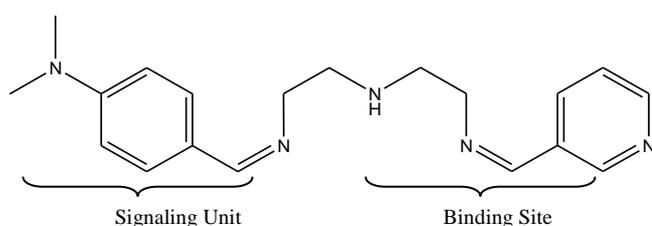


# Fluorescent Chemosensor Bearing Amine and Benzenyl Functionality for Fe<sup>3+</sup> Ions Detection in Aqueous Solution

Sharizal Hasan, Salamiah Zakaria, and Siti Nur Ain Mohd Adnan

**Abstract**—Recently designing of fluorescent chemosensor for heavy metal ions detection with high specificity and sensitivity have been explored. In this works, two steps synthesis of A was prepared using Schiff base technique. Monocondensed ligand was prepared by reacting diethylenetriamine with 4-dimethylaminobenzaldehyde, followed by attaching 3-pyridinecarbaldehyde on the other side of diethylenetriamine. Sensor A was fully characterized by FT-IR, <sup>1</sup>H-NMR and elemental analysis (CHN). The signal at 1639.46 cm<sup>-1</sup> in FT-IR spectrum was assigned to C=N, formed after condensation reaction in between aldehyde and amine. NH<sub>2</sub> peak at 3278.78 cm<sup>-1</sup> still appeared proved the monocondensed ligand. <sup>1</sup>H-NMR values at 8.19 ppm and 2.72 ppm were assigned to HC=N and -NH<sub>2</sub> respectively. Dicondensed ligand was formed after addition of 3-pyridinecarboxaldehyde. NH<sub>2</sub> signal in both FT-IR and <sup>1</sup>H-NMR spectrum was absent indicating both amines in triamine undergone condensation to form dicondensed. <sup>1</sup>H-NMR spectrum at 8.19 ppm was assigned to (HC=N) appeared due to the formation of imine proton. The fluorescent spectral measurements revealed that A was selective towards Fe<sup>3+</sup> ions but not for other metal ions such as Co<sup>2+</sup>, Ni<sup>2+</sup>, Cu<sup>2+</sup> and Zn<sup>2+</sup>. The detection limit of A was 6.49 × 10<sup>-5</sup> M and expected to be useful as chemical sensor.

**Index Terms**—Diethylenetriamine, Fe<sup>3+</sup> ion, Fluorescence Chemosensor, Schiff base.



## I. INTRODUCTION

The detection of heavy metal ions are important in many applications, including environmental monitoring, waste management, developmental biology, and clinical toxicology. Transition metal ions represent an environmental concern when present in excess amounts, but at the same time some of them are present as essential elements in living organism. Among various transition metals, iron is the most abundant essential trace element in the human body which plays vital

roles in many biological processes [1]. Lack of iron in primary stages can cause anemia [2], kidney failure and heart diseases [3] Therefore, the demand for fast detection and selective sensor of Fe<sup>3+</sup> from other ions is important applications in environment and biological systems.

A number of techniques, such as inductively coupled plasma atomic emission spectrometry [4], electrochemical methods and fluorescence techniques, have been developed for Fe<sup>3+</sup> analysis. However, most of these techniques require expensive equipment, sample pretreatment, and trained operators [5]. Among these methods, much effort has been made in colour changes and emission fluorescent changes because they offers advantages such as sensitivity, selectivity, rapid response time, local observation and lower detection limits [6].

The development of efficient fluorescent chemosensors for various cations has received great attention because of the sensitivity of the techniques related to environmental and biological aspects [7]. A fluorescent chemosensors commonly consists of two parts, a receptor (recognition element) responsible for the molecular recognition of the metal ion linked to a fluorophore (fluorescence reporter) which responsible of signaling the recognition event [8]. The interaction of the analyte with the binding site caused changes in the electronic properties (e.g., enhancement or inhibition of absorption or fluorescence) of the signalling subunit resulting in sensing of the target ion. Therefore, an ideal fluorescent chemosensor must meet two basic requirements: firstly, the receptor must have the strongest affinity with the relevant target (binding-selectivity). Secondly, on the basis of good binding-selectivity, the fluorescence signal should avoid environmental interference (signal-selectivity) [9]. In this respect Schiff base ligands are very attracting to be used as sensing material for chemosensor because they are easy to coordinate with metal ions [10].

Fluorophores are particularly attractive optical molecules and have recently found applications in self-assembled chemosensors, for signal amplification by allosteric catalysis, in supramolecular analytical chemistry, and as fluorescent and photochromic chemosensors. Among various fluorophore, 4-dimethylaminobenzaldehyde is one of the most useful tools due high Stokes shift [11], [12], which makes it appropriate for constructing chemosensor. Therefore, 4-dimethylaminobenzaldehyde was chosen as a fluorophore, diethylenetriamine and 3-pyridinecarbaldehyde used as an ionophore due to their high fluorescence quantum yield and good coordination ability. Herein, we report a convenient and efficient route for the preparation of A i.e. N-{2-[(4-Dimethylamino-benzylidene)-amino]-ethyl}-N'-pyr

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The authors are with the Faculty of Applied Sciences, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia (e-mail: sharizal187@perlis.uitm.edu.my, salamiah882@perlis.uitm.edu.my, aainadnan@gmail.com).

idin-3-ylmethylene-ethane-1,2-diamine by using schiff base technique and its new application as a cation sensor. Chemosensor A shows excellent selectivity and sensitivity towards  $\text{Fe}^{3+}$  over other metal ions in aqueous solution.

## II. EXPERIMENTAL

### A. Materials and Instruments

All commercial grade chemicals and solvents were used without further purification. 4-diaminobenzaldehyde, diethylenetriamine and 3-pyridinecarbaldehyde were obtained from Sigma. The elemental analysis was carried out on Thermo Finnigan Flash EA 110 Elemental Analyzer. Infrared spectra were obtained on Perkin Elmer 100 spectrophotometer on KBr discs in the range  $4000\text{--}600\text{ cm}^{-1}$ .  $^1\text{H}$  NMR spectra were recorded on a Bruker Varian 600 Hz using chloroform- $d$  and acetone- $d_6$  solutions with TMS as internal standard. The fluorescence spectra were recorded on Luminescence Spectrometer LS 55 equipped with quartz cuvettes of 1 cm path length. The excitation and emission slit widths were 10 nm. All emission spectra was recorded at  $24 \pm 1^\circ\text{C}$ . Stock solutions for analysis were prepared (0.1 M for compound A ( $\text{CH}_3\text{OH}/\text{H}_2\text{O}$ , 9:1 (v/v),  $\text{Tris-HNO}_3 = 10\text{ mM}$ ,  $\text{pH} = 7.0$ ) immediately before the experiments. The solutions of metal ions were prepared from perchlorate salts of  $\text{Cu}^{2+}$ ,  $\text{Zn}^{2+}$ ,  $\text{Co}^{2+}$ ,  $\text{Ni}^{2+}$  and  $\text{Fe}^{3+}$ . The studies on the binding properties of A were carried out in solution ( $\text{CH}_3\text{OH}/\text{H}_2\text{O}$ , 9:1 (v/v),  $\text{Tris-HNO}_3 = 10\text{ mM}$ ,  $\text{pH} = 7.0$ ). The different metal ion solutions (10 equiv.) were prepared by dissolving the desired amount of metal salts in  $\text{H}_2\text{O}$ . The fluorescence titration was performed with a series of  $5 \times 10^{-5}\text{ M}$  solutions of A containing various equivalents of  $\text{Fe}^{3+}$  ions. Binding studies were confirmed by job's plot and nonlinear curve fitting methods. The association constant ( $K_a$ ) were calculated by the linear Benesi-Hildebrand equation from fluorescence (Eq. (1)) study by,

$$\frac{1}{(F - F_0)} = \frac{1}{(F_\alpha - F_0)} + \frac{1}{K(F_\alpha - F_0)} \times \frac{1}{[M^{n+}]} \quad (1)$$

where  $F$ ,  $F_0$  and  $F_\alpha$  are the emission intensities, respectively in the absence and infinite concentration of the metal ion ( $M^{n+}$ ) [13].

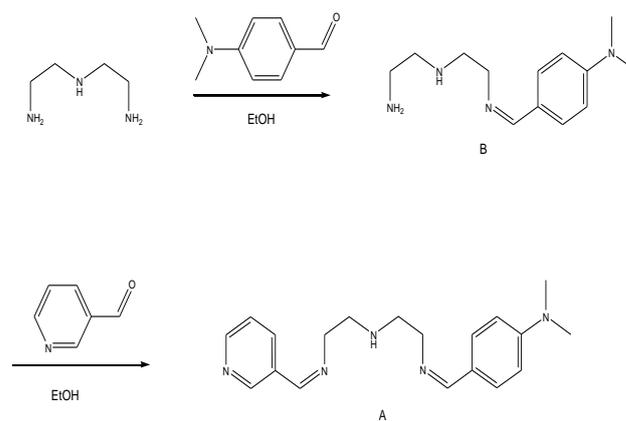
### B. Synthesis

A convenient synthetic route for compound A from commercially available compounds is provided and depicted in Scheme 1.

Compound B: Diethylenetriamine (0.01 mol) and 4-dimethylaminobenzaldehyde (0.01 mol) were dissolved in ethanol (50 ml). The reaction mixture was stirred and refluxed for 6 h. After the solvent was evaporated under reduced pressure, the oily product was dried in dessicator overnight to removed excess solvent to afford a yellow solid product. Yield: 2.2 g (84%). IR ( $\text{cm}^{-1}$ ): 1633 (C=N), 3278.78 ( $\text{NH}_2$ ), 1602.60 (Ar, C=C).  $^1\text{H}$  NMR (600 MHz, Acetone- $d_6$ )  $\delta$  9.74 (s, 1H), 8.96 – 8.81 (m, 2H), 8.44 (d,  $J = 7.8\text{ Hz}$ , 1H), 8.18 – 8.11 (m, 1H), 7.91 – 7.83 (m, 1H), 7.56 – 7.48 (m, 2H), 7.48 –

7.39 (m, 1H), 7.35 – 7.24 (m, 1H), 7.13 (dd,  $J = 8.8, 2.8\text{ Hz}$ , 0H), 6.78 – 6.67 (m, 2H), 3.65 – 3.48 (s, 2H), 3.12 (s, 7H), 2.59 – 2.49 (m, 1H), 1.94 (s, 2H) ppm. Anal. Calc. for  $\text{C}_{13}\text{H}_{22}\text{N}_4$ : C, 66.63; H, 9.36; N, 23.91. Found: C, 60.65; H, 8.99; N, 22.27.

Compound A: Compound B (0.012 mol) and 3-pyridinecarbaldehyde (0.012 mol) were dissolved in ethanol (50 ml). The reaction mixture was stirred and refluxed for 48 h. After the solvent was evaporated under reduced pressure, the oily product was dried in dessicator overnight to removed excess solvent. Yield: 3.3 g (76%). IR ( $\text{cm}^{-1}$ ): 1633 (C=N), 3278.78 ( $\text{NH}_2$ ), 1602.60 (Ar, C=C), 1521.13 (Ar, C=C).  $^1\text{H}$  NMR (600 MHz, Chloroform- $d$ )  $\delta$  8.08 (m, 4H), 3.59 (d,  $J = 6.2\text{ Hz}$ , 2H), 2.87 (d,  $J = 12.9, 4.5\text{ Hz}$ , 6H), 2.62 (s, 1H), 1.94 (d,  $J = 2\text{ Hz}$ ).



Scheme 1. Chemical structure and synthetic route of compound A.

## III. RESULTS AND DISCUSSIONS

### A. Synthetic Design of Chemosensor A

The two step synthesis of the benzenyl based chemosensor A is shown in Scheme 1. Briefly, Schiff base reaction between 4-dimethylaminobenzaldehyde and diethylenetriamine in ethanol affords the product B which is then purified by the recrystallization in methanol and characterized by analytical and spectroscopic techniques.

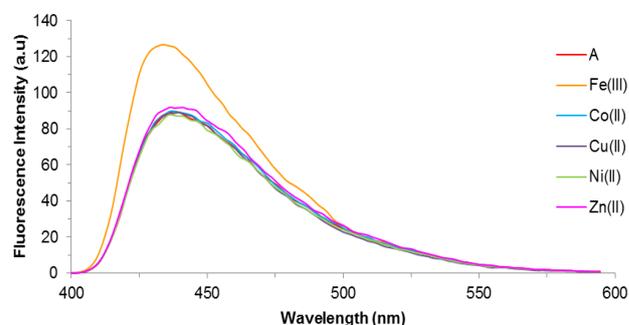


Fig. 1. Fluorescence spectral changes of A ( $5 \times 10^{-5}\text{ M}$ ) ( $\text{CH}_3\text{OH}/\text{H}_2\text{O}$ , 9:1 (v/v),  $\text{Tris-HNO}_3 = 10\text{ mM}$ ,  $\text{pH} = 7.0$ ) in the presence of various metal ions (0-10 equiv. of each,  $\lambda_{\text{ex}} = 385.6\text{ nm}$ ).

### B. Evaluation of Selectivity

A significant feature of a sensor is its high selectivity towards specific analyte over others. Hence, the selectivity of the sensor for metal cations was initially examined in solution

(CH<sub>3</sub>OH/H<sub>2</sub>O, 9:1 (v/v), Tris-HNO<sub>3</sub> = 10 mM, pH = 7.0). The fluorescence emission spectra of the A with metal ions were studied. As shown in Fig. 1, the emission maximum and the fluorescence intensity slightly changed after treatment with Fe<sup>3+</sup>, while other metal ions (such as Cu<sup>2+</sup>, Zn<sup>2+</sup>, Co<sup>2+</sup> and Ni<sup>2+</sup>) caused no significant change. Sensor A showed a weak fluorescence. As a result, A exhibits a selective detection of Fe<sup>3+</sup> when compared to other metal ions by a fluorescence turn-on response. The competitive experiments were carried out in the presence of 1 equiv. of Fe<sup>3+</sup> mixed with 1 equiv. of miscellaneous metal ions, including Cu<sup>2+</sup>, Zn<sup>2+</sup>, Co<sup>2+</sup> and Ni<sup>2+</sup>, respectively. Compared the probe with Fe<sup>3+</sup>, there were no distinct variations in the emission intensity of the probe with the mixture of Fe<sup>3+</sup> and other interfering metal ions. The emission intensity of the solution at 126.67 nm (emission maxima) is shown in Fig. 2.

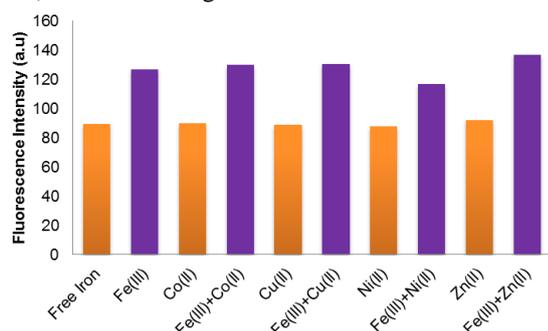


Fig. 2. Fluorescence emission spectra changes of competitive selectivity of A ( $5 \times 10^{-5}$  M) (CH<sub>3</sub>OH/H<sub>2</sub>O, 9:1 (v/v), Tris-HNO<sub>3</sub> = 10 mM, pH = 7.0) toward Fe<sup>3+</sup> (1 equiv.) in the presence of other metal ions (1 equiv.).

### C. Stoichiometry and Binding Mode Studies

In order to determine the binding ability and limit of detection of Fe<sup>3+</sup> with A, the fluorescence titrations of A were performed by gradually increasing the concentration of Fe<sup>3+</sup>. Fluorescence intensity was increased with increasing the concentration Fe<sup>3+</sup> (0–10 equiv.). According to the fluorescence titration curve (Fig. 3), the peak maxima at 126.67 nm for A versus Fe<sup>3+</sup> concentration were plotted and a good linear fluorescence response and regression coefficient ( $R^2 = 0.9973$ ) was observed ranging from 0 to 360  $\mu$ M (Fig. 4). The Job plot for the binding between A and Fe<sup>3+</sup> exhibited a 1:1 stoichiometry for the A–Fe<sup>3+</sup> complex formation (Fig. 5). Complex emission intensity was gradually increased with increasing the concentration of A as it reached a maximum mole fraction is 0.5. Afterwards, the intensity decreased with further addition of A, which eventually established a 1:1 (A:Fe<sup>3+</sup>) binding stoichiometry. In addition, the binding stoichiometry between A and Fe<sup>3+</sup> was also confirmed by the Benesi–Hildebrand nonlinear curve fitting method (Fig. 6). The association constant was found to be  $K_a$   $1.52 \times 10^4$  M for the A–Fe<sup>3+</sup> complex on the basis of Benesi–Hildebrand analysis. This value is within the range ( $10^3$ – $10^5$ ) [14] of those previously reported for Fe<sup>3+</sup> binding sensors. This  $K_a$  value was also supported the Job's plot. The detection limit of A, is  $6.49 \times 10^{-5}$  M. According to the state regulations, the concentration of the iron ions in the sewage discharge is not more than 179  $\mu$ M [15]. These results suggest that A could be used as Fe<sup>3+</sup> sensor in in environmental samples. Precision is an important analytical parameter for sensor application. Based on job plot study, we proposed the structure of A–Fe<sup>3+</sup>

complex as shown in scheme 2.

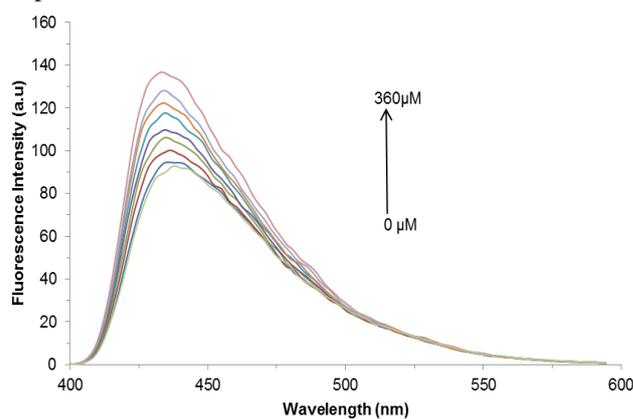


Fig. 3. Fluorescence emission spectra changes of competitive selectivity of A ( $5 \times 10^{-5}$  M) (CH<sub>3</sub>OH/H<sub>2</sub>O, 9:1 (v/v), Tris-HNO<sub>3</sub> = 10 mM, pH = 7.0) toward Fe<sup>3+</sup> (0–360  $\mu$ M) with an excitation wavelength at 385.6 nm.

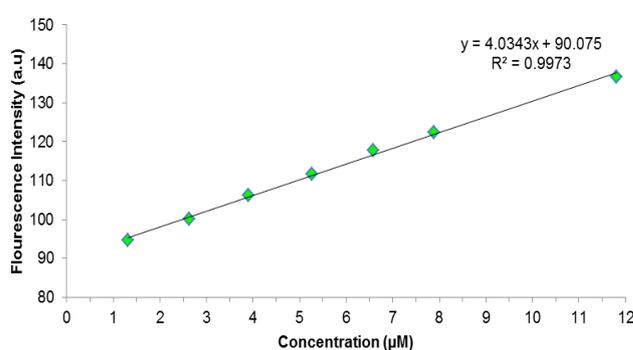


Fig. 4. Fluorescence emission spectra changes of competitive selectivity of A ( $5 \times 10^{-5}$  M) (CH<sub>3</sub>OH/H<sub>2</sub>O, 9:1 (v/v), Tris-HNO<sub>3</sub> = 10 mM, pH = 7.0) toward Fe<sup>3+</sup> (0–360  $\mu$ M) with an excitation wavelength at 385.6 nm.

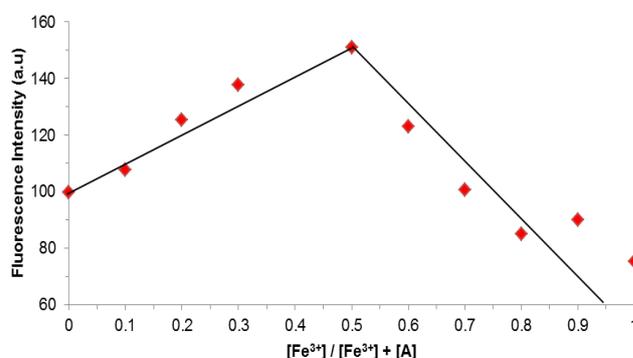


Fig. 5. Job plot of a 1:1 complex of A and Fe<sup>3+</sup>, where the intensity at 150 nm was plotted against the mole fraction of Fe<sup>3+</sup>. The total concentration of Fe<sup>3+</sup> with receptor A was  $10 \times 10^{-5}$  M.

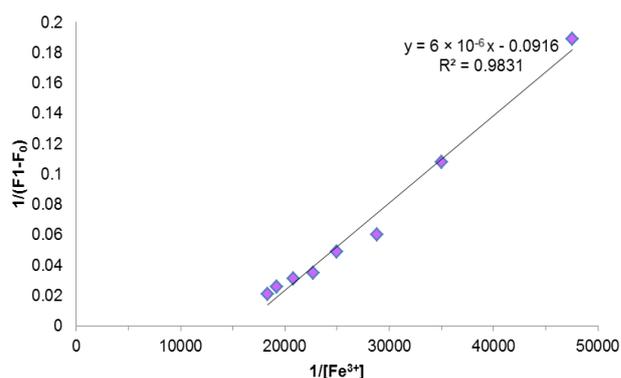


Fig. 6. Benesi–Hildebrand plot of A ( $5 \times 10^{-5}$  M) based on 1:1 binding stoichiometry ( $\lambda_{ex}$  = 385.6 nm).

#### D. Effect of pH

To study the practical applicability of this chemosensor the effects of pH on the fluorescence response of chemosensor A to  $\text{Fe}^{3+}$  were investigated (Fig. 7). The experiments were carried out at a pH range from 3.0–11.0, with the concentration of fixed at  $5 \times 10^{-5}$  M and  $\text{Fe}^{3+}$  at  $1 \times 10^{-5}$  M. Sensitivity of A and A- $\text{Fe}^{3+}$  at different pH values were studied to explore its photophysical properties in  $\text{CH}_3\text{OH}-\text{H}_2\text{O}$  solution (9:1 v/v). The results showed that the sensor A exhibits a weak fluorescence over a wide range of pH except a small enhancement 7.0 pH ranges. In acidic medium (pH <6.0), fluorescence intensity of chemosensor quenched due to the protonation of the amine groups prevents the formation of A- $\text{Fe}^{3+}$  complexes. In basic medium (pH >8.0), the partial precipitation of  $\text{Fe}(\text{ClO}_4)_3$  perchlorate may decrease in the emission intensity. Therefore, sensor A exhibits good fluorescence response towards  $\text{Fe}^{3+}$  at pH 7.0, which is favorable for its application in real samples as most of the samples exist at neutral conditions.

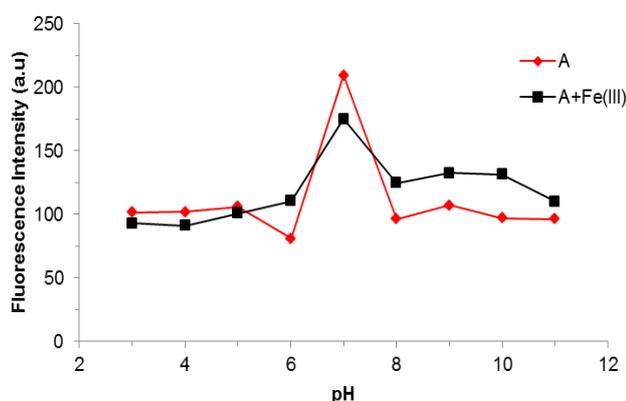
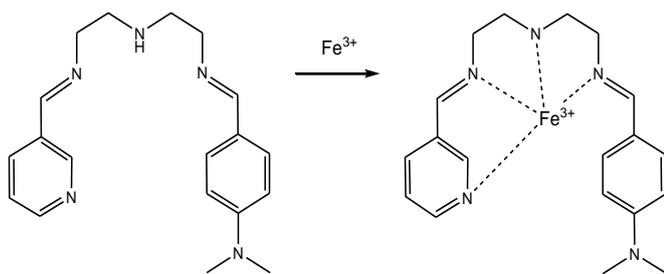


Fig. 7. The variation in fluorescence intensity with the pH of the sensor A ( $5 \times 10^{-5}$  M) and corresponding 1.0 equiv.  $\text{Fe}^{3+}$ .



Scheme 2. Proposed binding mechanism of the chemosensor A with  $\text{Fe}^{3+}$ .

#### IV. CONCLUSION

In conclusion, a simple and sensitive benzenyl derived fluorescent chemosensor A was developed for the detection of  $\text{Fe}^{3+}$  ions in  $\text{CH}_3\text{OH}-\text{H}_2\text{O}$  solution with lower detection limit of  $6.49 \times 10^{-5}$  M. The sensor A specifically recognizes  $\text{Fe}^{3+}$  over other heavy metal ions. The sensor could be applied for monitoring  $\text{Fe}^{3+}$  in environment at pH7. In future, the sensor A could be used as a potential probe for the detection  $\text{Fe}^{3+}$  ions in biological and environmental monitoring works.

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**Sharizal Bin Hasan** was born in Kedah, Malaysia on January 8, 1970. He graduated from Universiti Kebangsaan Malaysia, Bangi, Selangor Malaysia with his M.Sc degree in chemistry in 1993 and he received his Ph.D. in inorganic chemistry from The University Of Queensland, Brisbane, Australia, 2011. Now he is a lecturer at Universiti Teknologi MARA, Malaysia.

The previous publications that have been published by Sharizal were "Environmental Geochemical Mapping on Distribution of Metal Contamination in Top soils Perlis, Malaysia", SNM Ripin, S Hasan, ML Kamal *Journal of Medical and Bioengineering*, 3(4), 2014, "Chelating agents role on thermal characteristics and phase formation of modified

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**Salamiah Zakaria** was born in Kedah, Malaysia on March 4, 1979. She graduated from Universiti Putra Malaysia, Selangor, Malaysia, with her B.Sc degree in industrial chemistry in 2002 and she received her M.Sc in combinatorial technology & catalysis from Universiti Malaya, Kuala Lumpur, Malaysia, 2006. Now she is a lecturer at Universiti Teknologi MARA, Malaysia.

The previous publications that have been published by Salamiah were “Understanding the complexity of a catalyst synthesis: Co-precipitation of mixed Cu, Zn, Al hydroxycarbonate precursors for

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**Siti Nur Ain Binti Mohd Adnan** was born in Kelantan, Malaysia on April 17, 1991. She graduated from Universiti Teknologi MARA, Perlis, Malaysia with her B.Sc degree in applied chemistry in 2013 and she currently pursue her M.Sc in chemistry at Universiti Teknologi MARA, Perlis Malaysia.