J Incl Phenom Macrocycl Chem (2012) 72:357–365
DOI 10.1007/s10847-011-9987-5

ORIGINAL ARTICLE

Spectrofluorometry study of β-cyclodextrin and *N*-phenyl-1-naphthylamine inclusion complex and its analytical application via artificial neural network

Sing Muk Ng · R. Narayanaswamy

Received: 25 March 2011 / Accepted: 11 May 2011 / Published online: 26 May 2011

Abstract The interaction between β-cyclodextrin (βCD) and *N*-phenyl-1-naphthylamine has been studied spectrofluorimetrically and found to form a 1:1 (βCD:NPN) inclusion complex at optimum conditions of pH 8 with the formation time of 120 s. The association constant of the complex was established to be 6.0×10^2 M, while a remarkable enhancement in fluorescence intensity was also observed at 445 nm with excitation of 334 nm. A spectroflurometric method for the detection of *N*-phenyl-1-naphthylamine has been developed having a dynamic range linear up to 4.67×10^{-7} M with a limit of detection of 0.58 nM. The repeatability study at two different βCD concentrations of 1.0×10^{-4} and 4.0×10^{-4} M was found to give RSD values of 2.40 and 1.42%, respectively. Artificial neural network (ANN) has been utilised to model the analytical system and successfully extended the analytical dynamic range up to 8.0×10^{-7} M from the original 4.67×10^{-7} M, brief network training and the optimum parameters of are described in this work.

Keywords Inclusion complex · β-Cyclodextrin · *N*-Phenyl-1-naphthylamine · Fluorescence · Artificial neural network

S. M. Ng (✉)
School of Engineering, Computing, and Science, Swinburne University of Technology Sarawak Campus, Jalan Simpang Tiga, 93350 Kuching, Sarawak, Malaysia
e-mail: smng@swinburne.edu.my

R. Narayanaswamy
Centre for Instrumentation and Analytical Science, School of Chemical Engineering and Analytical Science, The University of Manchester, P.O. Box 88, Sackville Street, Manchester M60 1QD, UK

Introduction

N-Phenyl-1-naphthylamine (NPN) is a lipophilic crystalline solid that is mainly used as antioxidant in rubber, greases, lubricating oil and transformer oil [1, 2]. It is also used as raw material for the production of dyes and other organic chemicals. NPN is believed to be toxic and the effect towards health is of much concern [3]. This is especially for those who are working directly under environments with high exposure of NPN such as at the production plants, rubber related industries or those oils related activities. Besides that, the release of NPN directly or indirectly to the environment is of high possibility due to its wide usages [4, 5]. This may be due to leakage of close system of greases and lubricating oils, the leakage of jet oils and the indirect discharge or decay of rubber related products. Upon entering the environment, it may causes carcinogenic effect and illness like Dermatitis to living organisms that have been directly in contact with it [6–11].

The detection and quantification of NPN is commonly carried out using established conventional methods such as mass spectroscopy and chromatography [12, 13]. These methods no doubt can produce accurate and sensitive detection of NPN, but the methodology of these methods involve highly skilled personal, time consuming and the use expensive instrumentations. It will be of great advantage to develop a simple and cheap method for the detection of NPN. This is a challenging task as NPN is lack of specific chemical functional groups that can be used to interact with any detection system or ligand. However β-cyclodextrin (βCD), a cyclic oligosaccharides consisting of seven D-(+)-glucopyranose units has the potential to be used as sensing reagent for NPN. It is due to the well-known properties of βCD in forming inclusion complexes with various guest molecules of different polarities and physical dimensions

[14–17]. Based on this, βCD has been readily adopted in various applications such as for developing analytical methods [18, 19], enzyme-subtract interactions [20], drug deliveries [21] and catalytic activities [22]. In addition, the formation of inclusion complex can alter the photochemical and photo-physical properties of the guest molecules, which turns to be useful for quantification purposes.

Generally, inclusion complexes formed between βCD and guess molecules have lower value of association constant compared to the interaction of metal ions with chelating ligands. Due to this, the typical double reciprocal (Benesi–Hildebrand) plots can be adopted to evaluate the formation constant of the system [23]. In cases where optical signal change is detected upon complexing, it can be used for quantification purpose but the linear range of the calibration curve is often short due to this weak inclusion interaction. This directly narrows down the detection range and causing limitation for real in situ applications. Therefore, a powerful tool for data modelling such as artificial neural network (ANN) can be utilised to overcome the short linear range weakness. ANN is a computational model that imitates the working system of human brain. The network consists of many individual 'nods' working in parallel, which is interconnected to each other with different weights. These weights are generally obtained by the network during the training sessions while the network architecture is still under construction. Once a neural network model is completely constructed, it has the ability to predict an output of a trained system with reasonable accuracy even if the variables of the system are not fully understood [24]. Due to this, ANN application has gained many interests in various different fields including analytical chemistry in simplifying various variable of a complex system. Conventional statistical methods have not managed to achieve such an outcome yet.

In this paper, βCD has been used to determine the concentration of NPN by monitoring the enhancement of fluorescence intensity due to inclusion complex formation. The basis chemistry behinds the inclusion complex formation was studied using the standard fluorometric approach. As for analytical application, ANN has been used as a tool for data processing and modelling, which consist of an input layer, hidden layers and an output layer. The network was optimised and constructed for the best data fitting and data prediction using various optimization parameters. The training of the ANN was carried out based on pattern recognition of the fluorescence spectrums obtained during the formation of inclusion complex. The main objective of this study is to demonstrate the ability of βCD used as sensing reagent for NPN to sub-nanomolar range based on the exclusive inclusion complex phenomenon. The use of ANN as tool for facilitating the analytical application will be evaluated.

Experimental

Reagents and chemicals

All chemicals and reagents used are of analytical grade unless otherwise stated. The solution of βCD (1.5×10^{-2} M) was prepared by dissolving accurately 0.8513 g of βCD (purchased for Fisher Scientific) into 50 mL of double-distilled deionised water. Stock solution of *N*-phenyl-1-naphthylamine (NPN) (2.0×10^{-3} M) was prepared by dissolving 0.0219 g of NPN (purchased for Fisher Scientific) in an opaque 50 mL volumetric flask using acetonitrile (Aldrich). The working solution of NPN was prepared accordingly by further diluting the stock solution into the appropriate concentration of acetonitrile. The buffer solution was prepared as reported using potassium hydrogen phthalate (PHP), (BORAX) and (TRIS) (all from Aldrich) and pH was adjusted using hydrochloride acid (HCl) (37%) (from Fisher) and sodium hydroxide (NaOH) (from AnalaR).

Apparatus and instrumentations

All fluorescence measurements were recorded using Perkin-Elmer LS55 spectrofluorometer with standard quartz cell of 1.0 cm. pH for solution was checked using HI 9815 pH meter with the accuracy of pH 0.1. All digitised data obtained were processed using Microsoft Excel. The ANN network was constructed with Matlab 7.0 programme using a Pentium IV, 1025 RAM personal computer.

Procedure

Complex formation

A 0.015 mL portion of NPN (8.0×10^{-5} M) working solution was added with 1.0 mL of buffer solution (pH 8), followed by 1.0 mL of βCD and the total volume of the mixture was made up to 3.0 mL using deionised water. The mixture solution was stirred homogenously before transferred to as standard quartz cuvette. The fluorescence emission spectrum of the formed host–guest complex was recorded at the range of 350 to 600 nm with an excitation at 334 nm. Same protocol was used to record the βCD and NPN fluorescence spectrum except not mixing the reagents together and the spectrums were recorded individually.

Optimisation of experimental variables

The optimum pH of the system was determined using buffer solutions with different pH values (pH 3–12) and the optimum pH was defined as the one gives the highest

fluorescence enhancement after complex formation. The volume of pH buffer added was also determined by varying the amount of buffer from 0.5 to 2.0 mL with an interval of 0.5 mL. The kinetic of the complex formation was followed generally by recording the intensity of the emitted fluorescence upon mixing the βCD with NPN in buffer solution. The influence of βCD concentration was studied using a fix concentration of NPN (2.5×10^{-7} M), but varying the concentration of βCD from 1.0×10^{-3} to 1.0×10^{-2} M.

Determination of complex stoichiometry and association constant

The stoichiometry and association constant of the inclusion complex were evaluated under the optimum experimental parameters using the established experimental method. The concentration of βCD was varied in an increasing manner to a fix concentration of NPN and the enhancement of the fluorescence intensity was recorded. Assuming that the complex has host-guess ratio of 1:1, the following expression can be written

$$\beta\text{CD} + \text{NPN} \rightleftharpoons \beta\text{CD}{-}\text{NPN} \quad (1)$$

The association constant (K_{as}) can be derived as,

$$K_{as} = \frac{[\beta\text{CD}{-}\text{NPN}]}{[\beta\text{CD}][\text{NPN}]} \quad (2)$$

where [βCD], [NPN] and [βCD–NPN] are equilibrium concentrations. The typical double reciprocal (Benesi–Hildebrand) plots can be used to evaluate the association constant as given below:

$$\frac{1}{(F - F_0)} = \frac{1}{(F_\infty - F_0)K_{as}[\beta\text{CD}]_0} + \frac{1}{F_\infty - F_0} \quad (3)$$

where $[\beta\text{CD}]_0$ denotes the initial concentration of βCD; F_0 is the NPN fluorescence intensity in the absence of βCD; F_∞ is the fluorescence intensity when all NPN formed complex with βCD and F is the observed fluorescence intensity at each βCD concentration tested. When a plot of $1/F - F_0$ versus $1/[\beta\text{CD}]_0$ is constructed, linear plot will be obtained for complex having 1:1 ratio.

For complex having the stoichiometry of 1:2 ratio, the following expression is obtained:

$$\frac{1}{(F - F_0)} = \frac{1}{(F_\infty - F_0)K'_{as}([\beta\text{CD}]_0)^2} + \frac{1}{F_\infty - F_0} \quad (4)$$

A linear plot will be obtained for the plot of $1/F - F_0$ versus $1/([\beta\text{CD}]_0)^2$ when the complex stoichiometry is 1:2. Upon obtaining the stoichiometry of the complex, the association constant can be determined by dividing the intercept by the slope of the corresponding linear plot.

Repeatability study

Repeatability study of the system was carried out with a fixed final concentration of NPN of 2.5×10^{-7} M. Two different final concentrations of βCD of 1.0×10^{-4} and 4.0×10^{-4} M respectively were used for the study. The study was conducted in pH 8 buffer solution and having as stirring time of 10 min before recording the fluorescence measurements. Each of the βCD concentration fixed was repeated for 10 times using same protocol and condition.

ANN construction and training

The construction of or the ANN network was based on the simple Back-Propagated Delta Rule Networks (BP), which the overall network consisting of three layers; an input layer, output layer and hidden layer(s) which sandwiched in between the two layers. The network topology was constrained to feed-forward protocol, where the neural nodes were connected from the input layer to the hidden layer before reaching the output layer. Each layer was associated with its neurones and each neurone has its own activation function. For the construction of a best network for this study, optimisation of the network parameters was carried out by a back-propagating training process, where hidden layer learns to record and provide a representation for the input data. During this process, unit error obtained from the network output compared to experimental data was used to alter weights on the output units. Then the error at the hidden nodes was calculated by back-propagating error approach at the output. After obtaining these values, the values were used to alter the weights on the hidden nodes to minimise the error of the output. The network parameters identified to be optimised were the number of hidden layer, number of epoch (cycle/period of training) and the learning rate. In this particular study, the fluorescence intensity spectral corresponded to different concentrations of NPN will be feed as the input pattern for the construction of the network as illustrated in Fig. 1.

Result and discussion

Fluorescence spectra

NPN was fluorometrically measured and the spectral characteristics result showed a maximum emission at 462 nm with an excitation wavelength of 334 nm (Fig. 2). When βCD was introduced into the NPN solution, a blue shift of approximately 17 nm on the maximum wavelength of the emission was observed. The newly formed emission spectra have an obvious increment in the fluorescence intensity. The βCD was observed to give low or no

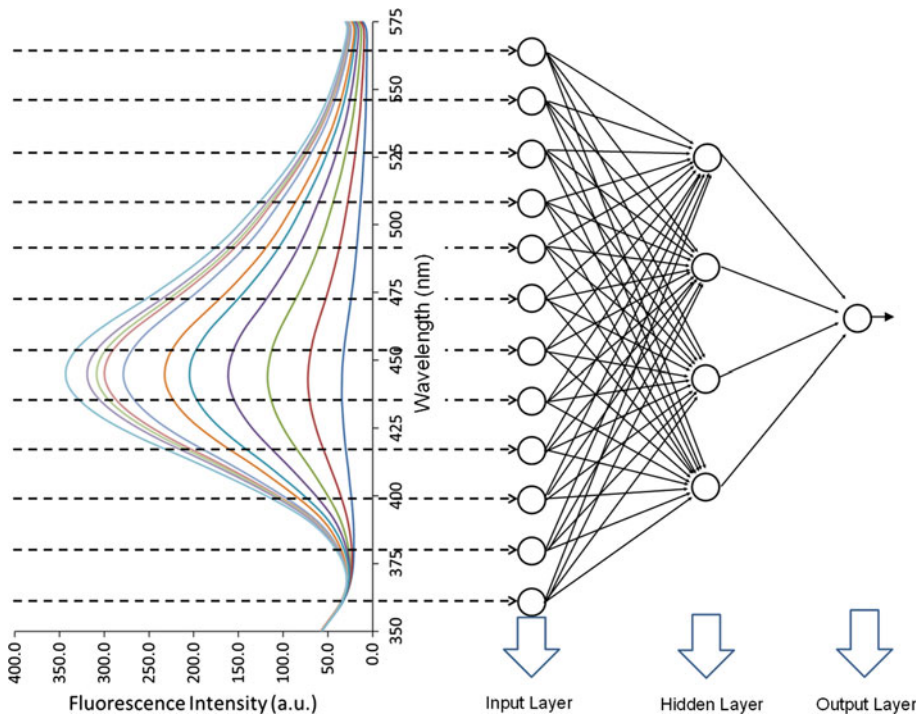

Fig. 1 Illustration of the basic of ANN architecture based on the fluorescence spectra recorded due to the inclusion complex formation of βCD with various concentration of NPN

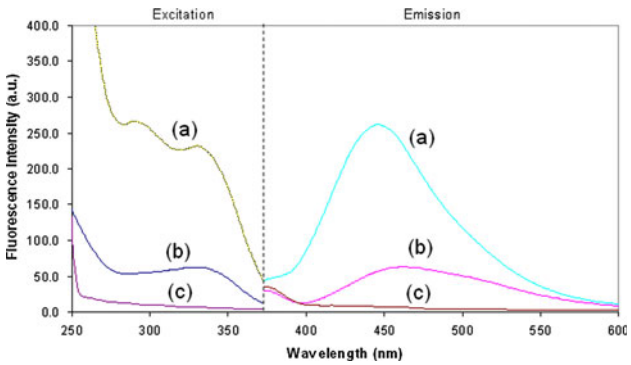

Fig. 2 Excitation and emission spectra recorded from (*a*) NPN with the present of βCD, (*b*) NPN with the absent of βCD and (*c*) βCD with the absent of NPN. Concentration of NPN; 2.5×10^{-7} M, βCD; 5.0×10^{-3} M

fluorescence intensity under the same condition of study. So the possible reason for the intensity enhancement observation was due to the formation of inclusion complex between NPN and βCD. NPN can enter the hydrophobic core of βCD under the acting forces such as Van der Waals bond and hydrogen bond. Besides that, the highly hydrophilic environment of the aqueous media can force the hydrophobic molecule into the cavity. This reduces the degree of motion freedom of the NPN molecule, which decreased the probability of the radiationless transition. Quenching that occurs in the aqueous environment will be also at its minimal level due to the shielding by the βCD shell. Hence the quantum efficiency of the fluorescence will increase. The correlation between the enhancement in fluorescence intensity and the formation of inclusion complex is well validated in the literature. For instance in the work by Abdel-Shafi and Al-Shihry [25], similar observation has been recorded in term of intensity enhancement, and their further study with proton nuclear magnetic resonance (^{1}H NMR) spectroscopy has proven the formation of inclusion complex. Latest, Bakkialakshmi and Menaka [26] proved the same correlation in their work dealing with the complexation of rhodamine 6G with βCD. Such observation was also recorded in our previous work that deals with the development of βCD imprinted polymer for the detection of NPN [27].

Optimisation of experimental variables

Influence of pH

βCD was reported to be instable in very low pH due to hydrolysis. Thus, the study has excluded the use of strong acidic buffer to avoid the degradation of βCD. The change in relative fluorescence intensity of NPN before and after the forming of complex as a function of pH from 3 to 12 was studied. The results obtained (Fig. 3) have showed a constant increment in fluorescence enhancement as the pH increases from 3 to 8. The maximum enhancement was recorded to be at the pH range of 8–11 before showing a drastic decrease upon reaching pH 12. This decrease may

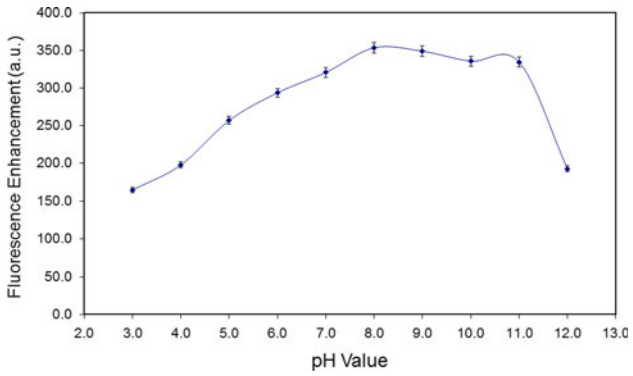

Fig. 3 Influence of pH on the net fluorescence enhancement of NPN–βCD complex for a fixed concentration of NPN and βCD

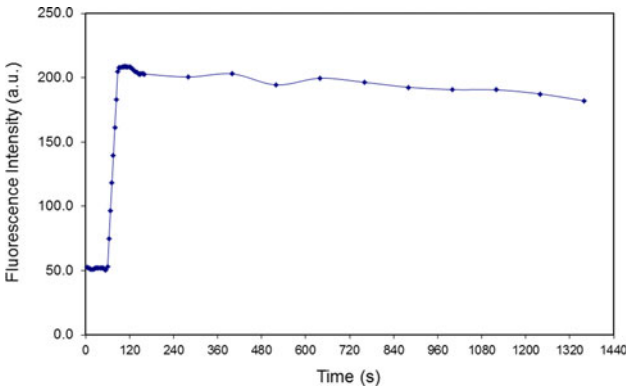

Fig. 4 Fluorescence intensity recorded during the formation of inclusion complex without external stimuli. Concentration of NPN; 2.5×10^{-7} M, βCD; 5.0×10^{-3} M

be due to the formation of fully hydrolysed βCD molecule, which is incapable to form inclusion complex. Optimum pH was determined to be between 8 to 11 range and pH 8 has been chosen for this study.

Influence of buffer volume

Buffer strength of the system was studied by varying the volume of the buffer added to the system. As the volume of the buffer added from 0.5 to 2.0 mL with an interval of 0.5 mL, the effect on the fluorescence enhancement was observed to be not significant. It was identified to have a decrease of only 6.45% in the enhancement when the volume of the buffer was increased.

Response time

Sufficient time for the formation of inclusion complex between NPN and βCD is needed before the intensity of the fluorescence can be recorded. This is to ensure consistency and reliability of the results. The results obtained (Fig. 4) from the study showed that the fluorescence intensity increase drastically upon the injection of βCD into the system and reached a stable signal after 10 min. The signal remained constant for over another 10 min without significant fluctuation. Hence, all the fluorescence recordings were performed after a minimum of 10 min, after all the involved ingredients were mixed together. The response time recorded here was under static condition after mixing of the ingredients without external physical stimuli like shaking of stirring. Time taken under this condition is assumed to be the maximal period required for the complexation to complete. However, the response time can be reduced by external stimuli if a more rapid analysis is needed for a specific application. It was reported by Algarra Gonzalez and Hernandez Lopez [28] that the response time was great reduced by sonication in their work dealing with the study of inclusion complexes of cyclodextrins and its derivatives with polyaromatic hydrocarbons (PAHs).

Influence of βCD concentration

The effect of βCD concentration on the fluorescence enhancement is shown in Fig. 5, where the insert is the raw fluorescence spectrum recorded with different concentrations of βCD. It is obvious that the intensity increases as more βCD was added at the initial stage. A gradually increment in the fluorescence intensity was recorded until reaching the concentration of about 6.0×10^{-3} M due to the formation of complex. No further enhancement was observed as the concentration of βCD was further increased up to 8.0×10^{-3} M. The fluorescence intensity showed a decrease as the concentration of βCD exceeded 8.0×10^{-3} M. This may be due the common factor of self-quenching phenomena as the concentration of the reagent reached a very high value.

Complex stoichiometry and association constant

The inclusion complex stoichiometry was obtained by fitting the experimental data obtained from the study with varying concentrations of βCD into the typical Benesi–Hildebrand equation. In order to avoid misinterpretation, the data obtained with extreme high concentration of βCD was excluded for the evaluation due to the quenching phenomenon that decreases the fluorescence intensity.

The first assumption of the complex stoichiometry was made based on 1:1 (βCD:NPN) ratio and thus Eq. 3 was adopted for the evaluation. The plot of $1/(F - F_0)$ versus $1/[\beta CD]_0$ was constructed and important information that could be derived is given in Table 1. The second assumption was made that the complex has a 2:1 stoichiometry and Eq. 4 was used for the evaluation by plotting $1/(F - F_0)$ versus $1/([\beta CD]_0)^2$. Important information from

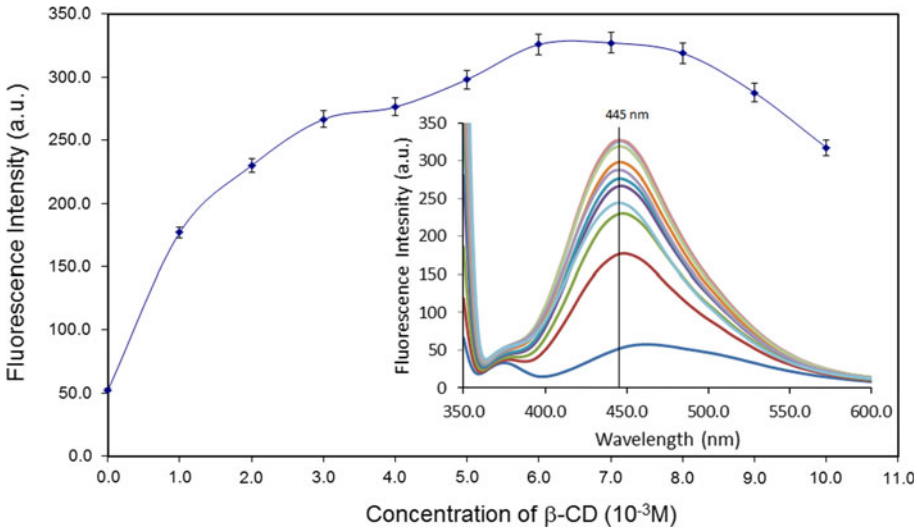

Fig. 5 Influence of βCD concentration on the fluorescence intensity for a fixed concentration of NPN (2.5×10^{-7} M). Inset is the raw spectra of the fluorescence profile record for each of the different concentration of βCD

Table 1 Information of the plots used to predict the stoichiometric ratio of the complex formation of NPN–βCD

Plot	Function	Linear correlation relationship	R^2
Equation 3	$1/(F - F_0)$ vs. $1/[\beta CD]_0$	$1/(F - F_0) = 5.0 \times 10^{-6}\ (1/[\beta CD]_0) + 0.0030$	0.9930
Equation 4	$1/(F - F_0)$ vs. $1/([\beta CD]_0)^2$	$1/(F - F_0) = 4.0 \times 10^{-9}\ (1/([\beta CD]_0)^2) + 0.0039$	0.9398

Both equations of the model were fitted with linear relationship

the second assumption was also compiled in Table 1 as for comparison. From the comparison result, the stoichiometry of the complex was confirmed to be 1:1 due to the linear line obtained from the plot with the assumption of 1:1 stoichiometry. The second plot with the assumption of 2:1 stoichiometry was concluded as having a non-linear relationship based to the low correlation coefficient ($\leq$0.9900) when a linear model was applied to the second plot. Based on the conclusion of 1:1 complex formation, simulation of the possible structure of the complex has been carried out using PC Model software. The most stable structure of complex was obtained by minimising the interaction energy of the two structures as illustrated in Fig. 6.

The apparent association constant was determined from the plot of $1/(F - F_0)$ versus $1/[\beta CD]_0$ by dividing the intercept by the slope of the plotted linear line. The association constant of the inclusion complex obtained from this experimental condition (25 °C) was determined to be 6.0×10^2 L mol^{-1}. This value is reasonable and consistent within the range that is usually recorded for such inclusion complex system. For instance, Algarra Gonzalez and Hernandez Lopez [28] has evaluated a value of 4.70×10^2 L mol^{-1} for the association constant of a fluorene-βCD under quite similar condition. In this case, NPN is portraying a stronger complex compared to the fluorene as it has an additional nitrogen atom that can contribute towards the formation of hydrogen bond with the hydroxide groups on the main βCD structure.

Figure of merits

Under the optimum experimental conditions, fluorescence enhancement of NPN by βCD was determined over a range of different concentrations of NPN concentrations. The average of four net fluorescence intensities at each concentration was plotted against the NPN concentrations (Fig. 7). The dynamic range of the system was determined to be linear up to 4.67×10^{-7} M with a correlation coefficient (R^2) of 0.9975 (inset figure, Fig. 7). Within the linear range, regression equation was determined to be $F = 6.0 \times 10^8\ [\beta CD] - 5.7743$. Due to the non-linearity in the relationship between the enhancement and concentration of NPN, only the linear dynamic range of the plot was used for the evaluation of limit of detection (LOD). The LOD is evaluated using 3σ/s, where σ is the standard deviation obtained from the blank signals and s is the slope of the linear calibration plot (inset figure, Fig. 7). The LOD thus calculated was determined to be 0.58 nM. The fluorescence intensity obtained from repeatability study conducted with each 10 samples of two different concentrations of βCD. The results gave relative standard deviation (RSD) values of 2.40 and 1.42% for the concentration of βCD 1.0×10^{-4} and 4.0×10^{-4} M, respectively. Since the well accepted deviation ceiling is 5%, both the RSD values were considerable low with the indication of highly repeatable result, which gives a very promising credit to be used for analytical application.

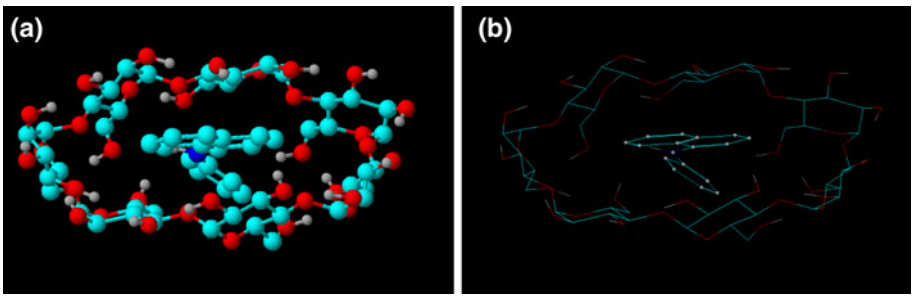

Fig. 6 Simulated structure of the NPN–βCD complex using PC-Model software based on 1:1 ratio using energy minimisation option. **a** The stick and ball view; **b** the stick view

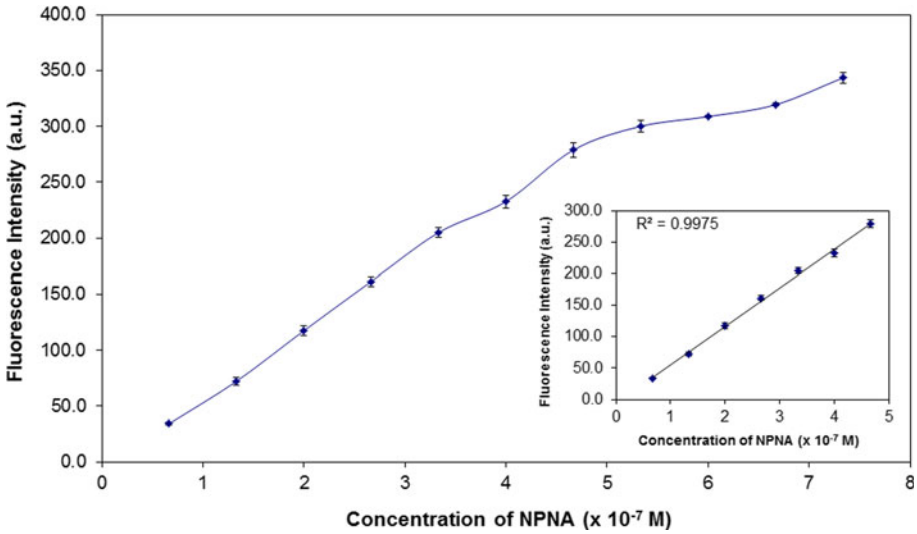

Fig. 7 Calibration plot and the dynamic range of NPN with βCD under standard and optimised conditions. Inset shows the linear range at the lower concentration range of NPN

ANN optimisation parameters

Pre-processing of data

The emission spectral (range from 370 to 570 nm) for the different concentrations of studied NPN was plotted in 3D (Fig. 8) to obtain an overview of the pattern that represented the data. The data points recorded over the range is considerably too large to be used for ANN training purpose, as over feeding into the network can cause problems such as saturation of the network training algorithm or causing the network optimization outcomes to diverge. Data selection and pre-processing is a vital step in neural network successful design. The pre-processing of data was done by mapping all the inputs and the outputs in a scaled range between +1 and -1. As for the selection of data, it was done through trial and error method and the one employed in this study was taking the effective range starting from 370 up to 570 nm with an increment of 5 nm. Data points in this range was observed to be significantly responding to the different concentrations of NPN, and manage to give a good representative of the overall analytical trend for this system. The selection of such data necessitates the input layer having 81 neurons each

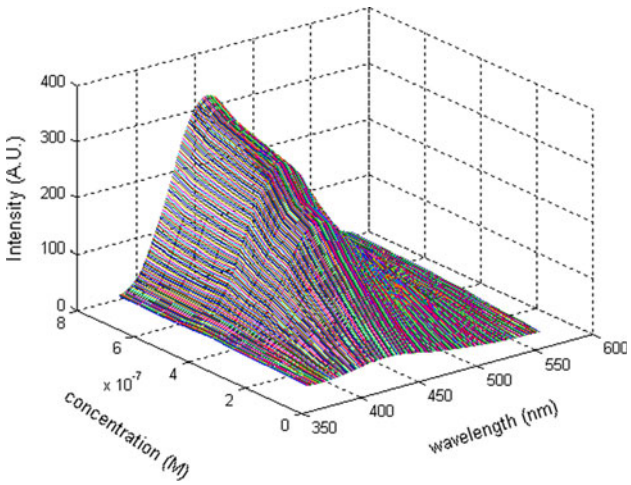

Fig. 8 3-Dimension (3D) plot of NPN concentrations versus fluorescence intensity at different wavelengths

corresponds to the fluorescence intensity at a particular wavelength.

Training and optimisation parameters

To avoid network overtraining the NPN data were randomly divided into three sets as the following:

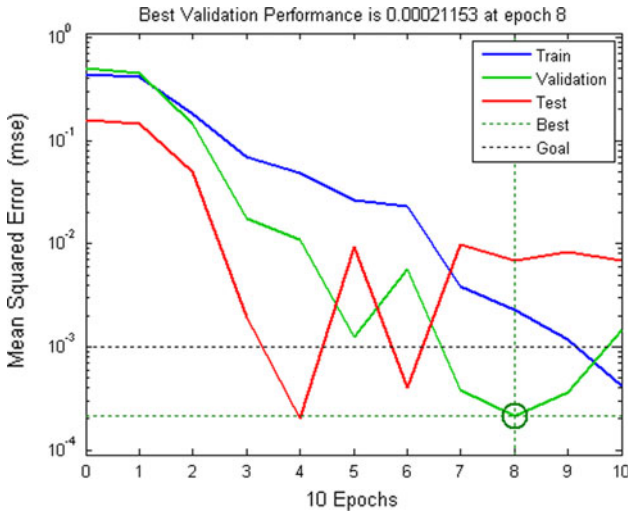

Fig. 9 Plot of the training errors, validation errors and test errors from ANN analysis

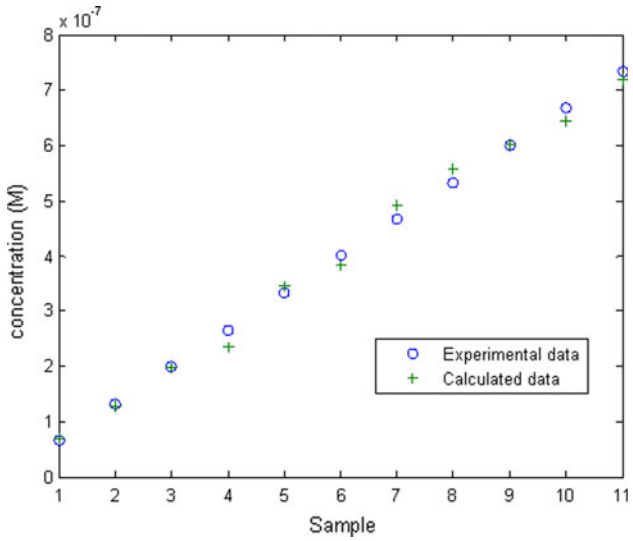

Fig. 10 Experimental and predicted concentrations of various samples recorded using the ANN as modelling tool

- 60% are used for training.
- 20% are used to validate that the network is generalizing and to stop training before over fitting.
- The last 20% are used as a completely independent test of network generalization.

The training was stopped when the validation error started to increase, which occurred at iteration 8 epochs. A plot of the training errors, validation errors, and test errors are shown in Fig. 9. In this particular case, the result is satisfactory as the final mean-square error is small and equal to 0.000212 and R^2 value is equal to 0.9930.

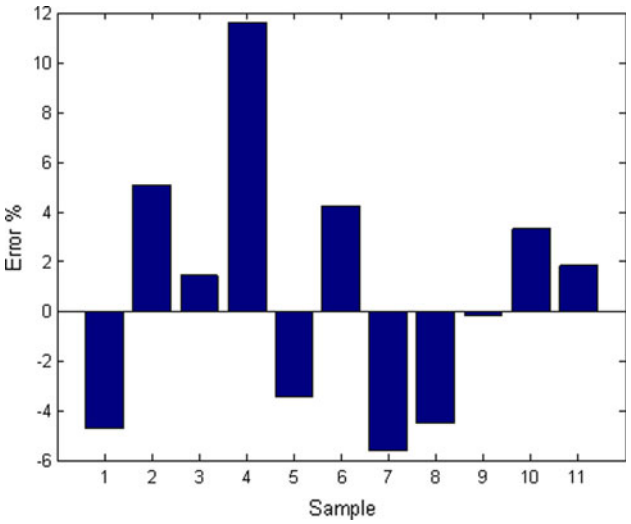

Fig. 11 Percentage of prediction error between experimental and calculated data obtained using the optimised ANN architecture

Validation and prediction

Figure 10 illustrates plot of experimental and predicted concentrations versus sample while Fig. 11 shows the error % between experimental and predicted data. The network topology used was having three hidden layers with 20, 15 and 15 hidden neurons respectively. The network has one output which is the concentration and 81 inputs which are the intensity measured at 370 nm and at a step of 5 nm to 570 nm. The predicted result demonstrated that the ANN output was fairly accurate and can be used to extend the NPN analysis to the full concentration range studied, which is up to 8.0×10^{-7} M.

Conclusion

A study has been conducted on the formation of inclusion complex between NPN and βCD. Basic insights of this inclusion complex have been review using spectrofluorometry method. Along with this study, it was found that the inclusion complex caused an enhancement of fluorescent intensity of the NPN. Based on this, a simple fluorometric method was developed for the detection of NPN in the sub-nanomolar range. In order to further maximise the capability, ANN has been successfully adopted for the data analysis and has extended the dynamic range of the system up to the full range of concentration studied in this work. Besides that, this work has demonstrated the use of ANN to predict a fairly accurate concentration of NPN using fluorescent intensity as input.

Acknowledgment We would like to thank to Dr. Read Al-Jowder for the advices and helps in ANN analyses.

References

1. Koennecker, G., Mangelsdorf, I., Wibbertmann, A.: N-phenyl-1-naphthylamine. IPCS Concise International Chemical Assessment Documents (9), pp. 1–25 (1999)
2. Davis, T.G., Thompson, J.W.: Synergistic antioxidants for synthetic lubricants. Ind. Eng. Chem. Prod. Res. Dev. **5**(1), 76–80 (1966)
3. Winder, C., Balouet, J.-C.: The toxicity of commercial jet oils. Environ. Res. **89**(2), 146–164 (2002)
4. Rosenberg, A.: Microbial metabolism of N-phenyl-1-naphthylamine in soil, soil suspensions, and aquatic ecosystems. Chemosphere **12**(11–12), 1517–1523 (1983)
5. Jungclaus, G., Avila, V., Hites, R.: Organic compounds in an industrial wastewater: a case study of their environmental impact. Environ. Sci. Technol. **12**(1), 88–96 (1978)
6. Fontana, L., Lasfargues, G., Ughetto, S., Rogier, S., Masdieu, E., Lafaure, M., Aublet-Cuvelier, B., Catilina, P.: The micronucleus assay in human exfoliated urothelial cells: application in a genotoxicity study of workers exposed to a mineral jelly containing sodium nitrite and N-phenyl-1-naphthylamine. Mutagenesis **16**(5), 449–452 (2001)
7. Wang, H., Wang, D., Dzeng, R.: Carcinogenicity of N-phenyl-1-naphthylamine and N-phenyl-2-naphthylamine in mice. Cancer Res. **44**(7), 3098–3100 (1984)
8. Vernot, E.H., MacEwen, J.D., Haun, C.C., Kinkead, E.R.: Acute toxicity and skin corrosion data for some organic and inorganic compounds and aqueous solutions. Toxicol. Appl. Pharmacol. **42**(2), 417–423 (1977)
9. Greenhouse, G.: The evaluation of toxic effects of chemicals in fresh water by using frog embryos and larvae. Environ. Pollut. **11**(4), 303–315 (1976)
10. Greenhouse, G.A.: Toxicity of N-phenyl-α-naphthylamine and hydrazine to *Xenopus laevis* embryos and larvae. Bull. Environ. Contam. Toxicol. **18**(4), 503–511 (1977)
11. Kalimo, K., Jolanki, R., Estlander, T., Kanerva, L.: Contact allergy to antioxidants in industrial greases. Contact Dermatitis **20**(2), 151–152 (1989)
12. Keller, M.A., Saba, C.S.: Chromatographic analysis of phenyl-1-naphthylamine and 4,4′-dioctyldiphenylamine and their intermediate oxidation products in oxidized lubricants. J. Chromatogr. A **409**, 325–335 (1987)
13. Bartl, P., Zuber, K., Leipold, M., Zeman, A.: Quality control of used synthetic aviation turbine oils by analytical methods. Fresenius' J. Anal. Chem. **314**(1), 25–28 (1983)
14. Palaniappan, K., Hackney, S.A., Liu, J.: Supramolecular control of complexation-induced fluorescence change of water-soluble, β-cyclodextrin-modified CdS quantum dots. Chem. Commun. **10**(23), 2704–2705 (2004)
15. Hapiot, F., Tilloy, S., Monflier, E.: Cyclodextrins as supramolecular hosts for organometallic complexes. Chem. Rev. **106**(3), 767–781 (2006)
16. Rekharsky, M.V., Inoue, Y.: Complexation thermodynamics of cyclodextrins. Chem. Rev. **98**(5), 1875–1918 (1998)
17. Connors, K.A.: The stability of cyclodextrin complexes in solution. Chem. Rev. **97**(5), 1325–1358 (1997)
18. Zhang, L.-Y., Sun, M.-X.: Fast determination of glutathione by capillary electrophoresis with fluorescence detection using [beta]-cyclodextrin as modifier. J. Chromatogr. B **877**(31), 4051–4054 (2009)
19. Esquembre, R., Pastor, I., Mallavia, R., Mateo, C.R.: Fluorometric detection of nitric oxide using 2,3-diaminonaphthalene incorporated in [beta]-cyclodextrin. J. Photochem. Photobiol. A: Chem. **173**(3), 384–389 (2005)
20. Srisimarat, W., Pongsawasdi, P.: Enhancement of the oligosaccharide synthetic activity of [beta]-galactosidase in organic solvents by cyclodextrin. Enzyme Microb. Technol. **43**(6), 436–441 (2008)
21. Oda, M., Saitoh, H., Kobayashi, M., Aungst, B.J.: [Beta]-cyclodextrin as a suitable solubilizing agent for in situ absorption study of poorly water-soluble drugs. Int. J. Pharm. **280**(1–2), 95–102 (2004)
22. Ishiwata, S., Kamiya, M.: Cyclodextrin inclusion: catalytic effects on the degradation of organophosphorus pesticides in neutral aqueous solution. Chemosphere **39**(10), 1595–1600 (1999)
23. Seelig, E.W., Tang, B., Yamilov, A., Cao, H., Chang, R.P.H.: Self-assembled 3D photonic crystals from ZnO colloidal spheres. Mater. Chem. Phys. **80**(1), 257–263 (2003)
24. Han, C.L., Sing, M.N., Ahmad, M., Taib, M.N.: Accurate zirconium detection at visible wavelength using artificial neural network. Anal. Lett. **38**(8), 1305–1316 (2005)
25. Abdel-Shafi, A.A., Al-Shihry, S.S.: Fluorescence enhancement of 1-napthol-5-sulfonate by forming inclusion complex with [beta]-cyclodextrin in aqueous solution. Spectrochim. Acta Part A Mol. Biomol. Spectrosc. **72**(3), 533–537 (2009)
26. Bakkialakshmi, S., Menaka, T.: Fluorescence enhancement of rhodamine 6G by forming inclusion complexes with [beta]-cyclodextrin. J. Mol. Liquids **158**(2), 117–123 (2011)
27. Ng, S.M., Narayanaswamy, R.: Molecularly imprinted [beta]-cyclodextrin polymer as potential optical receptor for the detection of organic compound. Sens. Actuators B: Chem. **139**(1), 156–165 (2009)
28. Algarra Gonzalez, M., Hernandez Lopez, M.: Determination of fluorene in sea-water by room temperature phosphorescence in organised media[dagger]. Analyst **123**(11), 2217–2221 (1998)