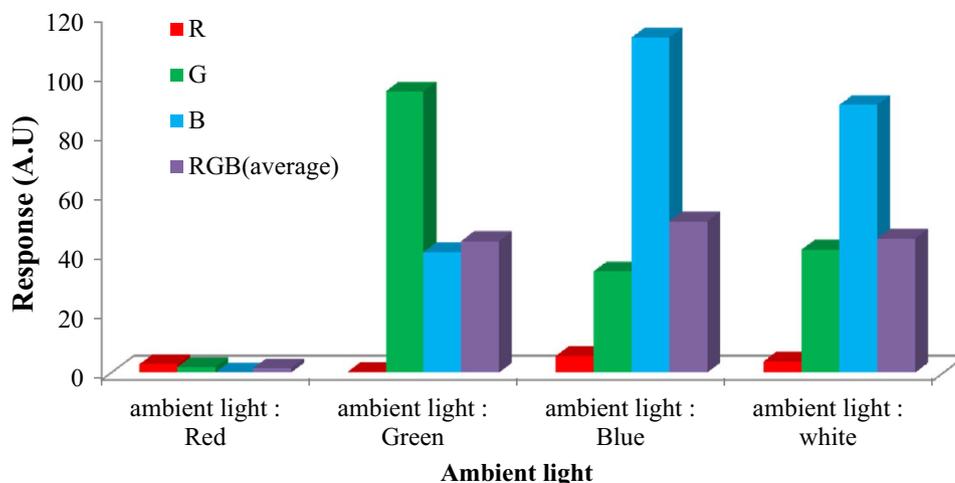
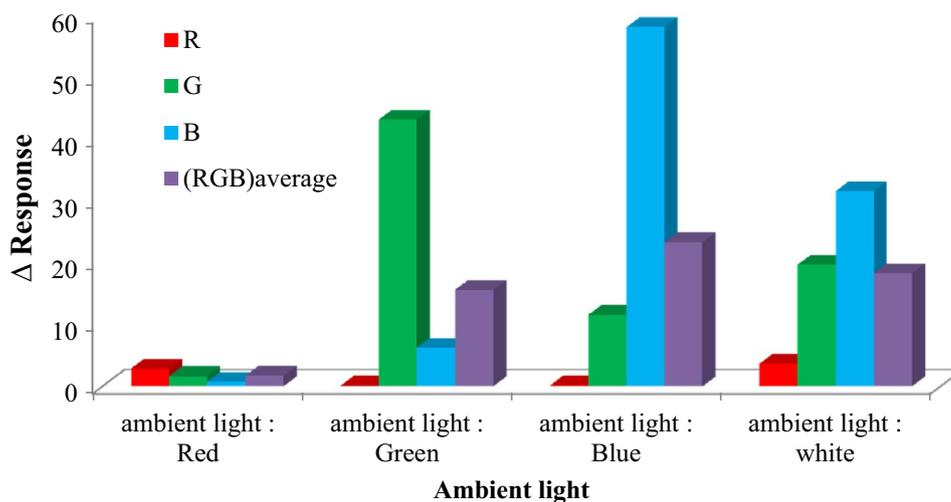


Fig. 4 Δ Response between low concentration of As(III), 10 and 20 $\mu\text{g mL}^{-1}$, as seen in the figure blue signal in the blue ambient light was the best sensitive signal. Conditions: all conditions are as in Table 1



Reaction of AsH_3 and coloring agent

The colorimetric methods used for determination of As by conventional HG involves the trapping of generated Arsenic in an absorbing medium containing colorimetric agent (indicator) and other species to increase the efficiency of Arsenic trapping and/or catalysis of the indicator reaction. Given the reduced properties of AsH_3 [5, 16, 18, 19], the reaction of Arsenic with redox indicators could be used for colorimetric determination of As. Fe(III)-1,10-phenanthroline complex is an inexpensive, common and rather nontoxic indicator that can be used as the redox indicator [32–34]. When Fe(III)-1,10-phenanthroline complex is completely reduced by Arsenic, it becomes red as a result of Fe(II)-1,10-phenanthroline generation. The measured complex color intensity is proportional to the concentration of As(III). The preliminary examination shows that in low concentration of Fe(III)-1,10-phenanthroline complex, the color intensity change is not desirable and in high concentration of the complex, the indicator solution is not stable. Thus, $10^{-3} \text{ mol L}^{-1}$ concentration of Fe(III)-1,10-phenanthroline complex was selected for subsequent studies. Since arsenic has low solubility in aqueous solution [5, 15], the addition of different surfactants such as nonionic surfactant (TritonX-100) and anionic surfactant (sodium dodecyl sulfate) to increase the solubility of arsenic in the aqueous indicator solution did not have any positive effects, causing a troublesome foaming and insoluble precipitate. Ethanol can also increase the solubility of arsenic in the aqueous solution [5, 35]. In this work, after addition of ethanol to the indicator solution, a significant color change increase was observed. However, there are serious limitations about ethanol addition. Large amount of ethanol can reduce the Fe(III)-1,10-phenanthroline complex to Fe(II)-1,10-phenanthroline red complex.

Effect of ethanol concentration

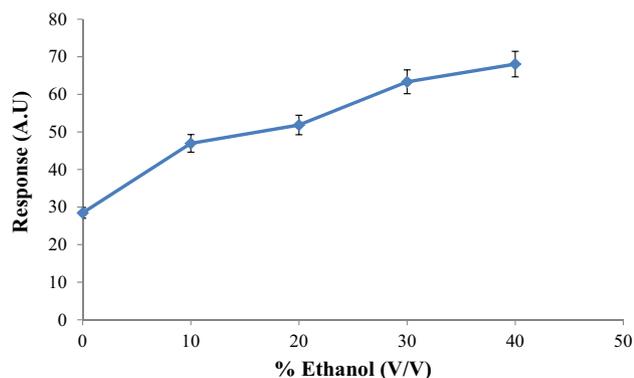
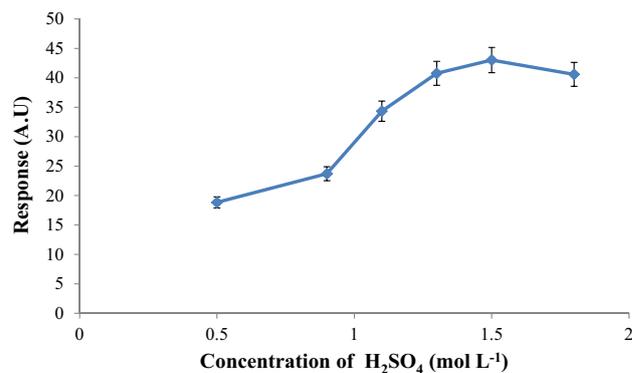
Ethanol concentration can affect the blank and sample measurements because excessive ethanol can lead to adverse reactions between ethanol and Fe(III)-1,10-phenanthroline complex and the production of Fe(II)-1,10-phenanthroline red complex, so that the indicator solution no longer can be used because of its instability over time. We studied the effect of ethanol concentration on the stability of indicator solution. For this purpose, we made a number of indicator solutions with different ethanol values (v/v) and studied spontaneity change of color over time. We observed that an indicator solution containing 30% (v/v) of ethanol was stable up to 5 h. As shown in Fig. 5, with an increase in ethanol volume fraction, the response is increased but for amounts greater than 30% (v/v) ethanol, the indicator solution becomes unstable. Therefore, we used 30% (v/v) ethanol in the indicator solution.

Effect of Fe(III)-1,10-phenanthroline concentration

Fe(III)-1,10-phenanthroline concentration can affect the responses of blank and sample. According to preliminary studies, ΔB value for blank analysis was nearly zero up to 0.001 mol L^{-1} of Fe(III)-1,10-phenanthroline complex—and it soared with an increase in Fe(III)-1,10-phenanthroline complex concentration, that indicates ethanol can reduce Fe(III)-1,10-phenanthroline to Fe(II)-1,10-phenanthroline complex [36–38]. Accordingly, the effect of Fe(III)-1,10-phenanthroline complex concentration in the range of $0.0005\text{--}0.002 \text{ mol L}^{-1}$ was studied. According to the results, the maximum sensitivity and stability was obtained at 0.001 mol L^{-1} Fe(III)-1,10-phenanthroline complex, so this concentration was selected for further studies.

Table 1 The optimized conditions

Parameters	Studied range	Selected condition
Best signal of light	Red, green, blue	Blue
Source of light	Red, green and blue LED	Three blue LED
Ethanol concentration % (v/v)	0–40	30
Fe (III)-1,10-phenanthroline concentration (mol L ⁻¹)	0.0005–0.002	0.001
Sample acidity (H ₂ SO ₄ , mol L ⁻¹)	0.5–1.8	1.5
Carrier gas flow rate (mL min ⁻¹)	10–60	20
NaBH ₄ concentration, % (m/v)	0.25–4.0	0.5
Indicator volume (mL)	1–5	4
Reaction time (min)	5–20	15

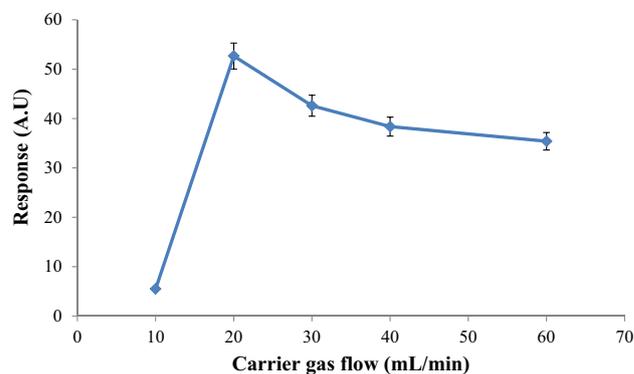
**Fig. 5** Effect of the ethanol concentration on the response. Conditions: As(III), 15 $\mu\text{g mL}^{-1}$; carrier gas flow, 60 (mL/min); NaBH₄, 2% (w/v); all other conditions are as in Table 1**Fig. 6** Effect of concentration of H₂SO₄ in the response. Conditions: As(III), 15 $\mu\text{g mL}^{-1}$; carrier gas flow, 60 (mL/min); NaBH₄, 2% (w/v); all other conditions are as in Table 1

Effect of sample acidity

Sulfuric acid is generally used for arsine generation in HG systems. The effect of sulfuric acid concentration on arsine generation in 15 $\mu\text{g mL}^{-1}$ of As(III) was investigated in the range of 0.5–1.8 mol L⁻¹. As show in Fig. 6, the maximum sensitivity was obtained at 1.5 mol L⁻¹ of H₂SO₄. The molar fraction of arsine plays an important role in its reaction with indicator solution. In lower concentrations of H₂SO₄ the rate of arsine production was slow with low molar fractional of arsine in terms of carrier gas (N₂). Additionally, high concentration of H₂SO₄ produced excessive amount of H₂ which subsequently decreased the molar fraction of arsine.

Effect of carrier gas (nitrogen) flow rate

The effect of N₂ flow rate was investigated in the range of 10–60 mL/min. The optimum N₂ flow rate was found to be 20 mL/min (Fig. 7). Since arsine is a highly unstable molecule, at lower flow rate, it was not fully transferred to the absorber tube and at higher flow rate, the reaction between arsine and indicator solution remained incomplete.

**Fig. 7** Effect of carrier gas (nitrogen) flow rate on the response. Conditions: As(III), 15 $\mu\text{g mL}^{-1}$; NaBH₄, 2% (w/v); all other conditions are as in Table 1

Effect of NaBH₄ concentration

The effect of NaBH₄ concentration on Arsine generation in 15 $\mu\text{g mL}^{-1}$ of As(III) was investigated in the range of 0.25–4% (m/v). The maximum response was obtained at

0.5% (m/v) NaBH_4 concentration. At higher concentration, a large amount of hydrogen gas was produced, which could decrease molar fraction of arsine, and therefore, impair the efficiency of reaction between arsine and indicator solution. At lower concentrations, HG of arsine remained incomplete.

Effect of indicator volume and reaction time

The effect of indicator volume was examined in the range of 1–5 mL. The maximum response was obtained at 4 mL. The efficiency of arsine trapping declined at low indicator volumes because arsine was rapidly passed through the indicator solution. At higher indicator volumes, the color intensity of indicator solution was reduced due to increased volumes. The effect of reaction time was also investigated in the range of 5–20 min, with the results suggesting that a reaction time of 15 min was sufficient to obtain maximum sensitivity.

Analytical figures of merit

Under optimum condition, as summarized in Table 1, a linear calibration graph was obtained over the range of 1–25 $\mu\text{g mL}^{-1}$ of As(III). The obtained linear regression equation was

$\text{Res} = 5.6335C + 1.2081$ where C represented the concentration of As(III) ($\mu\text{g mL}^{-1}$) and coefficient of determination or squared correlation coefficient (R^2) was 0.9947 (Fig. 8). Detection limit based on $3\sigma/m$ was $0.39\ \mu\text{g mL}^{-1}$ where σ indicates the standard deviation of five measurements of the blank and m is the slope of the calibration curve. The relative standard deviation (RSD)

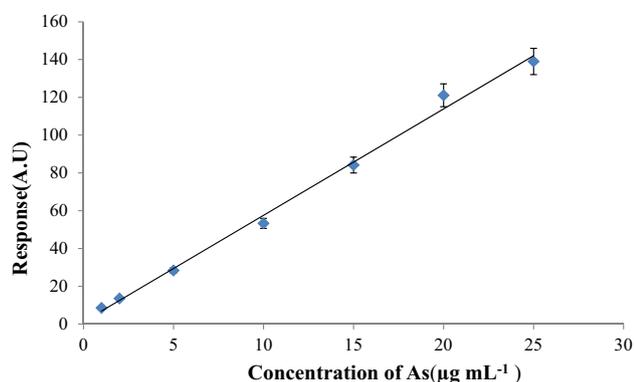


Fig. 8 Calibration graph of As(III) with linear regression equation $\text{Res} = 5.6335C + 1.2081$ where, C is the concentration of As(III) ($\mu\text{g mL}^{-1}$) and squared correlation coefficient $R^2 = 0.9947$

for five replicate measurements of 10, 15 and 20 $\mu\text{g mL}^{-1}$ of As(III) were 0.89, 2.43 and 3.08%, respectively.

Assessment of interference effects

The effects of various ionic species on the determination of 15 $\mu\text{g mL}^{-1}$ As(III) were studied in the presence of 15 $\mu\text{g mL}^{-1}$ of foreign ions, as shown in Table 2. Metal ions with hydride production ability such as (Bi, Ge, Pb, Sb, Se, Sn, Te) have huge impact on HG method. They produce metal-hydride like arsine in hydride generation process, which can produce positive error. Nitrate and nitrite have known interferences in hydride generation of As(III) [1]. They are powerful oxidizing ion that can oxidize arsine derived from hydride generation. The interferences of transition metal ions with HG based on NaBH_4 reduction is well known [7]. The mechanism of most transition metal ions interference is due to a preferential reduction of interfering ion to the metal under the hydride generation conditions. It is possible that the finely dispersed precipitated metal then adsorbs and decomposes the gaseous hydride (nickel and other group VIII elements are effective hydrogenation catalysts and can absorb hydrogen in large amounts). Insoluble nickel arsenide or similar compounds may then be formed in a secondary reaction [39–41].

A suitable method for removing interferences of transition metal ions is separated them before hydride generation

Table 2 Effect of interferences on the determination of 15 $\mu\text{g mL}^{-1}$ As(III) in the presence of 15 $\mu\text{g mL}^{-1}$ of foreign ions

Foreign ion	Recovery As(III) (%) ^a
Cl^-	96
Br^-	94
I^-	108
PO_4^{3-}	95
NO_3^-	8
NO_2^-	11
K^+	103
Ca^{2+}	102
Mg^{2+}	102
Al^{3+}	93
Fe^{2+}	107
Fe^{3+}	101
Cu^{2+}	35
Ag^+	18
Ni^{2+}	28
Ge^{4+}	145
Pb^{4+}	152
Sb^{3+}	162

^aRecovery As(III) (%) = $100 \times [\text{response of As(III) in the presence of foreign ion} / \text{response of As(III)}]$

Table 3 Results of determination of As(III) using proposed method

No. of sample	Sample matrix	As(III) added ($\mu\text{g mL}^{-1}$)	As(III) found ($\mu\text{g mL}^{-1}$)	Recovery (%) ^a
1	Industrial wastewater	0	1.37 ± 0.05^b	–
2		2	3.56 ± 0.01	109.3
3		6	7.15 ± 0.06	96.3
4		11	12.94 ± 0.07	105.1

^aRecovery (%) = $100 \times [(C_t - C_i)/C_s]$, where C_t is the total concentration achieved after standard addition, C_i is the initial concentration found before standard addition and C_s is the standard added concentration

^bConfidence limit based on five replicate analyses with confidence interval of 95%

step. The separation of transition metal ions with Chelex100 resin is well known [5].

Analysis of industrial wastewater

To evaluate the analytical applicability of the proposed method, the recommended procedure was used to determine As(III) in a sample of industrial wastewater. The proposed procedure was then implemented using the standard addition calibration method. The results are shown in Table 3. There is a good agreement between the results and known values, which indicate the successful applicability of the proposed method for determination of As(III) in complex industrial samples containing many foreign species without any sample preparation.

Conclusion

For the determination of inorganic As(III) in the industrial wastewater, a new green colorimetric method was proposed for the analysis of inorganic As(III) in μg level, based on hydride generation. This method used a compact digital camera as the detector with image processing. The proposed method was simple and inexpensive without the need for expensive devices and toxic solvents, which allowed it to be used everywhere. It is based on arsine generation and color reaction with Fe(III)-1,10-phenanthroline complex in the presence of ethanol, which could produce deep red color.

It was found that the basic color of blue intensity of Fe(II)-1,10-phenanthroline' complex is related to concentration of As(III), which was extracted by Image J—image processing software.

The main advantages of the proposed method are the employment of a cheap and available detector (digital compact camera) instead of expensive and professional devices such as UV–Vis spectrophotometer, atomic absorption spectroscopy (AAS) and atomic fluorescence spectroscopy (AFS), and also use of non-toxic indicator based on $\text{Fe}^{3+}/\text{Fe}^{2+}$ redox system in aqueous solution, compared to common indicators such as silver diethyldithiocarbamate in

organic solvent like morpholine—chloroform, as well as fast determination of As(III) in complex matrices with unknown disturbance. Future studies in this area can concentrate on the determination of other heavy metals ion in industrial wastewater using methods similar to those utilized in this work.

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References

- M.H. Arbab-Zavar, M. Chamsaz, T. Heidari, Speciation and analysis of arsenic (III) and arsenic (V) by electrochemical hydride generation spectrophotometric method. *Anal. Sci.* **26**(1), 107–110 (2010)
- J. Das et al., Low-cost field test kits for arsenic detection in water. *J. Environ. Sci. Health Part A* **49**(1), 108–115 (2014)
- X. Meng, C. Jing, G.P. Korfiatis, *A review of redox transformation of arsenic in aquatic environments, in biogeochemistry of environmentally important trace elements* (American Chemical Society, Washington DC, 2002), pp. 70–83
- M. Burguera, J. Burguera, Analytical methodology for speciation of arsenic in environmental and biological samples. *Talanta* **44**(9), 1581–1604 (1997)
- M. Hashemi, P. Modasser, Sequential spectrophotometric determination of inorganic arsenic species by hydride generation from selective medium reactions and colour bleaching of permanganate. *Talanta* **73**(1), 166–171 (2007)
- K.A. Francesconi, D. Kuehnelt, Determination of arsenic species: a critical review of methods and applications, 2000–2003. *Analyst* **129**(5), 373–395 (2004)
- X.-P. Yan, Z.-M. Ni, Vapour generation atomic absorption spectrometry. *Anal. Chim. Acta* **291**(1), 89–105 (1994)
- A. Campbell, A critical survey of hydride generation techniques in atomic spectroscopy (technical report). *Pure Appl. Chem.* **64**(2), 227–244 (1992)
- A.G. Howard, M.H. Arbab-Zavar, Determination of “inorganic” arsenic (III) and arsenic (V), “methylarsenic” and “dimethylarsenic” species by selective hydride evolution atomic-absorption spectroscopy. *Analyst* **106**(1259), 213–220 (1981)
- A. Caiminagua et al., Electrochemical generation of arsenic volatile species using a gold/mercury amalgam cathode. Determination of arsenic by atomic absorption spectrometry. *Anal. Chem. Res.* **3**, 82–88 (2015)

11. J.M. Costa-Fernandez et al., Direct coupling of high-performance liquid chromatography to microwave-induced plasma atomic emission spectrometry via volatile-species generation and its application to mercury and arsenic speciation. *J. Anal. At. Spectrom.* **10**(11), 1019–1025 (1995)
12. F. El-Hadri, A. Morales-Rubio, M. de la Guardia, Atomic fluorescence spectrometric determination of trace amounts of arsenic and antimony in drinking water by continuous hydride generation. *Talanta* **52**(4), 653–662 (2000)
13. Z. Zou et al., Ultrasensitive determination of inorganic arsenic by hydride generation-atomic fluorescence spectrometry using Fe_3O_4 @ ZIF-8 nanoparticles for preconcentration. *Microchem. J.* **124**, 578–583 (2016)
14. Y.-L. Feng et al., Off-line separation and determination of inorganic arsenic species in natural water by high resolution inductively coupled plasma mass spectrometry with hydride generation combined with reaction of arsenic (V) and L-cysteine. *Anal. Chim. Acta* **375**(1–2), 167–175 (1998)
15. J.R. Farrell, P.J. Iles, Y.J. Yuan, Determination of arsenic by hydride generation gas diffusion flow injection analysis with electrochemical detection. *Anal. Chim. Acta* **334**(1), 193–197 (1996)
16. M.H. Arbab-Zavar, M. Hashemi, Evaluation of electrochemical hydride generation for spectrophotometric determination of As (III) by silver diethyldithiocarbamate. *Talanta* **52**(6), 1007–1014 (2000)
17. J.A.G. Neto, R. Montes, A.A. Cardoso, Spectrophotometric detection of arsenic using flow-injection hydride generation following sorbent extraction preconcentration. *Talanta* **50**(5), 959–966 (1999)
18. G. Stratton, H.C. Whitehead, Colorimetric determination of arsenic in water with silver diethyldithiocarbamate. *J Am Water Works Assoc* **54**(7), 861–864 (1962)
19. S. Kundu et al., Spectrophotometric determination of arsenic via arsine generation and in-situ colour bleaching of methylene blue (MB) in micellar medium. *Talanta* **58**(5), 935–942 (2002)
20. E.P. Moraes et al., Low-cost method for quantifying sodium in coconut water and seawater for the undergraduate analytical chemistry laboratory: flame test, a mobile phone camera, and image processing. *J. Chem. Educ.* **91**(11), 1958–1960 (2014)
21. W. da Silva Lyra et al., Indirect determination of sodium diclofenac, sodium dipyrone and calcium gluconate in injection drugs using digital image-based (webcam) flame emission spectrometric method. *Anal. Methods* **3**(9), 1975–1980 (2011)
22. R. Gupta, R.G. Reifenberger, G.U. Kulkarni, Cellphone camera imaging of a periodically patterned chip as a potential method for point-of-care diagnostics. *ACS Appl. Mater. Interfaces.* **6**(6), 3923–3929 (2014)
23. K. Grudpan et al., Applications of everyday IT and communications devices in modern analytical chemistry: a review. *Talanta* **136**, 84–94 (2015)
24. S. Ayas et al., Counting molecules with a mobile phone camera using plasmonic enhancement. *ACS Photonics* **1**(1), 17–26 (2014)
25. Q. Wei et al., Detection and spatial mapping of mercury contamination in water samples using a smart-phone. *ACS Nano* **8**(2), 1121–1129 (2014)
26. E.H. Doeven et al., Red–green–blue electrogenerated chemiluminescence utilizing a digital camera as detector. *Anal. Chem.* **86**(5), 2727–2732 (2014)
27. N. Moonrungrsee, S. Pencharee, J. Jakmunee, Colorimetric analyzer based on mobile phone camera for determination of available phosphorus in soil. *Talanta* **136**, 204–209 (2015)
28. J. Sankaran et al., Accuracy and precision in camera-based fluorescence correlation spectroscopy measurements. *Anal. Chem.* **85**(8), 3948–3954 (2013)
29. www.imagej.net
30. www.adobe.com/Photoshop
31. A.M. Featherstone, et al., Determination of arsenic species in seawater by hydride generation atomic fluorescence spectrometry. *J. Anal. At. Spectrom.* **13**(12), 1355–1360 (1998)
32. E.L. Wehry, A. Ward Robert, Photoreduction of tris (1,10-phenanthroline) iron(III). *Inorg. Chem.* **10**(12), 2660–2664 (1971)
33. G. Somidevamma, G.G. Rao, Colorimetric determination of iron (III) with 1,10-phenanthroline. *Fresenius Z. Anal. Chem.* **187**(3), 183–187 (1962)
34. I.M. Kolthoff, D.L. Leussing, T.S. Lee, Reaction of ferrous and ferric iron with 1,10-phenanthroline. III. The ferrous monophenanthroline complex and the colorimetric determination of phenanthroline. *J. Am. Chem. Soc.* **72**(5), 2173–2177 (1950)
35. S.S. Michael, Determination of arsenic in sulfide samples containing antimony by atomic absorption spectrometry. *Anal. Chem.* **49**(3), 451–453 (1977)
36. Y. Zhang et al., Facile hydrothermal synthesis of vanadium oxides nanobelts by ethanol reduction of peroxovanadium complexes. *Ceram. Int.* **39**(1), 129–141 (2013)
37. Nassr, A.B.A.A., M. Bron, Microwave-assisted ethanol reduction as a new method for the preparation of highly active and stable CNT-supported PtRu electrocatalysts for methanol oxidation. *ChemCatChem* **5**(6), 1472–1480 (2013)
38. S.-R. Wang, W.J. Tseng, Aggregate structure and crystallite size of platinum nanoparticles synthesized by ethanol reduction. *J. Nanopart. Res.* **11**(4), 947–953 (2009)
39. B. Welz, M. Melcher, Mechanisms of transition metal interferences in hydride generation atomic-absorption spectrometry. Part 1. Influence of cobalt, copper, iron and nickel on selenium determination. *Analyst* **109**(5), 569–572 (1984)
40. B. Welz, M. Melcher, Mechanisms of transition metal interferences in hydride generation atomic-absorption spectrometry. Part 2. Influence of the valency state of arsenic on the degree of signal depression caused by copper, iron and nickel. *Analyst* **109**(5), 573–575 (1984)
41. B. Welz, M. Melcher, Mechanisms of transition metal interferences in hydride generation atomic-absorption spectrometry. Part 3. Releasing effect of iron(III) on nickel interference on arsenic and selenium. *Analyst* **109**(5), 577–579 (1984)

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