CHAPTER 1

INTRODUCTION

1.1 OBJECT AND SCOPE

During the last two to three decades the chromatographic separation based on molecular sorption on synthetic ion exchange resins has received greater attention because of its versatility. The process does not require chemical regeneration of the resin, is simple in operation and uses simple solvents as eluents which should make the process attractive.

In chromatography the sorption coefficient of a solute is a basic parameter and related to the behaviour of the solute in the column and its appearance in the effluent. This fact calls for the independent determination of sorption coefficient prior to the chromatography of the solutes.

Another important factor is the method of detection of the component in the effluent. Ultraviolet absorption measurement serves as one of the best analytical tools for the estimation of dilute solutions. When this method is employed to detect the compounds with molar absorptivity of 10^4, it is usually possible to detect as little as one to ten nanograms. Compounds with the lower absorptivity have correspondingly higher detection limits as predicted by Beer's law.

The object of the present work is to contribute to the sorption studies with ion exchange resins and the application to separations. The work includes the study of ultraviolet absorption spectra of substituted benzoic acids and their sorption - equilibrium and sorption - elution behaviour with ion exchange resins.

1.2 ION EXCHANGE RESINS

Ion exchange materials[1-12] are of a wide variety. These may be organic or inorganic and natural or synthetic. Synthetic materials are usually superior, because their properties can be better controlled. The common general structural principle is a frame work with electric surplus charge and mobile counterions. Synthetic organic exchangers are the most significant of the ion exchange materials. These are gels and the matrix consists of an irregular macromolecular three dimensional net work of hydrocarbon chains containing ionogenic groups distributed more or less uniformly throughout its structure. Depending upon the ion active group attached to the matrix, the ion exchange resins are classified as cation exchange resins (weakly or strongly acidic) and anion exchange resins (weakly or strongly basic). The earlier ion exchange resins were condensation products, first obtained by Adams and Holmes (1935), of formaldehyde with phenols or arylamines. Better resins were later introduced based on the copolymerisation of styrene and divinylbenzene.

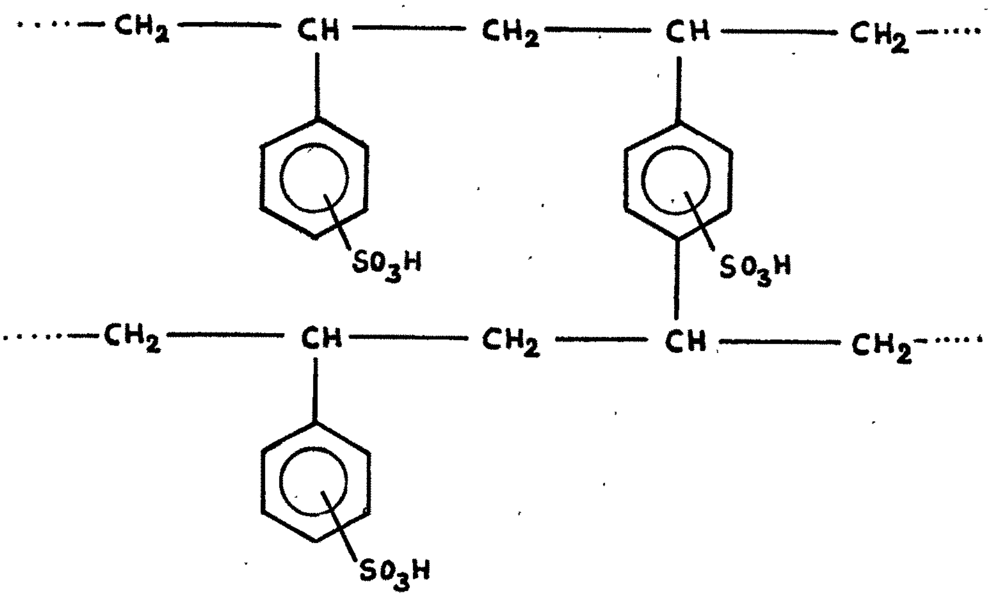
1.2-1 Sulfonated Polystyrene Resins :

Sulfonated copolymers of styrene and divinylbenzene (DVB) constitute a class of resins most widely used. The copolymer matrix has excellent physical strength and is not easily subjected to degradation by oxidation, hydrolysis and elevated temperature. Typical products are Amberlite IR-120, Dowex 50, Duolite C-20, Ionac C-240 and Permutit Q.

The initial step in the synthesis of the resin is the production of copolymer beads of proper size, crosslinking and internal physical structure. This is carried out by suspension or pearl polymerization technique. The monomer mixture, containing the appropriate quantity of each monomer and a free radical catalyst such as benzoyl peroxide, is agitated in water containing a small amount of suspension stabilizer such as inorganic clays, alumina, organic methyl cellulose or polyvinyl alcohol. The purpose of the suspension stabilizer is to disperse the monomer liquid in globules of the proper particle size and to prevent agglomeration during the transition from the liquid to the solid phase. The polymerization temperature ranges from 70°C to the reflux temperature. The rate of agitation, nature of the stabilizer and the viscosity of the solution would determine the particle size distribution. After polymerization, the beads are washed to remove adhering material and then dried.

The molecules of styrene form the polymeric chains while the DVB provides crosslinks between the chains. The degree of crosslinking is controlled by the ratio of divinylbenzene to styrene in the original mixture. However, pure divinylbenzene is too expensive to be used for this purpose and a mixture of about equal weights of divinylbenzene and ethylstyrene is used industrially. Both the divinylbenzene and ethylstyrene, in turn, consist of a mixture of their three isomers. The conventional numerical measure of degree of crosslinking is the nominal divinylbenzene content which refers to the mole per cent of the pure divinylbenzene in the original polymerization mixture. The presence of ethylstyrene results in the ethyl substituent in some of the benzene rings. The variation in composition of the commercial divinylbenzene accounts in part for the differences observed among different batches of supposedly identical resins.

The next step is the sulfonation of the beads. The sulfonation may be carried out with any of the several sulfonating agents including sulfuric acid, sulfur trioxide, oleum or chlorosulfonic acid or with mixtures, by stepwise addition of these at about 100°C in appropriate amount to ensure good mixing during the reaction. The reaction is exothermic and temperature must be carefully controlled to avoid cracking of the polymer beads. Practically every benzene ring, including those belonging to the bridge, is sulfonated preferentially in para position and the double sulfonation of a single ring is unlikely for steric reasons. An exchange capacity of about 5.1 meq/g of dry resin is normally realized which agrees with the monosulfonation of the aromatic rings. The structure of the resin may be imagined as :



For very low crosslinked resins the bridging of aromatic rings through sulfone can occur by electrophilic ring substitution mechanism.

Sulfonated beads are then hydrated and converted to the sodium salt. Care must be exercised in both of these steps to avoid bead breakage. In the hydration procedure the concentrated acid is replaced with a concentrated electrolyte solution which is gradually diluted with water. Another technique designed to minimize bead breakage includes swelling of the beads in an organic solvent such as toluene or chlorinated hydrocarbons prior to sulfonation. This has proved helpful in improving the physical properties of the finished product, increasing the reaction rates and decreasing the tendency for extra sulfone crosslinking.

Less completely sulfonated resins are desired sometimes for industrial and analytical purposes.

In recent years, a polymerization technique has been developed that yields a crosslinked ion exchange structure entirely different from the conventional homogeneous gels and having a rigid macroporous structure, similar to that of conventional adsorbents such as alumina, silica and the carbons, which is superimposed on the gel structure. In contrast to the conventional ion exchange resins, these resins have been designated as macroreticular ion exchangers. These resins have unusual and interesting properties such as large porosity, greater resistance to oxidation, good physical strength and rigidity.

1.3 BENZOIC ACIDS

The carboxyl group is one of the most interesting entities met in organic molecules. The presence of the carboxyl group makes a molecule an acid. Organic acids comprise a very large and diverse group of substances ubiquitous in the plant kingdom, and are used in almost all synthetic organic products, either as part of the final composition or in one or more of the processing stages. Organic acids can be broadly classified as : Aliphatic acids, Alicyclic acids, Aromatic acids, Heterocyclic acids and Amino acids, of which aromatic acids, particularly those carrying hydroxy groups, are of interest.

Aromatic acids are weak acids. The ionization constants (Table 1) of these acids depend upon the type and position of the substituents in the aromatic nucleus. The ionization constants of these acids can be increased by intramolecular hydrogen bond formation. For this reason, salicylic acid is a stronger acid than its meta and para analogues and 2,6-dihydroxy benzoic acid is even stronger.

Table 1 : pK values of some substituted benzoic acids (25°C)

Benzoic acid	pK	Benzoic acid	pK
H	4.20	2,3-diOH	2.94
o-OH	2.97	2,4-diOH	3.29
m-OH	4.08	2,5-diOH	2.89
p-OH	4.48	2,6-diOH	1.22
o-OMe	4.09	3,4-diOH	4.48
m-OMe	4.09	3,5-diOH	4.05
p-OMe	4.47	2,3-diOMe	3.98
p-OEt	[illegible]	2,4-diOMe	4.36
p-Cl	3.98	3,4-diOMe	4.45
p-Br	3.97	2-OH-5-Br	2.62

Aromatic acids[13-15] occur in plants as free acids or esters, more frequently they occur as esters in essential oils and resins and as glycosides. They are also found in the animal organism.

Benzoic acid, the simplest aromatic acid, is found in small amounts in a few fruits, in resins and in essential oils as esters e.g. Peru balsam, Tolu balsam. It is widely used for preserving foods, curing tobacco and manufacturing benzoates and benzoyl compounds.

Salicylic acid is found in fruits of Cherry and flowers of Spiraea ulmaria. It also occurs as its methyl ester in oil of Wintergreen. Its major uses are in pharmaceuticals and dyeing industries. m-Hydroxybenzoic acid is used as an organic intermediate in the manufacture of germicides, plasticizers and epoxy resins. p-Hydroxybenzoic acid is found in barley grains, in the bark of Pinus sylvestris together with vanillic, ferulic and protocatechuic acids. Its propyl and methyl esters are used as preservatives in food, cosmetics and pharmaceuticals. Anisic acid is found in aniseed oil, fennel oil, star anise oil and in labdanum gum. It is used in pharmaceuticals as an antiseptic and deodrant.

o- and p-Chlorobenzoic acids are used as intermediates for the synthesis of pharmaceuticals, dyes, preservatives and agricultural chemicals.

2,3-Dihydroxybenzoic acid is found in the buds of Populus balsemifera and occurs as glucoside in leaves of Vinca minor. 2-Hydroxy-4-methoxybenzoic acid methyl ester and its glycosides occur in the root of Primula viscosa and P. officinalis.

Protocatechuic acid is widely distributed in leaves, flowers, fruits, woods and barks both free and esterified, also in tannins. It is used as an antioxidant and plant growth regulator. Vanillic acid is found together with p-hydroxybenzoic acid in the straw of papaver somniferum. It is used as a nontoxic food preservative, disinfectant, sun screen agent and pharmaceutical ingredient. Gentinic acid is found in culture media of pencillium species and in many flowering plants particularly those of a woody nature. 2-Hydroxy-5-methoxybenzoic acid is found in the roots of Primula primverose. Veratric acid occurs in seeds of veratrum sabadilla together with the alkaloid veratrine.

Recognition of the presence of benzoic acids and related compounds in many biological systems has stimulated the development of numerous chromatographic methods for their separation and identification. In the present work sorption behaviour of some mono and disubstituted benzoic acids on synthetic ion exchange resins has been studied and the possibilities of separating some closely related acids, depending on their sorption behaviour, are explored.

1.3-1 : Synthesis of Benzoic Acids :

The following benzoic acids used in this study were synthesized according to the procedures given in the literature.

p-Alkoxybenzoic acids[16-18] : p-Alkoxybenzoic acids were prepared by boiling under reflux p-hydroxybenzoic acid (1 mole) dissolved in alcoholic potassium hydroxide (2 moles) with appropriate alkyl iodide (1.1 mole) for nearly 2-3 hours. Under these conditions little or no esterification took place. The free acid liberated by the addition of concentrated hydrochloric acid was recrystallized from glacial acetic acid to obtain fine crystals. p-Ethoxybenzoic acid, m.p. 197°C; p-n-propoxybenzoic acid, m.p. 147°C; p-n-butoxybenzoic acid, m.p. 147°C and p-iso-propoxybenzoic acid, m.p. 163°C.

<u>2-Hydroxy-3-methoxybenzoic acid</u>[19]: A suspension of freshly prepared silver oxide (0.4 mole) in water (500 ml) containing sodium hydroxide (1 mole) was heated to 55°C. 2-Hydroxy-3-methoxybenzaldehyde (30 g) was added in one portion and the suspension was stirred for five minutes without external heating. The temperature rose to 80°C. The suspension was filtered while hot, the filterate was cooled and acidified with dilute hydrochloric acid. A solid gummy mass precipitated which when recrystallized from benzene and then from water gave yellow crystals, m.p. 151-2°C.

<u>Dimethoxybenzoic acids</u> : Dimethoxybenzoic acids were prepared by refluxing the corresponding dihydroxybenzoic acid (1 g) in acetone (200 ml) with anhydrous potassium carbonate (12 g) and dimethylsulfate (12 ml) for 10-12 hours. The acetone was removed by distillation and potassium carbonate dissolved in water. The residue was boiled with 10% sodium hydroxide, cooled and the solution on acidification yielded the dimethoxybenzoic acid which crystallized from dilute alcohol. 2,3-Dimethoxybenzoic acid[19], m.p. 126°C; 2,4-dimethoxybenzoic acid[20], m.p. 109°C; 2,5-dimethoxybenzoic acid[21], m.p. 76°C; 2,6-dimethoxybenzoic acid[21], m.p. 186-7°C; 3,4-dimethoxybenzoic acid[21,22], m.p. 181-2°C; 3,5-dimethoxybenzoic acid[21], m.p. 185-6°C.

2-Hydroxy-4-methoxy and 2-hydroxy-5-methoxybenzoic acids : These acids were prepared from the corresponding dihydroxybenzoic acids by the partial methylation using acetone, anhydrous potassium carbonate and dimethylsulfate, and crystallized from dilute alcohol. 2-Hydroxy-4-methoxybenzoic acid,[23] m.p. 160-1°C; 2-hydroxy-5-methoxybenzoic acid,[21] m.p. 145°C.

2-Hydroxy-5-bromobenzoic acid[24] : Bromine (2.7 ml) in glacial acetic acid (25 ml) was added dropwise at 40-50°C to a mixture of salicylic acid (7 g), glacial acetic acid (50 ml) and concentrated sulfuric acid (5 ml). After 30 minutes at 100°C water was added to give 2-hydroxy-5-bromobenzoic acid which crystallized from dilute alcohol, m.p. 165-6°C.

2-Methoxy-5-bromobenzoic acid[25] : Dimethylsulfate (3.4 ml) was added dropwise to a well stirred solution of 2-hydroxy-5-bromobenzoic acid (2.2 g) and potassium hydroxide (1 g) in water (10 ml) cooled to below 5°C. After 2 hours, the mixture was warmed to room temperature and stirred for 12 hours with periodic addition of alkali to keep the solution basic. After refluxing for two hours the solution was cooled which on acidification gave 2-methoxy-5-bromobenzoic acid. It crystallized from dilute alcohol, m.p. 120-1°C.

Benzoic acid and other substituted benzoic acids studied were commercial products (C.P. grade). All the acids were recrystallized and the melting points were checked with literature values.[21]

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