CHAPTER 1

Introduction

1.1 Flow Injection Analysis (FIA) [1]

Flow injection (FI) methods, were first described by Ruzicka and Hansen in the mid -1970s. The inception of FIA in turns was the results of a long search for better laboratory techniques in solution manipulation, which could match the efficiency of the computer age. The important stages of development are shown in Figure 1.1, which also shows the relation between the various techniques for automated solution analysis and the scheme for their classification.

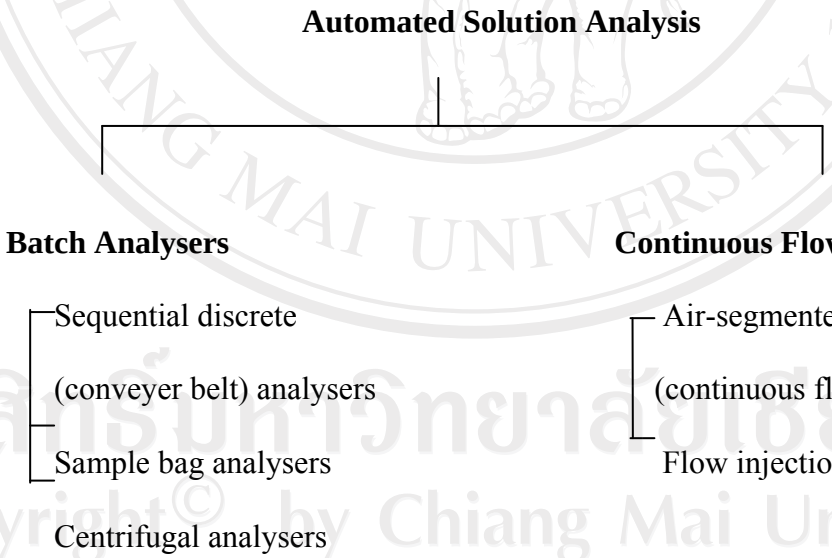

Figure 1.1 Stages of development and classification of automated solution analysis [1]

1.1.1 Principle of FIA [1, 2]

Flow injection analysis (FIA) is based on the injection of liquid sample into a moving, non-segmented continuous carrier stream of a suitable liquid. The injected sample form a zone, which is then transported toward a detector that continuously records the absorbance, electrode potential, or other physical parameter as it continuously changes due to the passage of the sample material through the flow cell. And three basic principles of FIA are based on a combination of sample injection, controlled dispersion and exact timing.

The simplest flow injection analyzer (Figure 1.2a) consists of pump, which is used to propel the carrier stream through a narrow tube, by means of which a well defined volume of a sample solution is injected into the carrier stream in a reproducible manner; and a micro-reactor in which the sample zone disperses and reacts with the components of the carrier stream, forming the species that is sensed by a flow through detector and recorded. A typical recorder output has the form of a peak (Figure 1.2b), the peak height H, width W, or area A of which is related to the concentration of the analyte.

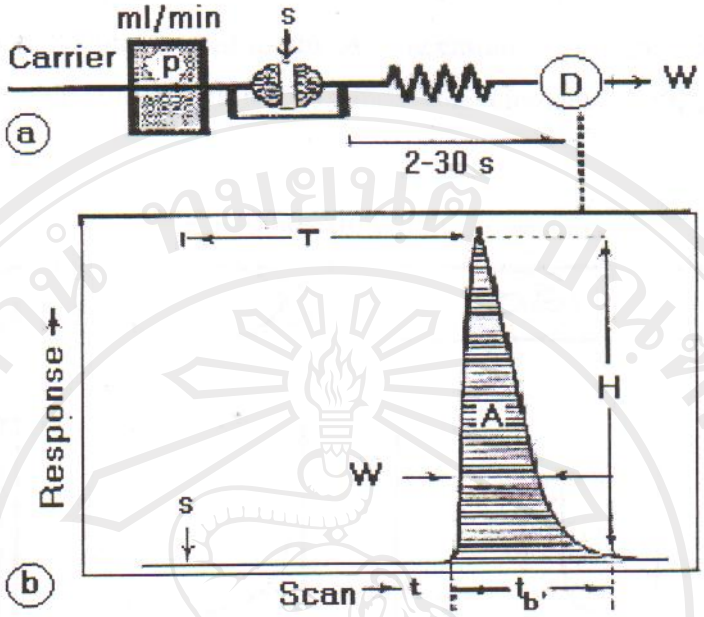

Figure 1.2 The basic components of FIA system; (a) The simplest single-line FIA manifold; S is injection port, D is the flow cell and W is the waste. (b) The analog output has the form of a peak, the recording starting at S (time of injection t_0). H is the peak height, W is the peak width at a selected level, and A is a peak area. T is the residence time corresponding to the peak height measurement, and t_b is the peak width at the base line [2].

1.1.2 Dispersion [2, 4-5]

The most common physical phenomenon in manipulation of sample zone in the FIA system is the dispersion. The shape of the resulting zone is determined by two main processes: convective transport and diffusion transport. Convective transport result form mechanical flow driven by a propelling system. It consists of two processes: turbulent and laminar flows (Figure 1.3a). The turbulent flow occurs for non-segmented liquid in narrow tubing. In FIA, laminar flow is predominant and

causes the sample zone to spread in a parabolic form due to higher velocity at the center of tubing (about 2 times the average velocity).

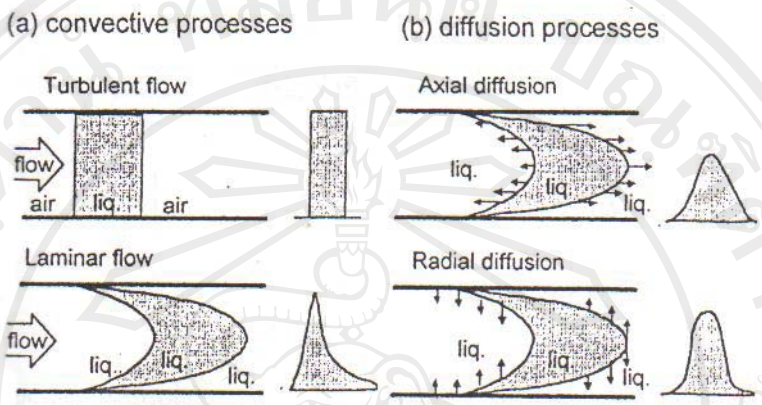

Figure 1.3 General types of transport in closed tubes and the recorded profiles at the detector [5].

Diffusion transport is caused by concentration gradients. There are two types of diffusion processes: axial and radial, as shown in Figure 1.3b. Axial diffusion is insignificant compared to convective flow, but the radial diffusion contributes more significantly to sample dispersion. This process, termed “secondary flow”, results in a washout effect accounting for the low mutual contamination of samples successively injected into the carrier stream and also serves to limit band spreading. At low flow rate it may even be the major mechanism for dispersion. In fact, flow injection analyses usually performed under conditions in which dispersion by both convective process and radial diffusion occurs as shown in Figure 1.4c.

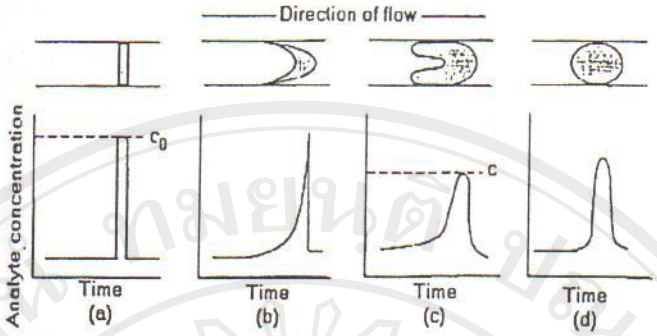

Figure 1.4 Effect of convection and diffusion on concentration profile of analyses at the detector: (a) no dispersion; (b) dispersion by convective process; (c) dispersion by convective process and radial diffusion; (d) dispersion by diffusion [3].

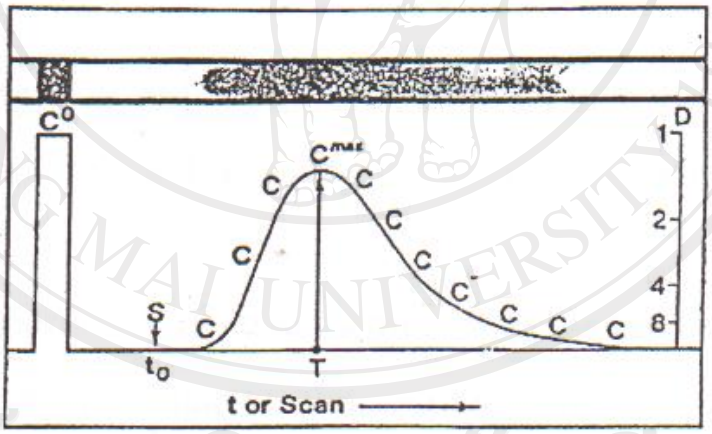

Figure 1.5 Dispersed sample zone in flow system; an original homogenous sample zone (top left) disperses during its movement through a tubular reactor (top center), thus changing from an original square profile (bottom left) of original concentration C^0 to a continuous concentration gradient with maximum concentration C_{max} at the apex of the peak [4].

A simple dispersion experiment is used to describe the dispersion by means of the dispersion coefficient as shown in Figure 1.5. A sample solution is homogenous and has the original concentration C^0 that, would yield a square signal. The height of square signal would be proportional to the sample concentration (Figure 1.5, left). When sample zone is injected, forming a dispersed zone whose form depends on the geometry of the channel and flow velocity. Therefore, the response curve has the shape of a peak reflecting a continuum of concentration (Figure 1.5, right), which composed of a certain concentration (c) of individual elements of fluid.

The dispersion coefficient (D) is defined as the ratio of the analyte concentration before and after the dispersion takes place:

$$D = C^0/C_{max} \qquad (1.1)$$

Where C^0 is the original concentration of injected sample solution and C_{max} is the concentration of dispersed sample solution.

Dispersion may be considered in term of the three general categories:

(1) Low dispersion systems ($D < 2$) are used whenever one intends to prevent the original concentration of the analyte in the injected fluid zone being diluted by the carrier.

(2) Medium dispersion system ($2 < D < 10$) are also used in single channel FI systems, where reagents are used as carrier streams, to attain adequate mixing of sample and reagent.

(3) Large dispersion ($D > 10$) and medium are used to achieve sample dilutions, usually to bring the analyte concentration into an appropriate range for readout.

The FI experimental parameters which may influence the dispersion including sample volume, carrier flow rate, flow rate ratio between sample carrier and merging reagent and geometrical dimensions and configurations of manifold components. Varying the value of these parameters confers a significant degree of control over the dispersion characteristics and facilitates optimization of a flow injection system for many diverse applications.

1.1.3 FIA Instrumentation [5-7]

The basic components of a simple FI manifold typically consist of a propulsion system, an injection or insertation system, a transport and reaction system, and a detection system.

(a) Propulsion system

The liquid propulsion system is a basic unit in all flow analysis system. FIA is a technique based on highly reproducible timing, a feature that demands pulseless and reproducible flow rate in liquid propulsion. The high versatility of FIA also demands easily manageable propulsion devices, which will not depreciate the flexibility of the technique. For FIA system various pump types have been used, including peristaltic (most often used in FIA system), syringe and reciprocating piston pumps. A peristaltic pump is a highly versatile propulsion device, which is no doubt used most frequently, not only in FIA but also in other continuous flow analysis systems, because it may accommodate several channels whereby, according to individual tube diameters, equal or different pumping rates may be obtained. The peristaltic pump consists of a motor-driven wheel with peripherally placed rollers and a compression

cam (or band) which is squeezed against the rollers. One or several pump tubes are affixed so that they rest on a minimum of the rollers at all times. (Figure 1.6)

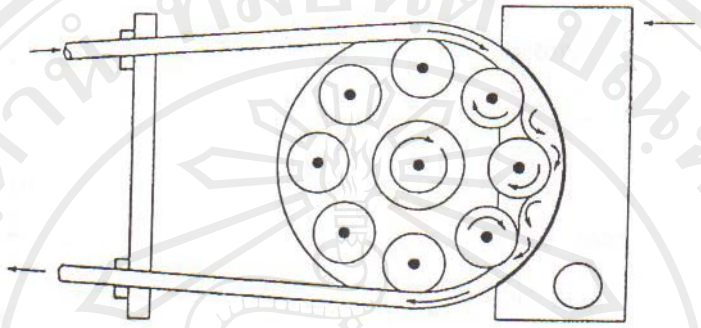

Figure 1.6 Relationship between the rollers of a peristaltic pump and the pump tubes [3]

(b) Injection or insertion system

The injectors employed in FIA are similar in kind to those used in HPLC, but it is necessary for FI valves to withstand extremely high pressures as for HPLC. For a successful analysis, it is vital that the sample solution is injected rapidly as a pulse or plug of liquid; in addition, the injections must not disturb the flow of the carrier stream. The earliest injection system employed in FIA was as simple as a syringe and hypodermic a needle. Currently, the injection systems most frequently used are the rotary valve, proportional injector, solenoid valve and multi-injection system.

(c) Transport and reaction system

The transport system is an integral component of any flow analysis system. The function of transport system is to provide connections between the different components of the system. Normally, the transport system consists of small-bore tube of I.D. such as PTFE tubing of 1.0 mm I.D.

The connectors used in an FIA system serve the proposed of joining the tubes to one another and to the other parts of the system. In FIA, there is a wide range of connectors, but basically there are either dual (linear or V-shaped) or triple (T-, Y- or W-shaped).

The reactor is a major component of the transport system. The main function of reactor is to promote the reproducible radial mixing of two or more components merged through the system. The reactor is usually made of PTFE tubing. There are many types of the reactor such as straight open tube, coiled tube, mixing chamber, single-bead string reactor (s.b.s.r.) and knitted or 3-D reactor.

(d) Detection system

The detection system is sensing part of the FI manifold, which allows continuous monitoring of a given property of the sample or its reaction product and provide qualitative and quantitative information of the analyte. In theory, any detection system, which could be adapted for flow through detection may be used as detectors for FIA. These include the spectrophotometer, nephelometer, fluorimeter, radiometric and various electrochemical detectors.

1.2 Reverse Flow Injection Analysis (rFIA) [3, 6, 7]

Johnson and Petty [6] was the first who described the technique in which a small volume of reagent solution is injected into a sample and carrier streams. This technique was named reverse flow injection analysis (rFIA) to contrast it with the normal technique, normal flow injection analysis (nFIA). In rFIA only small volumes of reagent are used and, also because the determinant concentration in the reagent zone increases with increasing dispersion, the determination is carried out with only slightly dilution [3, 6, 7]. This technique is very suitable for using expensive reagents and for determining of the sample which is plentiful and inexpensive.

1.3 Sequential Injection Analysis (SIA)

A sequential injection analysis (SIA) is becoming an important tool in analytical process. An analytical system based on SIA system is also simple because it is totally computer controlled and has minimal need for maintenance and recalibration. Reagent consumption and waste production are also minimal.

SIA was developed as the second generation of flow injection techniques in 1990[8]. The principles of SIA are similar to those of FIA, namely sample injection, controlled dispersion and reproducible timing. In contrast to FIA, SIA employs a computer controlled multiposition valve and pump operated synchronously. The SIA provides various advantages such as widespread recognition in the automation methods, easy to use, low sample and reagent consumption, low cost of analysis, versatility and tremendous flexibility in manifold design, detectors and high precision. There are many applications of quantitative analyses, which can be achieved by

sequential injection systems such as environmental monitoring, bioprocess monitoring, industrial monitoring and monitoring in pharmaceutical products. Attempts will be made to design and fabricate a homemade, low-cost fully automated SIA analyzer which is made in Thailand to reduce and/or replace the expensive imported commercial ones.

Sequential injection (SI) (Fig. 1.7), the second generation of FIA techniques, is the most versatile one. In its simplest form, the sample zone (red) is injected along with a zone of reagent (blue) into a carrier stream (light blue). During flow reversals of the carrier stream, the sample and reagent zones disperse within each other, while on their interface the reaction product (yellow) is formed. A flow through detector records changes in a desired physical parameter when the reaction product reaches the flow cell. The underlying principle of SI is flow programming. Sequential injection has been microminiaturized in the Lab-on-Valve format, and serves as a platform for bead injection.

Figure 1.7 Sequence zone of SIA systems [9]

1.3.1 Programmable Flow of SIA

Sequential injection uses programmable, bi-directional discontinuous flow, precisely choreographed by means of computer control. Sample and reagents are injected sequentially, by means of a multiposition valve, into a carrier stream using a single syringe pump placed upstream of the valve. Shown here are sample and

reagent zones, at the interface where a detectable product is formed. Flow reversal (D, E) transports the reaction mixture into the detector (Fig. 1.8). Each step can be described as follows: A = The sample was loaded into the holding coil, B = The reagent was loaded into the holding coil, C = The stack zone was aspirated into the holding coil to improve mixing and dispersion, D = The product was produced and was propelled to the detector and E = The product was monitored by the detector and the signal was recorded.

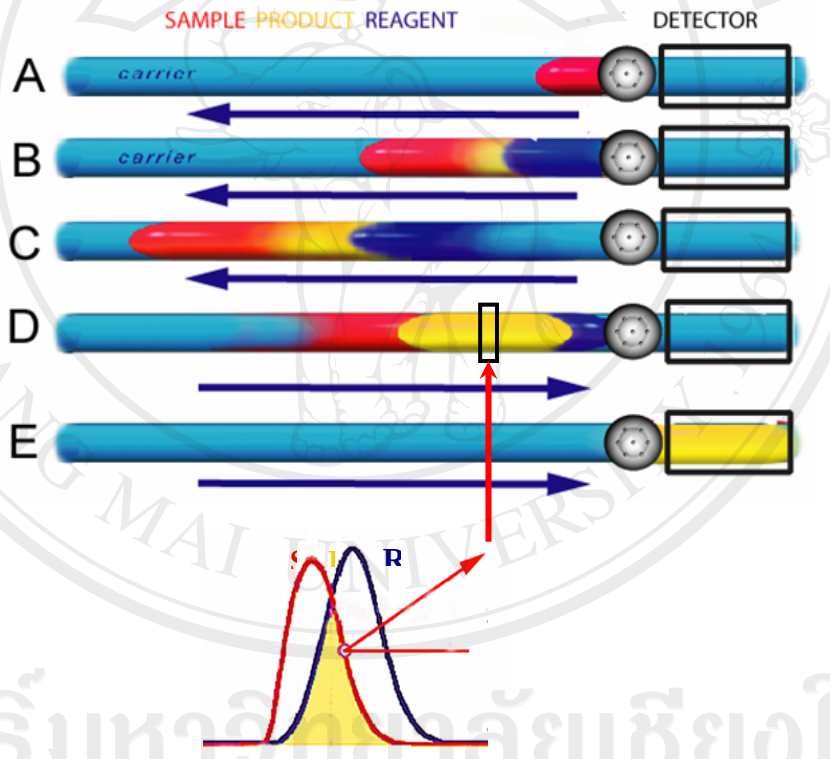

Figure 1.8 Structure of injected zones and concentration profiles as seen by the detector; R-reagent; S-sample; P-composite region where the analyte is transformed into a detector product [9]

1.3.2 Sequential Injection Analyzer

A general schematic flow diagram of a sequential injection analyzer is depicted in Fig. 1.9. The versatility of the technique is centered on a selection valve (SV) where each port of the valve allows a different operation to be performed.

An important advantage of SIA is the versatility that the multi-position valve provides [10–13]. Each port of the valve is dedicated to a specific purpose and the combinations of sample, standards, reagents and detectors around the valve are easily modified to suit a particular analysis. The basic components of the system are a pump with only one carrier stream, a single selection valve, a single channel and a detector. The concept is based on the sequential injection of a sample zone and a reaction zone(s) into a channel [14–18]. In this way, a stack of well-defined zones adjacent to each other is obtained in a holding coil. After the valve has been selected to the detector position, the flow in the carrier stream is reversed and the zones mutually disperse and penetrate each other as they passed through a reaction coil to the detector. The flow reversal as a result of the injection step, therefore, creates a composite zone in which sample and reagent zone penetrate each other due to combined axial and radial dispersion. Controlled dispersion and reproducible sample handling [19–27] are integral and indispensable prerequisite for the success of SIA. Computer control of the SIA system is, therefore, an essential prerequisite [28–34] because an analytical procedure often requires a complex and high reproducible flow patterns. Some of the prerequisites of process analyzers are that the system should be simple and robust, reliable with a low frequency of maintenance and that the consumption of reagents should be very low.

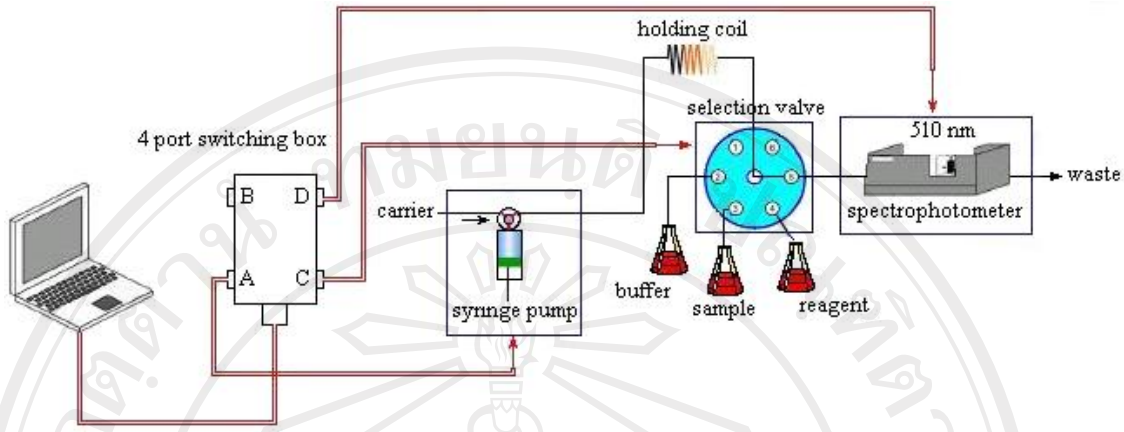

Figure 1.9 Schematic flow diagram of a sequential injection analyzer

The core elements of the SI network were [25]:

(a) A selection valve (SV) was furnished with central communication channel that can be made to address each of the peripheral port.

(b) A syringe pump (SP) was used as liquid driver that allows the manipulation of sample and reagent volumes at the low μl level with high precision and reproducibly permits flow reversals and exploitation of stopped flow schemes.

The SIA assembly includes the following essential parts [35]:

(a) Pump

Syringe pumps have been most widely used to aspirate zones and propel the stack of zones through the detector. Some researcher have used peristaltic pump. The requirements for the pump are that it is precise, reproducible, bi-directional, and able to measure mall volumes. Computer control is imperative. However, it is

relatively expensive which requires priming before using and has a limited reservoir volume.

(b) Selection Valve

The selection valve must allow random access of the ports. Small dead volume and zero cross contamination between ports are essential features of good selection valve. The common port is connected to the pump through the holding coil. Other ports are connected to reagent solutions, samples and the detector flow cell. The 10 port multi-position valve is by far the most widely used.

(c) Connectors and Reactors

While an i.d. of 0.5 to 0.8 mm tubing is a typical how line for a majority of SI system, there are also many tubing materials available for reactor coils and connection lines. Teflon and PEEK are the most frequently used polymers. Stainless steel is another material that has the advantages of heat conductivity, gas impermeability, and surface properties that minimize protein adsorption. A majority of polymer tubing is transparent and is often color coded, so that tubing i.d. can be identified at glance. Connectors made of color-coded polymers are fitted with ferrules that are designed to grip tubing while the connector nut is being tightened. Since all SI systems operate at low pressure, it is not necessary to use connectors designed for HPLC. It is, however, very important to use nuts, ferrules and fittings from a single manufacturer, as products from different sources are often incompatible, resulting in leaking.

(d) Detector

The wide ranges of detectors that are employed for FIA are suitable for SIA. Almost detectors are inserted with suitable flow cell.

(e) Software

The important of SIA is the SIA program. This sequence of events results in the assembly of the stack of zones in holding coil and subsequent transport to the detector flow-cell. Microprocessor control is imperative. Several packages have been written to achieve this. Some software are used for SIA such as AnalySIA, Flow TEK™, Lab VIEW, and FIAlab.

1.3.3 SIA Dispersion Zones [1, 9, 36]

The sequential injection technique, sample injection, controlled dispersion and reproducible timing is the same as those of on which flow injection is based. The difference is that SI uses programmable flow to control these parameters. The key parameters in SIA are zone sequencing and the mutual dispersion of the zones. Fig. 1.10 is shown the sample and reagent injection provides the initial input, serving as a starting point for the initial concentration (C^o) of analyte (red) and reagent (blue).

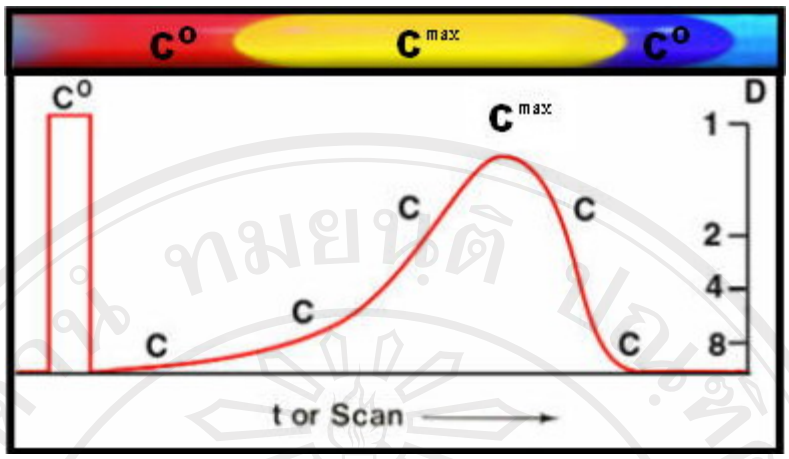

Figure 1.10 Dispersed sample zones of SIA system [9]

The dispersion coefficient (D) has been defined as the ratio of concentrations of sample material before (C^o) and after (C) the dispersion process has taken place in that element of fluid that yields the analytical readout that is:

$$D = \frac{C^0}{C} \qquad (1.1)$$

Where C^o is the original concentration of the constituent of interest in the solution to be injected, and C the concentration of that fluid element of the dispersed solution zone, which is under consideration. When the fluid element with the highest concentration is concerned (i.e. readout at SI peak maximum), equation 1.1 is expressed as:

Which, for $C = C_{max}$

$$D = \frac{C^0}{C_{max}} \quad (0<D<\alpha) \qquad (1.3)$$

The dispersion of the sample zone has to be adjusted to suit the requirement of the intended measurement. Thus, for direct measurements (e.g. pH, ICP, AAS, conductivity, potentiometry) limited dispersion (D = 1-2) is required.

For reagent-based chemistries such as colorimetry, fluorescence or chemiluminescence, sample and reagent zones must mix in a suitable proportion and a medium dispersion (D = 2-10) has to be achieved. And for extensive sample dilution a large dispersion (D = 10-10000) may be necessary.

Controlled dispersion takes place as stacked zones move upstream into the holding coil and then move back through the valve into a detector. This process forms a well-defined concentration gradient that is seen as a continuum of elements with varying concentrations of analyte, product and reagent. To produce a readout that is proportional to the initial concentration of the analyte, it is essential to achieve complete overlap of sample by reagent zones. The overlap is evaluated by measuring the dispersion coefficient of the sample ($D = C^o / C_{max}$) as it yields a degree of sample dilution. Reagent zones will be less diluted as they are stacked in the holding coil after the sample, where they travel a shorter path and are dispersed to a lesser degree.

Reproducible timing in a SI system is achieved through repeatability of all events of the measurement cycle. This includes sequencing of sample and reagent into the holding coil, transport of stacked zones to the detector and length of the stop flow period. Therefore T is the time elapsed from the moment of injection (T^o) to the moment of peak maximum readout (T_{max}) or to the end of the stop flow period.

The SIA experimental parameters or factors which may influence dispersion include [1]:

1. Sample volume
2. Flow rate ratio between sample and merging reagent
3. Geometrical dimensions and configurations of manifold components
4. Viscosity of the fluids
5. Temperature

Under normal conditions, the last two factors have very limited effect on the dispersion, and in most cases may be neglected.

1.3.4 Mixing and Zone Overlap of SIA

Since the reaction product (yellow) (Fig. 1.11) is formed at the interface between the sample and reagent zones, it is essential to maximize zone overlap by increasing the amplitude of the forward flow. As the stacked zones are pushed into the holding coil (HC), axial dispersion is promoted, since the center of the stream travels at twice the mean flow velocity.

Figure 1.11 Forward and reversal flow of SIA system [9]

The resulting parabolic profile telescopes the trailing zone toward the leading edge of the sample zone, and the radial dispersion promotes mixing of adjacent parallel layers of sample and reagent. Upon flow reversal, the flow velocity profile is suddenly inversed. First, radial mixing is caused by local turbulence, and then axial dispersion and zone overlap are increased when the stacked zones travel downstream toward the flow cell (FC). Combined volumes of sample and reagents define the amplitude of flow reversal. When a spacer zone of carrier solution is injected, zone overlap and mixing are further promoted.

1.4 Aluminum

1.4.1 Occurrence and Significance [37]

Aluminum (Al) is the second element in Group IIIA of the periodic table; it has an atomic number of 13, an atomic weight of 26.98, and a valence of 3. The average abundance in the earth's crust is 8.1%; in soils it is 0.9 to 6.5%; in streams it is 0.4 mg L^{-1}; in U.S. drinking waters it is 0.054 mg L^{-1}, and in groundwater it is less than 1 x 10^{-4} mg L^{-1}. Aluminum occurs in the earth's crust in combination with silicon and oxygen to form-feldspars, micas and clay minerals.

Aluminum's occurrence in natural waters is controlled by pH and by very finely suspended mineral particles. The cation Al^{3+} predominates at pH less than 4. Above neutral pH the predominant dissolved form is $Al(OH)_4^-$.

1.4.2 Application of Aluminum [37-38]

The reflecting power of the metal, Coupled with the lightness and resistance to corrosion of aluminum, bring the application of aluminum alloy as a roofing material,

aircraft frames, car engines and components, bridges, building structures, superstructures on ships, scaffolding and ladders. Similarly it is used in the linings of cold-weather clothing (e.g., anoraks) and in survival bags for emergency use on mountain. High electrical conductance and low density give aluminum a great advantage over copper when used for overhead electrical transmission lines. High thermal conductance and resistance to corrosion lead to the application of aluminum in kitchen utensils and the food chemistry. Aluminum potassium sulfate (alum) is used in water-treatment processes to flocculate suspended particles, but it may leave a residue of aluminum in the finished water.

1.4.3 Hazard Evaluation and Limiting Concentration

Environmental contact with aluminum compound cannot be avoided since it is the third common element in the earth's crust. Aluminum is nonessential for plants and animals. Concentrations exceeding 1.5 mg L^{-1} constitute a toxicity hazard in the marine environment, and levels below 0.2 mg L^{-1} present a minimal risk. The United Nations Food and Agriculture Organization's recommended maximum level for irrigation waters is 5 mg L^{-1}. The possibility of a link between elevated aluminum level in brain tissues and Alzheimer's disease has been raised. The U.S. EPA secondary drinking water regulations list an optimal secondary maximum contaminant level (SMCL) of 0.05 mg L^{-1} and maximum SMCL of 0.2 mg L^{-1}.

1.4.4 Determination of Aluminum

Several methods have been developed for the determination of the trace amounts of aluminum in environmental materials but none of them is fully satisfactory. Graphite

furnace atomic absorption spectrometry (GFAAS) provides high sensitivity [39] but frequently serious contamination problem arise, which increase the detection limit. Other atomic spectrometric methods such as inductively coupled plasma atomic emission spectrometry and flame AAS are usually combined with sample preconcentration [40] because of their poor sensitivity for aluminum. Molecular fluorimetric methods are very sensitive, but usually need extraction of the fluorescent complex into an organic medium [41] Moreover, the kinetics of this reaction is too slow for automation. Electrothermal atomic absorption spectrometry is the most widely used method and can produce reliable results, provided the matrix effects on standardization are recognized and corrected [42]. A brief review of aluminum determination is shown in Table 1.1.

Table 1.1 A brief review of the methods for the determination of aluminum

Technique	Condition	Range of aluminium concentration , LOD ($\mu g\ L^{-1}$)	Reference
ICP-AES	λ = 167.02 nm , voltage = 580 V, integration = 1, gain = 10 , slit = 20/15	2 – 2000, 0.500	43
AAS	3-(3′,4′-dihydroxyphenylazo-1′)-1,2,4-triazole (TRIAP) as mark Al, wavelength 460 nm, acetate buffer pH 6.46	0.060 – 1.188	44

Table 1.1 (continued).

Technique	Condition	Range of aluminium concentration , LOD ($\mu g\ L^{-1}$)	Reference
GF-AAS	pyrocatechol violet (PV) immobilised on an Amberlite XAD-1180 support, pH 8-9, 2 M HCl 5-10 ml as eluent, wavelength 309.3 nm	0.021	45
ET-AAS	acetylacetone as extraction solvent, wavelength 309.3 nm	0.300	46
Spectrofluorimetry	5-bromo-salicylaldehyde salicyloylhydrazone (5-Br-SASH) as the reagent, acetate buf. pH 5.4, λ_{ex} = 370 nm and λ_{em} = 460 nm	0 – 120, 1.1	47
Spectrophotometry	Morin as the reagent, λ_{max} = 421 nm	0.01 - 5	48

Nowadays, Flow injection method and Sequential injection method play important role for Al(III) determination. A number of these methods are based on various detectors such as Spectrofluorimeter and Spectophotometer. A brief review of FIA and SIA for determination of aluminum is shown in Table 1.2

Table 1.2 A brief review of FIA and SIA for the determination of aluminum

Technique	Condition	Range of aluminum concentration , LOD ($\mu g\ L^{-1}$)	Reference
FIA-spectrofluorimetry	8-hydroxyquinoline-5-sulphonic acid as reagent, hexadecyltrimethylammonium chloride as surfactant	10 - 500, 0.5	49
FIA-Spectrophotometry	eriochrome cyanine R (ECR) as reagent, pH = 2, λ_{max} = 535 nm	-	50
SIA-spectrofluorimetry	morin as reagent, Tween-20 as non-ionic surfactant, λ_{ex} = 495 nm and λ_{em} = 420 nm	50 -100, 3	51

1.5 Bromopyrogallol Red [52]

Bromopyrogallol red (BPR) or 5′,5′′-dibromopyrogallolsulfonephthalein is red powder. It slightly dissolved in water and dissolve in ethanol. Moleccular formula of BPR is $C_{19}H_{10}Br_2O_9S$ and molecular weight is 574.15. The structure of BPR is shown in Figure 1.12.

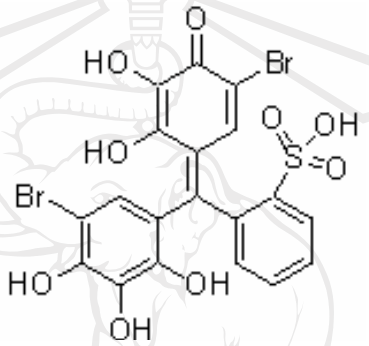

Figure 1.12 The structure of bromopyrogallol red [52]

Bromopyrogallol red was first used by R. M. Dagnall and T. S. West [53] in 1964 as a reagent for silver. In 1981, He Xi-Wen and Donald P. Poe [54] studied the reaction of iron(II) and iron(III) with bromopyrogallol red and hexadecyltrimethylammnium bromide. Bromopyrogallol red indicator can be reaction in various metal. The review of BPR reagent for determining some metals were concluded in Table 1.3.

Table 1.3 A brief review of BPR reagent for the determination of some metals

Metal	Wavelength (nm)	Surfactant	Mole-ratio of	Molar absorptivity, ε ($L\ mol^{-1}\ cm^{-1}$)	Linear range ($mg\ L^{-1}$)	Reference
Ag	635	-	-	5.10×10^4	0.02-0.20	53
Fe	635	Cetyltrimethyl ammonium bromide (CTAB)	Fe : BPR : CTAB 1 : 3 : 6	5.20×10^4	0.05- 5.00	54
Al	623	n-tetradecyl trimethylammonium bromide (TDTA)	-	5.05×10^4	0.1-0.4	55
Cd	654	Crystal violet (CV)	Cd : BPR : CV 1 : 1 : 2	1.79×10^5	0- 400	56
Sn	304	Nonyl phenox polyethoxyethanol (OP) and Cetyltrimethyl ammonium bromide (CTAB)	-	8.2×10^4	0.1-2.5	57

Table 1.3 (Continued).

Metal	Wavelength (nm)	Surfactant	Mole-ratio of	Molar absorptivity, ε ($L\ mol^{-1}\ cm^{-1}$)	Linear range ($mg\ L^{-1}$)	Reference
Mo	637	Nonyl phenox polyethoxyethanol (OP) and Cetyltrimethyl ammonium bromide (CTAB)	Mo : BPR : CTAB 1 : 2 : 4	1.35×10^5	0.06-0.80	58
Ge	550	-	Ge : BPR 1: 2	2.05×10^4	0.20-3.00	59
Sb	555	Triton X-100	-	-	0.25-5.00	60

1.6 Research Aims

The aims of this research can be summarized as follows:

1. To design and construct a flow injection and sequential injection with spectrophotometric detection system for the determination of aluminum.

2. To investigate the optimum conditions for the determination of aluminum by flow injection and sequential injection spectrophotometric method.

3. To apply the proposed method to the determination of aluminum in water samples.