Spectrophotometric Determination by Azo Coupling Reaction of Bisphenol A Using Benzidine Reagent

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Abstract: New spectrophotometric method for Bisphenol A determination has been developed according to the current study. A colored complex called Bisphenol A can be obtained through the combination of benzidine in an alkaline solution. The chemical reaction produces a dark yellow compound which shows absorbance at 452 nm. The analysis showed Beer's law compliance from 5–14 g/mL with R2 value at 0.999 and LOD at 0.3470 g/mL while LOQ at 0.1190 g/mL. This reaction solution demonstrated a molar absorptivity value of 2872.8 $L \cdot mol^{-1} \cdot cm^{-1}$ accompanied by a relative standard deviation of 0.00125%. The recovery value for this method reached 102.2311% and the Sandal sensitivity measurement produced a result of 0.07937 g/mL. Bisphenol A detection through this method succeeded in a series of wastewater samples which included measurements from Tap water along with Diyala, Khresan, and Mahroot Bridge. The technique exhibited a strong correlation and excellent conformity to Beer's law while ensuring high precision, accurate detection, and low measurement limits. The ability to detect BPA at trace levels was achieved by optimizing reaction parameters and reagent dosages. This method proved to be a reliable tool for assessing BPA contamination in drinking water sources and industrial effluents, as demonstrated by its application to environmental samples from various sources. Its cost-effectiveness, ease of implementation, and high sensitivity make it an effective monitoring approach for environmental assessments.

1 INTRODUCTION

The industrial organic molecule known as Bisphenol A (BPA) serves as a component for producing epoxy resins and polycarbonate plastics. BPA functions as a vital organic substance in numerous consumer items including plastic bottles together with food can linings as well as medical devices and electrical equipment and dentistry supplies [1]. BPA provides plastics with better strength and transparency together with thermal stability yet its widespread use leads to critical environmental problems since it shifts into food containers and natural environments where humans can encounter it multiple ways [2]. Human consumption of BPA is common because research proves that this chemical gets into food and drinks through plastic storage containers that handle heat or acid exposure [3]. BPA ranks as an endocrine-disrupting chemical (EDC) since it duplicates hormones by becoming active in estrogen receptors and disturbs the body's natural hormone activity thereby producing possible dangerous biological impacts [4]. Studies link chronic exposure to low BPA concentrations to an elevated danger of heart disease plus infertility and brain development problems and metabolic conditions and fetal congenital defects [5].

The toxicological and epidemiological study of BPA continues because scientists have established a connection between the chemical and hormone-related cancer development including prostate and breast cancer [6], [7]. BPA functions both as a significant environmental danger point while impacting human wellness negatively. BPA migrates to surface then groundwater sources after its entrance through industrial waste, plastic degradation and wastewater effluents thus contaminating ecosystems while harming aquatic life [8]. Research shows that BPA causes its accumulation in marine organisms leading to disruption of hormonal balance and inhibited development and reproduction until it disrupts the natural ecosystem balance [9]. The European Chemicals Agency (ECHA) and U.S. Food and Drug

Administration (FDA) established strict regulations regarding BPA usage in food contact materials especially baby bottles and infant food containers because of public concern [10]. Other countries such as Canada along with Japan and France have moved beyond European legislation by banning BPA applicability or supporting BPA-free polymers for substitution purposes [11]. The continuous detection of BPA remains challenging because its substitute chemicals BPS and BPF might produce equivalent biological consequences [12].

The accurate analysis provided by gas chromatography-mass spectrometry alongside high-performance liquid chromatography demands expensive specialized tools along with prolonged analytical periods that reduce their suitability for daily commercial work [13]. The analytical methods used for BPA detection have experienced substantial progress throughout recent years. UV-Vis spectrophotometry has gained popularity as a BPA detection method because it offers easy operation and low cost and rapid analysis time which fulfil requirements of environmental and regulatory applications [14], [15]. The identification of phenolic chemicals including BPA finds success through Azo coupling reactions which have become one of the most successful spectrophotometric detection techniques [16]. Azo coupling detects BPA through its reaction with specific reagents such as benzidine that yields a measurable colored compound at a precise spectroscopic wavelength [17].

The detection method proves suitable for measuring BPA in water and plastic items and industrial waste because of its high sensitivity combined with easy operation[18]. The research develops and optimizes a spectrophotometric assessment method through azo coupling processes to accurately measure BPA concentrations because BPA detection requires immediate attention [18]. The research analyzes vital reaction-sensitive and accuracy-affecting parameters by studying various reagent concentrations alongside temperature control and acid types and sequence order of reagent addition [19]. The method's detection capacity together with its sensitivity to low doses of BPA is checked through LOD and LOQ measurements [20]. A dependable analytical tool aimed at better environmental and industrial BPA monitoring will assist regulatory bodies in their efforts to minimize human exposure while addressing health and ecological problems according to this study [21].

2. EXPERIMENTAL

2.1 Material

All substances and reagents used during the study received first-rate quality selection.

2.2 Equipment Used

The Shimadzu 800 UV-Visible Spectrophotometer produced in Japan served as the main device, European-made Velp Scientific water bath, Geemy Plc-03 centrifuge, Taiwan, Electrical Balance: China's Kern & SOHN GmbH.

2.3 Preparation of Standard Solution

All standard solutions were prepared in volumetric flasks using analytical-grade reagents and distilled water, with concentrations verified gravimetrically/ volumetrically:

1) The preparation involved dissolving 0.1 g of benzidine into 25 mL of ethanol to make a 100 µg/mL standard solution. The dissolved solution was poured into a 100 mL volumetric flask while adding the needed quantity of distilled water to reach the specified measurement level.
2) A 100 mL volumetric flask received its maximum capacity using distilled water following the dissolution of 0.1 g Bisphenol A into a 100 µg/mL standard solution.
3) 1 g of sodium nitrite dissolved in a 100 mL volumetric flask received additional distilled water to create a 1% w/v solution which filled the capacity.
4) A 1% w/v solution of urea was prepared by dissolving 1 g sulfamic acid in water which filled a 100 ml volumetric flask. An additional amount of distilled water was added to reach the appropriate level of solution.
5) A 100 mL volumetric flask received distilled water until it reached the brim followed by the addition of 5.4 mL of 18.41 M concentrated phosphoric acid to establish a 1 M phosphoric acid solution.

6) 5.46 ml of 18.29 M concentrated sulfuric acid was added in a 100 mL volumetric flask and complete with distilled water for preparing a 1 M solution of sulfuric acid.
7) The solution of 1 M acetic acid prepared by adding 5.74 mL of 17.431 M acetic acid and complete of 100ml volumetric flask with distilled water.
8) In 100 mL volumetric flask added 8.40 ml of 11.96 M hydrochloric acid followed by distilled water addition for creating a 1 M hydrochloric acid solution.
9) A 4 g of sodium hydroxide added in a 100 mL volumetric flask and complete with distilled water until the flask reached the mark to yield a 1 M sodium hydroxide solution.
10) A 1 M solution of potassium hydroxide was prepared by dissolving 5.6 g of potassium hydroxide into a 100 mL volumetric flask and adjusting it to volume with distilled water.
11) A solution with one molar barium hydroxide was prepared by dissolving 1.71 g of barium hydroxide with a small amount of distilled water and then filling a 10 mL volumetric flask to the mark.
12) A 1 M solution of sodium bicarbonate was prepared by dissolving (8.4 g) of the compound in water before adjusting its volume to 100 mL with distilled water.

2.4 General Azo Coupling Procedure

The prepared azo compound accomplished by adding 0.9 mL of 100 µg/mL benzidine in a volumetric flask 10mL in ic bath, followed by adding 0.6 mL of 1 hydrochloric acid, 0.4 mL of 1% sodium nitrite, 0.6 mL of urea 1% solution to eliminated excess sodium nitrite, 1mL of 100 µg/mL of Bisphenol A, and 0.8mL of 1mL of potassium hydroxide solution, the absorption was determined using uv-vis. The maximum wavelength absorption was determined.

2.5 Suggested Protocol for Environmental Water Samples

The waste water samples were collected from some locations including Diyala, Khresan, Mahroot Bridge and tap water, the samples kept on plastic bottles and filtered with filter papers before analysis and then in series of 10 mL volumetric flasks added the optimal volumes, 0.9 mL benzidine, 0.6 mL of HCl, 0.4mL $NaNO_2$, 0.6mL urea, 1 mL of 10, 20 µg/mL of Bisphenol A, 0.8mL KOH, Apply each solution to make up the total volume of the solution. The spectrophotometer served to measure the quantitative absorbance of the solution.

3 RESULTS AND DISCUSSION

3.1 Bisphenol A Spectrophotometric Determination in an Aqueous Solution Utilizing the Azo Coupling Reaction

The diazotization of benzidine and its coupling with BPA to form a dark yellow product was reported at 452 nm, Figure 1 show the spectrum of absorption of dark yellow product versus blank.

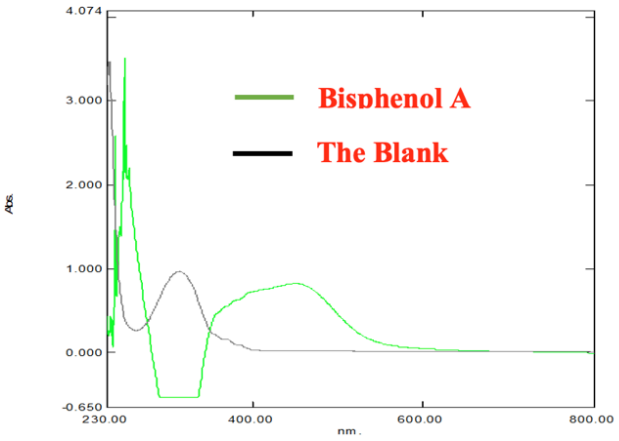

Figure 1: The green line show how Bisphenol A absorbs dye spectra while the black line compares the blank solution.

3.2 Study the Optimal Conditions for the Reaction

This study featured multiple tests that evaluated different parameters affecting the absorption of colored azo dye products.

3.2.1 Effect of the Type of Acid

The experimental procedures involved creating acids solutions with 1 M concentration. The data in Table 1 and Figure 2 demonstrate that hydrochloric acid 1 M achieves maximum Bisphenol A absorption with an absorbance value of 0.481.

Table 1: Data on absorption for the effect of acid type.

Acid Type	Absorbance at 452 nm
HCl	**0.481**
H_2SO_4	0.446
H_3PO_4	0.465
CH_3COOH	0.404

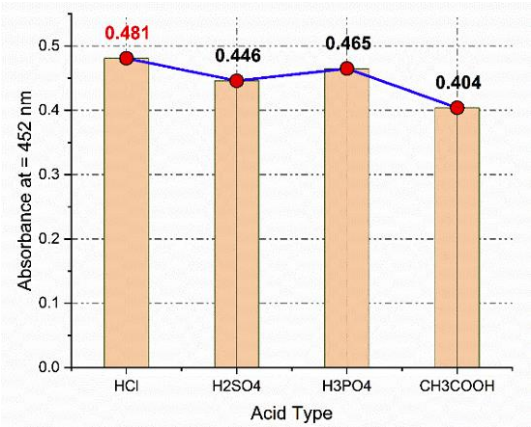

Figure 2: Acid type's effect on absorbance value.

3.2.2 The Effect of Acid Volume

A series of experiments contained 1 M hydrochloric acid solutions prepared with different volume quantities. Table 2 shows that the combination of 0.6 mL hydrochloric acid at 1 M concentration results in the best color product absorption 0.501. Figure 3 shows how the absorbance increases as acid volume rises until it drops sharply because the basic phenol molecule becomes unreactive. The combination of 0.7 mL hydrochloric acid with color product yielded the maximum absorption during subsequent testing sessions to verify the peak absorption volume.

Table 2: The effect of acid volume on the colored Bisphenol A product's absorbance.

Acid volume (1M)	Absorbance at 452nm
0.1	0.423
0.2	0.431
0.3	0.445
0.4	0.463
0.5	0.484
0.6	**0.501**
0.7	0.498
0.8	0.493
0.9	0.486
1.0	0.481

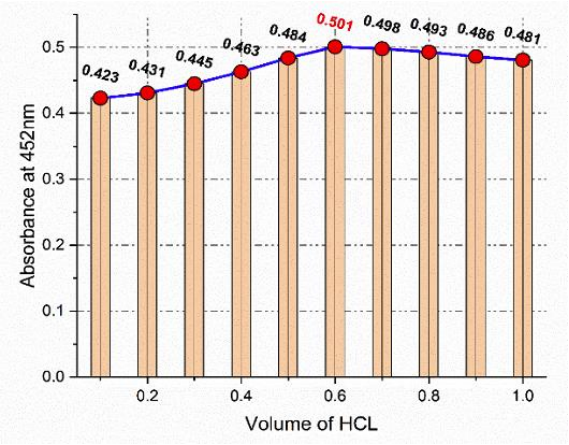

Figure 3: The effect of the hydrochloride acid volume at a 1 M concentration on absorbance value.

3.2.3 The Influence of the Base Type

Colored azo product solution preparation used potassium hydroxide at a concentration of 1 M. Results in Table 3 and Figure 4 show that potassium hydroxide 1 M proved to be the most efficient base choice for Bisphenol A compound since it exhibited an absorbance reading of 0.527.

Table 3: Effect of the type of base on the absorbance of the colored products of Bisphenol A.

Base Type (1M, 1mL)	Absorbance at 452nm
NaOH	0.502
KOH	**0.527**
$NaHCO_3$	0.439
$Ba(OH)_2$	0.487

3.2.4 The Effect of the Ideal Volume of 1 M of KOH

The base volume in potassium hydroxide solution range from 0.1 mL to 1 mL at a 1 M concentration. The data in Tables 4 and Figure 5 indicate that using

0.8 mL of 1 M potassium hydroxide solution produces the best results for colored product by achieving an absorbance level of 0.544.

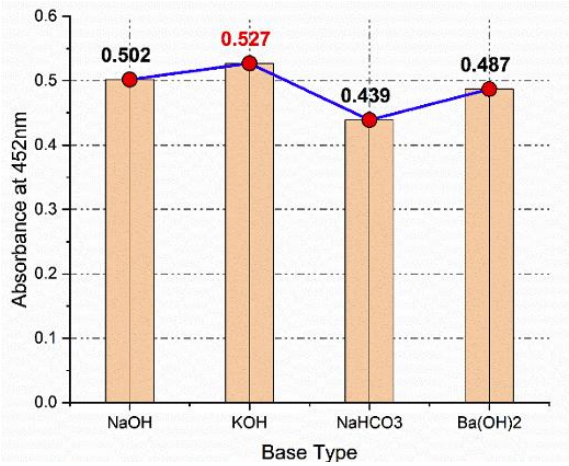

Figure 4: Base type's effect on the colored product's absorbance.

Table 4: Effect of volume on absorbance of the colored product of Bisphenol A.

Base volume (1M)	Absorbance at 452nm
0.1	0.487
0.2	0.491
0.3	0.508
0.4	0.517
0.5	0.520
0.6	0.538
0.7	0.540
0.8	**0.544**
0.9	0.535
1.0	0.527

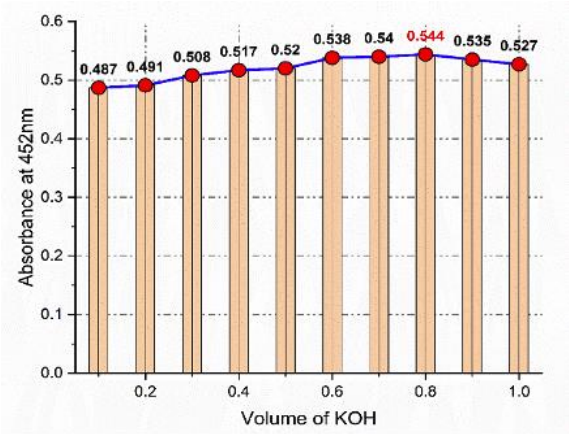

Figure 5: The effect of base volume KOH on the colored Bisphenol A's absorbance.

3.2.5 The Effect of the Optimal Volume of 1% of Sodium Nitrite

A 1% sodium nitrite solution displayed various concentration levels within the experimental setup that resulted in data display in Table 5. The amount of 1% sodium nitrite solution determines how much colored complex Bisphenol A the solution accepts according to the data presented in Figure 6. The experimental results demonstrate that using 0.4 ml of sodium nitrite produces the maximum absorption of 0.631 making it the optimal condition for Bisphenol A detection. The data shows absorption grows when sodium nitrite volume increases up until absorption starts to decrease.

Table 5: Effect of 1% volume of sodium nitrite on the absorbance of the colored product of Bisphenol A.

V of 1% Sodium Nitrite	Absorbance at λ max = 452
0.1	0.603
0.2	0.610
0.3	0.627
0.4	**0.631**
0.5	0.624
0.6	0.609
0.7	0.589
0.8	0.567
0.9	0.559
1.0	0.543

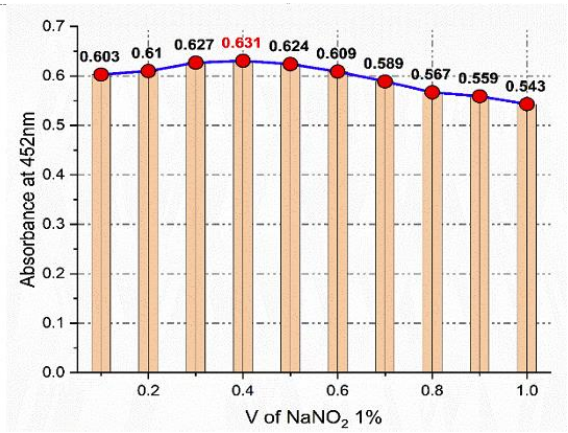

Figure 6: Effect of 1% sodium nitrite volume on the colored complex Bisphenol A.

3.2.6 Effect of Optimal Volume of 1% Urea

The data from Table 6 and Figure 7 demonstrate that using 0.6 mL of 1% urea solution yields the greatest absorbance of 0.755 for the Bisphenol A

product. The study reveals that increases in urea concentration result in higher absorbance readings until a turning point where nitrite gas formation produces rapid absorbance decreases.

Table 6: Effect of 1% volume of urea on absorbance value.

V of 1% urea	Ab at λ max = 452
0.1	0.681
0.2	0.695
0.3	0.708
0.4	0.731
0.5	0.741
0.6	**0.755**
0.7	0.734
0.8	0.692
0.9	0.650
1.0	0.634

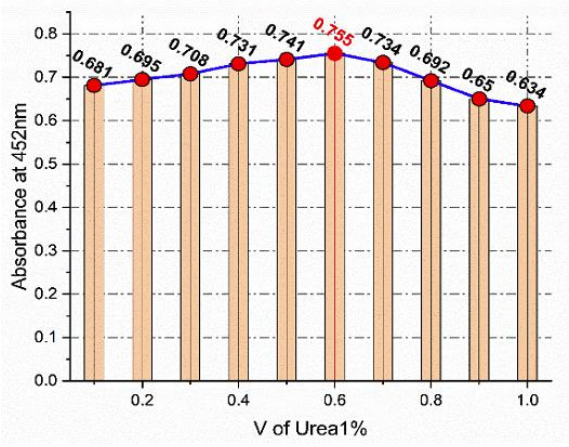

Figure 7: Effect of 1% urea volume on the colored product Bisphenol A.

3.2.7 Effect of Reagent Volume 100 µg/mL

Bisphenol A solution was added to different amounts of benzidine reagent with concentration 100 µg/mL. Results in Table 7 with Figure 8 show that the most suitable amount of benzidine reagent 0.9 mL with Bisphenol A at its peak absorbance 0.791. The absorption reaction increases with increasing reagent volume although excessive volume leads to reduced absorbance since an excessive volume limits the conjugation capacity for phenol.

3.2.8 The Effect of Reaction Time on the Product's Color Stability

The reaction period from 5-60 minutes generated multiple testing outcomes that researchers documented using Table 8 and Figure 9. The experimental results indicated a reaction completion time of 40 minutes because Bisphenol A showed the highest absorbance value at 0.822.

Table 7: The effect of reagent volume at a concentration of 100 µg/mL on absorbance value.

V of (100 µg/mL) Reagent	Absorbance at λ max = 452
0.1	0.691
0.2	0.710
0.3	0.726
0.4	0.734
0.5	0.758
0.6	0.764
0.7	0.771
0.8	0.784
0.9	**0.791**
1.0	0.751

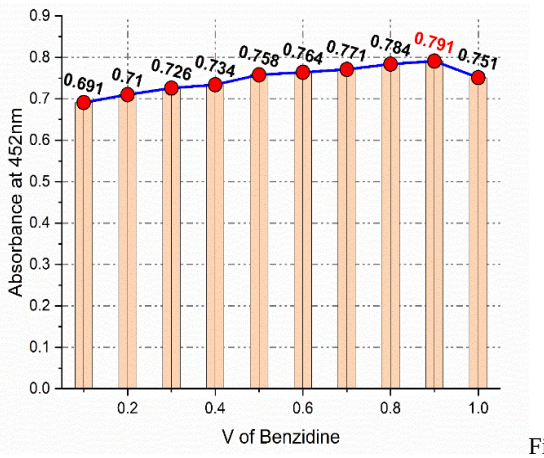

Figure 8: Effect of Benzidine volume 100 µg/ml on colored product absorption.

Table 8. Reaction time's effect on the stability of the Bisphenol A colored product.

Time (min)	Ab at λ max = 452
5	0.491
15	0.556
20	0.621
25	0.708
30	0.732
35	0.810
40	**0.822**
45	0.818
50	0.783
55	0.745
60	0.705

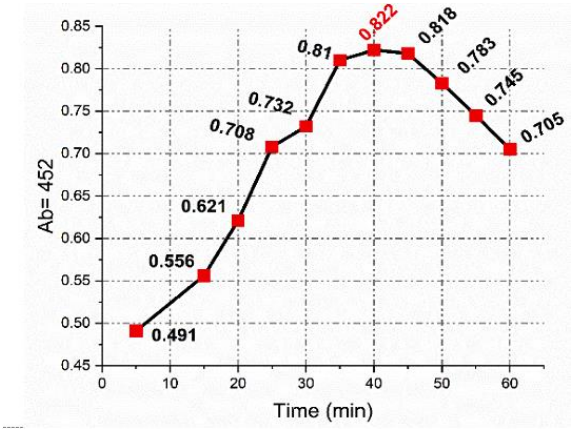

Figure 9: Reaction time's effect on the stability of a phenol complex's colored product.

3.2.9 Effect of Adding Sequence

The experimental results appear in Table 9 along with Figure 10. The optimal addition sequence for Bisphenol A production involved 1, which resulted in a maximum absorbance reading of 0.821.

Table 9. Shows the Effect of the addition sequence.

No.	Addition	λmax=452
1	ABCDEF	**0.821**
2	ABCDFE	0.440
3	EABCDF	0.750

A: Benzidine, B: Hydrochloride acid, C: Sodium nitrite, D: Urea, E: Bisphenol A, F: Sodium carbonate.

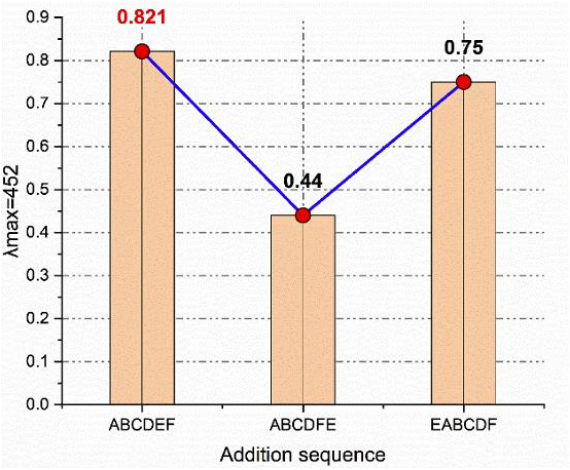

Figure 10: Effect of the addition sequence on the absorbance of the colored product of Bisphenol A.

3.2.10 Solvent Effect

The study employed a various of solvents including water and both ethanol and methanol alongside acetonitrile, 1-propanol and acetone. Data in Table 10 together with Figures 11 proves water provides optimal conditions for dissolving Bisphenol A at 0.820 as the main solvent. Water solvent stands as a top choice because it is cheap to obtain and easily accessible. The solvent operates as one of the environment-friendly solutions in existence.

Table 10: Effect of the solvent on the absorption of the colored product of Bisphenol A.

No.	Solvent	Abs
1	Water	**0.820** (in red)
2	Ethanol	0.754
3	Methanol	0.691
4	Acetonitrile	0.813
5	1-Propanol	0.793
6	Acetone	0.784

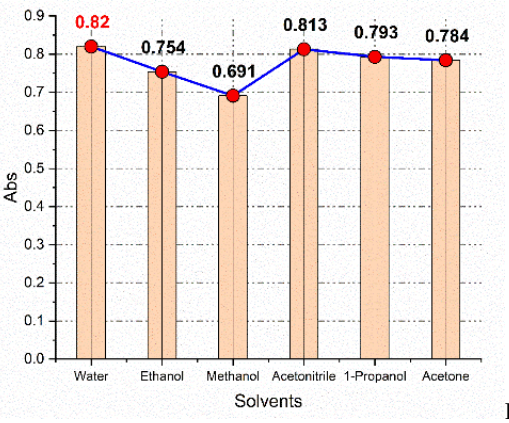

Figure 11: Effect of the solvent on the absorption of the colored product of the phenol complex.

3.2.11 Temperature's Effect on the Formation and Stability of the Colored Product

Multiple temperature conditions combined with different scientific tests formed the foundation of this study. The analysis in Table 11 and Figure 12 confirms that 30 °C represented the best temperature for Bisphenol A compound evaluation based on the highest observed absorption 0.805. Higher temperatures lead to decreased absorption strength during dissociation of the product which is evidenced through hue intensity.

Table 11: Effect of temperature on the absorption of colored product.

Temp.°C	Abs of BPA
5	0.612
10	0.744
15	0.698
20	0.782
25	0.667
30	0.805
35	0.636
40	0.783
50	0.749
60	0.694

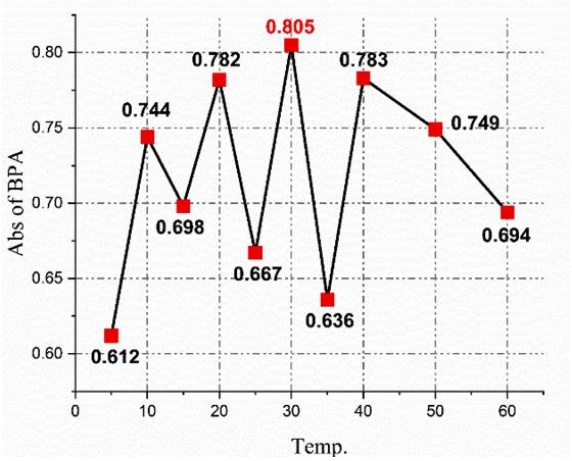

Figure 12: Temperature's effect on the colored product Bisphenol A absorbance.

3.3 The Nature of the Resulting Product

3.3.1 Method of Continuous Variation (Job's Method)

The obtained data in Table 12 and Figure 13 show that the ratio of BPA to benzidine reagent is 1:1.

Table 12: Continuous variation data for benzidine and Bisphenol A.

V of phenol/mL	V of Reagent/ mL	Abs of BPA
0.1	0.9	0.134
0.2	0.8	0.210
0.3	0.7	0.278
0.4	0.6	0.354
0.5	0.5	0.434
0.6	0.4	0.354
0.7	0.3	0.302
0.8	0.2	0.210
0.9	0.1	0.123

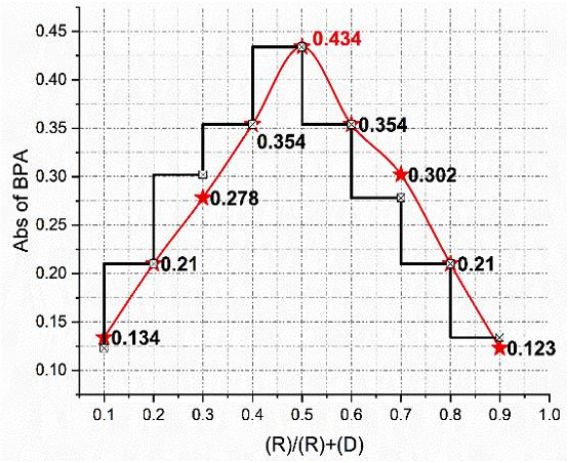

Figure 13: The method of continuous variation (JOB) for Bisphenol A.

3.3.2 Mole Ratio Method

The data presented in Table 13 and Figure 14 show that the stiochemistry ratio between reagent and phenol results 1:1. Figure 15 show the proposed.

Table 13: Absorbance values for the results of the mole ratio method for Bisphenol A, Benzidine.

Volume of phenol/mL	Volume of Reagent/ mL	Abs of BPA
0.1	0.9	0.134
0.2	0.8	0.210
0.3	0.7	0.278
0.4	0.6	0.354
0.5	0.5	0.434
0.6	0.4	0.354
0.7	0.3	0.302
0.8	0.2	0.210
0.9	0.1	0.123

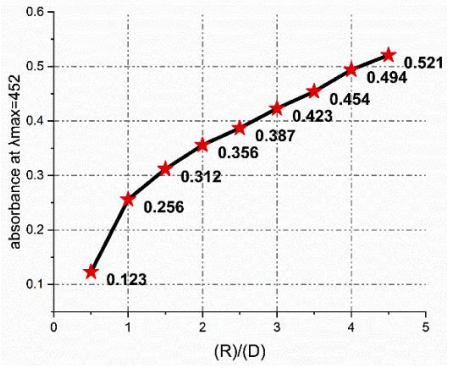

Figure 14: Curve of the Bisphenol A molar ratios method.

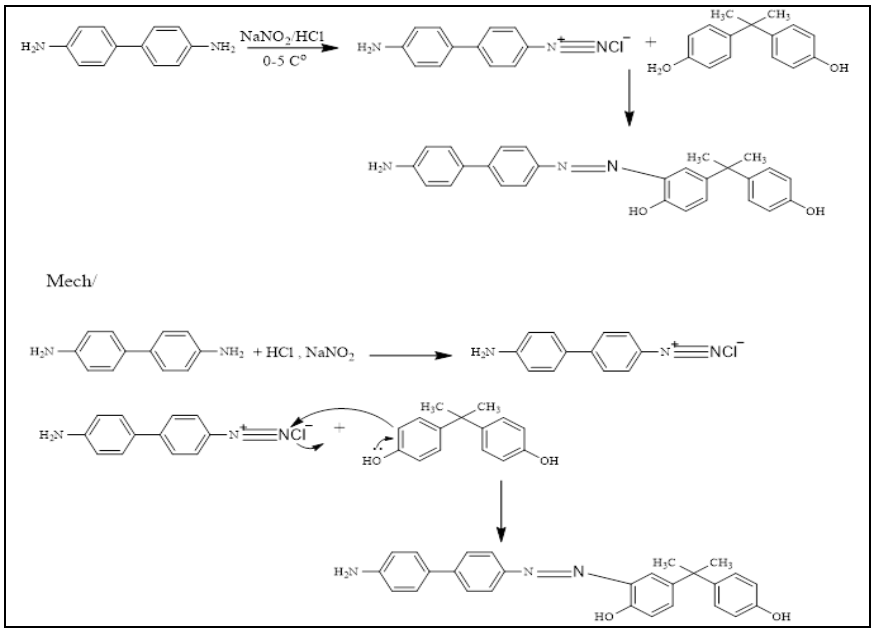

Figure 15: Proposed mechanism for the formation of the colored product of Bisphenol A.

3.4 Calibration Curve for Bisphenol A Complexed with Benzidine

The measurement of absorbance occurs at the wavelength that shows the best variation when compared to the blank solution. In a volumetric flask with 10 mL capacity added different amounts of Bisphenol A solution ranging from 1 mL at 5–14 µg/mL concentration and contained 0.6 mL of hydrochloric acid, 0.4 mL of sodium nitrite, 0.6 mL of urea, and 0.8 mL of potassium hydroxide. Table 14 and Figure 16 show a calibration curve for Bisphenol A consisting of concentrations that obeys with Beer's law within the 5 to 14 µg/mL range. The sensitivity of Sandal's reaches 0...07937 mg/cm^2 and the molar absorption coefficient for the product measures 2872.8 L/mol.cm.

Table 14: Calibration data for Bisphenol A complexed with Benzidine.

M (µg/mL)	Ab at λmax =452
5	0.135
6	0.146
7	0.161
8	0.173
9	0.184
10	0.20
11	0.210
12	0.223
13	0.234
14	0.250

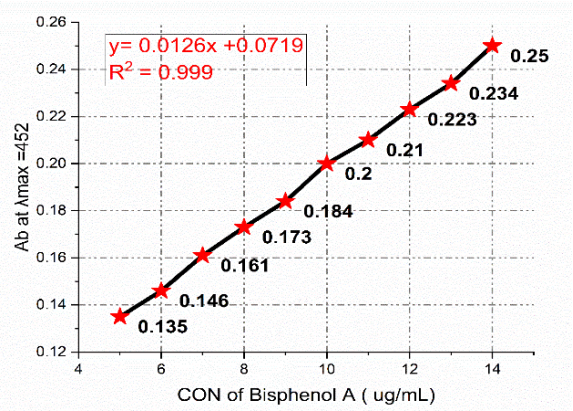

Figure 16: Calibration curve for Bisphenol A.

3.5 Interference Effect

A 1000 µg/mL solution of phenol contained 1 M of each interfering compound (Naphthol, Aniline, Benzoic acid, Nitrophenol, without interference) for testing how these substances affect the phenol. The volumetric vial containing 10ml receives further diluted distilled water after all additives reach their precise amounts. The spectrophotometer measures absorbance of Bisphenol A at wavelength 452 nm. Table 15 displays the findings for Bisphenol A. The measurement results from this table show that samples components do not influence Bisphenol A detection levels.

Table 15: Effect of interactions on the absorption of Bisphenol A.

No.	100ppm interference	Abs.
1	Naphthol	0.201
2	Naphtol	0.182
3	Aniline	0.049
4	Benzoicacid	0.137
5	Nitrophenol	0.486
6	Nitrophenol	0.399
7	Without interference	0.580

3.6 Detection Limit and Quantitative Limit for Drugs

The determination of detection and quantitative detection limits required performing ten blank solution measurements. Depending on Table 16.

3.7 Colored Output Stability Constant

The ratio between phenol and reagent stands at 1:1 according to the established method and previous calculations. Data from Table 17 demonstrates a high stability constant of the complex thus indicating its final dye remains enduring.

3.8 Accuracy and Precision Testing

The calibration curves allowed four different standard solutions (12, 9, 6, 3) to test the precision and accuracy levels of Bisphenol A. The data in Table 18 displays the influence of these characteristics. The best possible testing methods were employed to analyze five experimental replicates. Bisphenol A exhibits a recovery rate of 102.2311 which confirms high accuracy and precision in the obtained results.

Table 16: Calculating the detection limit and the quantitative limit for Bisphenol A.

Parameters	Bisphenol A
$\bar{x}^B$	0.320
$S^B = [(X_i - \bar{x})^2 / (n - 1)]^{1/2}$	0.145052
$LOD = \bar{x}^B + 3S^B$	0.3470
$LOQ = \bar{x}^B + 10S^B$	0.1190

Table 17: Stability constant data for the colored product of Bisphenol A.

V (3×10^{-4} M of Bisphenol A) /mL	As*	Am*	α	K ($L\cdot mol^{-1}$)	Mean of K ($L\cdot mol^{-1}$)
0.5	0.135	0.130	0.0384	2114.4578	9208.5843
0.7	0.161	0.159	0.0125	19276.3554	
0.9	0.184	0.180	0.0222	6234.9397	

Table 18. Accuracy and precision data for the proposed method for the determination of Bisphenol A.

Amt.BPA	12	9	6	3
F	12.1160	9.1780	6.1100	3.1244
R %	100.9667	101.9778	101.8333	104.1467
AvgR %	102.2311			
E_{rel}%	0.9667	1.9778	1.833	4.1467
Avg E_{rel}%	2.2311			
RSD%	0.0016	0.0019	0.0012	0.0003

Table 19: Data for determining Bisphenol A in samples.

Sample								
Stat. params	Water Tab		Diyala		Khresan		Mahroot	
M	10	20	10	20	10	20	10	20
F	9.2292	19.3310	9.854	19.770	9.4314	19.5242	9.3840	19.4178
R%	92.2920	96.6550	98.54	98.8530	94.3140	97.6210	93.8400	97.0890
Avg R %	94.4735		98.6965		95.9675		95.4645	
Erel %	-7.7080	-3.3450	-1.46	-1.1470	-5.6860	-2.3720	-6.1600	-2.9110
Avg Erel %	-5.5265		-1.3035		-4.029		-4.5355	
RSD %	0.0011	0.0004	0.0003	0.0016	0.0008	0.0006	0.0102	0.0077

3.9 Applications of Real Samples

A method to detect Bisphenol A measures its concentration in water solutions. The analytical technique is applied to various Bisphenol A samples that have a concentration between 10 and 20 mg/Meto1. The experimental findings in Table 19 demonstrate how the proposed testing method performs successfully to detect Bisphenol A in various samples. The results obtained are shown in Table 20.

Table 20: Statistical results of the proposed spectral method for estimation Bisphenol A.

Parameter	Bisphenol A
Colour of Product	Dark yellow
λ max	452 nm
Regression equation	y = 0.0126x + 0.0719
Standard deviation of regression	0.145052
Correlation coefficient (r)	0.99
C.L for slope (b±tSb) at 99%	0.012600 ± 0.3225475
C.L for Intercept (b±tSb) at 99%	0.07190 ± 0.61550
Concentration range (µg mL^{-1})	(5–14) mg/mL
Limit of Detection (µg mL^{-1})	0.3470
Limit of Quantitative (µg mL^{-1})	0.1190
Sandell's Sensitivity (µg mL^{-1})	0.07937
Molar absorbance ($L \cdot mol^{-1} \cdot cm^{-1}$)	2872.8
Composition of product	1:1
Recovery %	102.3211
RSD% n=4	0.00125
C.L for con.12 (µg mL^{-1})	12.1160 ± 0.04014
C.L for con.9 (µg mL^{-1})	9.1780 ± 0.03683
C.L for con.6 (µg mL^{-1})	6.1100 ± 0.01456
C.L for con.3 (µg mL^{-1})	3.1244 ± 0.0184

4 CONCLUSIONS

A reliable and sensitive spectrophotometric method was developed for the quantitative determination of Bisphenol A (BPA) based on an azo coupling reaction with benzidine. The method is characterized by a stable and intensely colored azo dye product, formed under optimized conditions of pH, reagent concentration, and reaction time. It exhibits excellent linearity over a broad concentration range, obeying Beer's law with a high correlation coefficient ($R^2 > 0.999$), and demonstrates high molar absorptivity, precision (low RSD%), and accuracy (recovery within acceptable limits). Low detection and quantification limits confirm the method's capability for trace-level analysis of BPA. Application to real environmental samples, including drinking water and industrial effluents, confirmed its practical applicability and reliability. Furthermore, the technique is simple, cost-effective, and does not require advanced instrumentation, making it a suitable tool for routine environmental monitoring of BPA contamination in water sources.

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