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# SAMPLE CLEANUP METHODS FOR ION CHROMATOGRAPHY

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## SUMMARY

Sample cleanup procedures for ion chromatography are reviewed. Ion-exchange resins in the batch mode are shown to be useful for pH adjustment, but suffer from some practical problems. The principles of membrane techniques, such as passive dialysis, Donnan dialysis and electrodialysis are discussed and these methods are shown to be especially suitable for ion chromatography. Chemical modification of the sample using disposable cartridge columns or precolumn reactions are discussed, with particular attention to practical aspects. Numerous applications of the above procedures are provided.

## INTRODUCTION

Sample handling includes such steps as sample collection, dissolution, cleanup, trace enrichment, and matrix elimination. All of these steps are important and are usually interrelated, but the sample cleanup step often presents difficult practical problems which are unique to ion chromatography (IC). This review will focus on some of the sample cleanup procedures which may be employed in IC. The additional phases of sample handling which are listed above will not be discussed.

After the sample has been dissolved, it is often necessary that some modification of the sample digest be performed before an injection can be made onto the ion chromatograph. This modification may involve a simple filtration step, or it may be more extensive and involve selective removal of the analyte from the sample or removal of interfering matrix components. Alternatively, it may be necessary to change the chemical form of the analyte to improve its separation or detection in the final analysis.

These cleanup procedures often take the majority of the total analysis time and contribute significantly to the final cost of the analysis, both in terms of labour and the consumption of materials. In addition, manipulation of the sample can often introduce a major source of imprecision which can greatly outweigh any variables in the chromatographic process itself. In many cases, the degree of success achieved in the sample cleanup step determines the ultimate success of the analysis.

Sample cleanup can be performed off-line, prior to the chromatographic analysis, or can be incorporated as an on-line process linked with the chromatographic

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hardware. The emphasis of this review will be on the off-line, or batch, methods since these are most commonly used. The goals of cleanup are to achieve: (i) reduction of the overall loading of sample on the column in order to prevent peak distortion and loss of chromatographic efficiency; (ii) removal of matrix interferences; (iii) concentration or dilution of the analyte; (iv) preparation of the sample in the solution most appropriate to the analysis.

## SAMPLE CLEANUP PROCEDURES IN IC

### *Sample filtration*

As with all other liquid chromatographic methods, ion chromatography requires that the sample be free from particulate matter to prevent fouling of capillary tubing, column end frits and other hardware components. Fortunately, sample filtration is very straightforward if disposable filter units are employed. Careful attention must be paid to sample contamination[1], particularly by nitrate ion released from the filter membrane. Ultrafiltration devices wherein the sample is forced under pressure through a membrane, can also be applied to difficult samples; for example, the removal of free calcium and magnesium ions from protein material in biological samples such as serum, milk and egg white[2].

### *Chemical modification of the sample using ion-exchange resins*

Perhaps the most common chemical modification of the sample performed in ion chromatography is adjustment of the pH of strongly acidic or alkaline samples. Injection of such samples without pH adjustment usually produces an unacceptable chromatogram because of baseline disturbances. In particular, system peaks are often caused by large discrepancies in pH between the sample and eluent. This is especially true when aromatic carboxylate salts are used as eluents with indirect UV absorption detection.

It is usually not possible to adjust the sample pH by simple addition of acid or base because of contamination of the sample by the acid anion or base cation, since these species may be of interest in the sample. In such cases it is often possible to use an ion-exchange resin in the batch mode to perform the pH adjustment. For example, high-capacity cation-exchange resin in the hydrogen form can be added to an alkaline sample in order to lower the pH. Similar procedures can be designed to suit different sample types by varying the form of the resin used to achieve alternative chemical modification of the sample. For example, a cation-exchange resin in the silver form will result in the precipitation of chloride from the sample, or a cation-exchange in the barium form can be used to lower the sulfate concentration in a sample.

This approach is simple and relatively effective, but suffers from a number of drawbacks. First, the sample volume required is large and the reaction time must be adjusted whenever the composition of the sample changes. Second, the resin used must be cleaned thoroughly to prevent contamination of the sample by ions leached from the resin material. Third, the sample volume may change due to uptake or release of solvent from the resin. Finally, some loss of sample components may occur due to adsorption on the resin.

TABLE I

APPLICATIONS OF SAMPLE CLEANUP USING ION-EXCHANGE RESINS

| *Sample* | *Species determined* | *Resin type* | *Resin form* | *Purpose of cleanup* | *Ref.* |
|---|---|---|---|---|---|
| Bread | $BrO_3^-$ | Dowex 50W-X8-10 | $Ag^+$ | $Cl^-$ removal | 3 |
| Brine | Anions | Dionex ICE suppressor | $Ag^+$ | $Cl^-$ removal | 4 |
| Brine | $SO_4^{2-}$ | Cation exchanger | $H^+$ | $Cl^-$ removal | 5 |
| Water | Aldehydes | Dowex 1X8 | Acetate | $Cl^-$ removal | 6 |
| Water | Anions | Bio-Rad X-4, X-8, X-16 | $Ag^+$ | $Cl^-$ removal | 7 |
| NaOH | Anions | Rexyn 101 16–50 mesh | $H^+$ | pH reduction | 8 |
| $Na_2CO_3$ fusion melt | Anions | Bio-Rad AG50W-X12 | $H^+$ | pH reduction | 9 |
| Water | $F^-$, $SiO_3^{2-}$ | Dowex, 50W-X8 | $H^+$ | Cation removal | 10 |
| HCl | Cations | Anion exchanger | $OH^-$ | pH increase | 11 |
| Urine | $Br^-$ | Cation exchanger | $CO_3^{2-}$ | Removal of interferences | 12 |

Cleanup with ion-exchange resins in the column mode is also common in IC. Here the resin is packed into a suitable container (which may be as simple as a Pasteur pipet), and the sample passed through. The principles discussed above for cleanup using the batch method apply equally well to the column mode. Some applications of the use of resins for sample cleanup are given in Table I. This table illustrates the common requirement for removal of chloride from samples.

*Chemical modification of the sample using membranes*

Dialytic techniques, in which selected sample components are transferred across a membrane, may be subdivided into *passive* dialysis and *active* (or Donnan) dialysis procedures. Passive dialysis involves diffusion of particles of a specified molecular weight range through a neutral membrane. On the other hand, active or Donnan dialysis is the transfer of ions of a specified charge sign through an ion-exchange membrane. When the dialysis is performed under the influence of an electric field, it is termed *electrodialysis*. Each of these approaches has been applied to the cleanup of samples for ion chromatography.

*Passive dialysis*

Passive dialysis is a very slow process which requires appreciable volumes of sample (*e.g.* 5 ml) and normally results in severe sample dilution. These factors have mitigated against its widespread use. Nordmeyer and Hansen[13] have described an automated device for the rapid dialysis of very small samples (*e.g.* 40 $\mu$l) which enables direct injection of the dialysate onto an ion chromatograph. This device is shown schematically in Fig. 1, from which it can be seen that the sample is introduced into the annular cavity formed between a hollow dialysis fibre and an external, concentrically mounted, small diameter PTFE tube. The eluent is contained inside the fibre and flow is stopped whilst solute components from the sample dialyse into the interior of the hollow fibre. Because of the small volumes involved, dialysis time is very short (typically less than 1 min), and the sample is then injected directly onto the ion

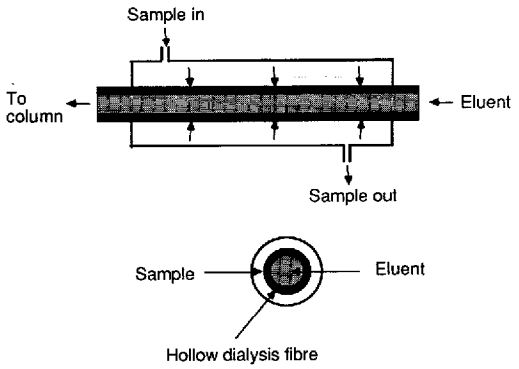


Fig. 1. Schematic representation of a passive dialysis-injection device. Adapted with permission from ref. 13.

chromatograph. When applied to the removal of free calcium from human serum, linear calibration curves were obtained and peak heights showed a relative standard deviation of less than 5% over a two-week period.

*Donnan dialysis*

Active or Donnan dialysis involves the transfer of ions through membranes which carry an ion-exchange functionality[14–16]. The process can be illustrated by reference to a dialysis system comprising 0.1 *M* NaCl (solution 1) separated from 0.001 *M* KCl (solution 2) by a cation-exchange membrane. This experimental arrangement is shown in Fig. 2. It can be shown that, at equilibrium, the following equation holds:

$$\frac{[Na^+]_1}{[Na^+]_2} = \frac{[K^+]_1}{[K^+]_2} \tag{1}$$

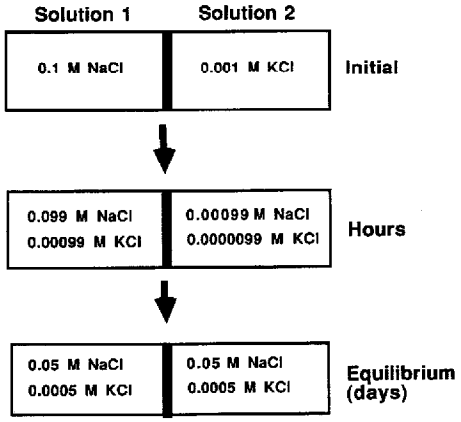


Fig. 2. Schematic representation of Donnan dialysis. The solid central line represents a cation-exchange membrane which separates solutions 1 and 2.

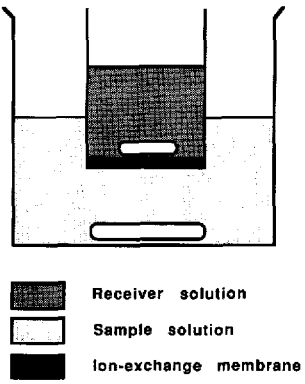


Fig. 3. Simple apparatus for Donnan dialysis.

where the brackets represent molar concentrations and the subscripts refer to the two solutions.

There is a strong tendency for the sodium ions to diffuse from the high concentration zone (solution 1) to the low concentration zone (solution 2). As this process occurs, corresponding transfer of potassium ions from solution 2 to solution 1 proceeds in order to preserve electroneutrality. Thus diffusion of 1% of the sodium into solution 2 is accompanied by transfer of 99% of the potassium into solution 1. If the volume of solution 1 is less than that of solution 2, then sample preconcentration can be accomplished. Eventually the system will attain chemical equilibrium, but this state is achieved only slowly because tranfer of chloride across the membrane is hindered. In the short term therefore, sample modification occurs. A simple form of apparatus for Donnan dialysis is shown in Fig. 3.

In terms of ion chromatographic sample cleanup, Donnan dialysis provides both matrix normalization and sample preconcentration. That is, moderate amounts of potential interferents, such as suspended solids, neutral solutes and ions of opposite charge sign to that of the analyte, neither influence the rate of Donnan dialysis nor are transported to a significant degree into the receiver[16–18]. At this stage, we will focus on the matrix normalization capabilities of Donnan dialysis, for which two distinct possibilities exist. First, Donnan dialysis can be used to selectively add an ion to a sample, or second, to remove a selected species from a sample.

*Selective addition of an ion to the sample.* This is the most commoonly employed application of Donnan dialysis in IC. It will be noted from Fig. 2 that an ion from the receiver solution enters the sample solution during the dialysis. Thus use of an acid as the receiver will result in transfer of hydrogen ions into the sample, which can be useful if the sample is highly caustic. This treatment is, in effect, the same process by which chemical suppression of the eluent is achieved in suppressed IC. Sample treatment using this method can be illustrated by the dialysis of sodium hydroxide solution using sulfuric acid as the receiver solution. Here hydrogen ions from the sulphuric acid solution exchange with sodium ions from the sodium hydroxide through a cation-exchange membrane. The pH of the sample is therefore lowered, whilst the anion content is theoretically unaltered, allowing subsequent determination of these anions by IC.

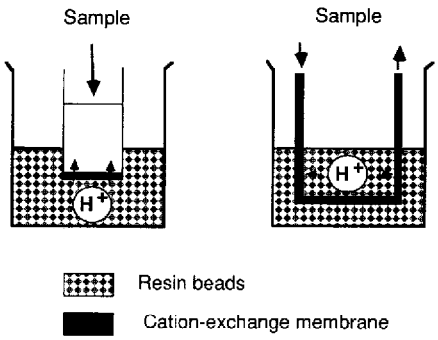


Fig. 4. Apparatus for dual ion exchange.

This method suffers from a practical limitation which seriously detracts from its routine use. This limitation is that the cation-exchange membrane is not entirely impervious to sulphate ions from the receiver solution, which means that the sample ultimately becomes contaminated with sulphate during analysis. This problem can be minimised by increasing the permselectivity of the membrane (*i.e.* its ability to permit the transfer of ions of only one charge sign), or by using an acid whose anion shows little tendency to penetrate the membrane.

An attractive alternative to the use of an acid as the receiver solution has been reported by Cox and Tanaka[19], who used a slurry of ion-exchange resin in the hydrogen form in place of the receiver solution. Since the counter anion is therefore the resin bead itself, transfer across the membrane is eliminated for physical reasons. This process has been called "dual ion-exchange" and Fig. 4 shows the apparatus used. It should be noted that the ion-exchange membrane may also be used in the form of a tube inserted into the resin slurry[20].

*Selective removal of an ion from the sample.* The second type of application of Donnan dialysis to sample cleanup in IC involves the extraction of the analyte ion(s) into a suitable receiver. This process accomplishes sample normalization, since the analyte ions are ultimately collected in a solution of known composition. A potential problem exists with this method in that determination of the analyte(s) by IC may be precluded by interference from the high concentration of ions in the receiver electrolyte. One possible solution to this problem is to use a carbonate salt solution as the receiver and to further treat this solution by the dual ion-exchange procedure discussed above. The carbonate and bicarbonate in the receiver are converted in the dual ion-exchange step to carbonic acid, following which the sample can be injected directly or the dissolved carbon dioxide removed prior to sample injection. The combination of Donnan dialysis and dual ion-exchange is a powerful method for the treatment of complex samples.

In both of the above methods of sample treatment, the membrane can be in sheet or tubular form[21]. It has been demonstrated that transfer of solutes across the membrane surface is improved if the sample is recirculated around the outside of the membrane tubing during dialysis[22]. Table II shows some applications of Donnan dialysis sample cleanup in ion chromatography.

TABLE II

SOME APPLICATIONS OF SAMPLE CLEANUP FOR IC USING MEMBRANE TECHNIQUES

| *Sample* | *Analytes* | *Process*[a] | *Membrane* | *Receiver* | *Ref.* |
|---|---|---|---|---|---|
| NaOH | $Cl^-$, $NO_3^-$, $SO_4^{2-}$ | DIE | Nafion 811 cation | Dowex 50WX4 ($H^+$) | 20 |
| NaOH | $NO_3^-$, $SO_4^{2-}$ | ME | Nafion 901 cation | — | 23 |
| NaOH | $PO_4^{3-}$ | DIE | Nafion 117 cation | Dowex 50WX4 ($H^+$) | 19 |
| $Na_2CO_3$ | $Cl^-$, $NO_3^-$, $SO_4^{2-}$ | DIE | Nafion 811 cation | Dowex 50WX4 ($H^+$) | 20 |
| NaCl | $SO_4^{2-}$ | DIE | Nafion 811 cation | Dowex 50WX4 ($H^+$) | 20 |
| Sugar[b], syrup[b] | Anions | DD | RAI R-1035 anion | $Na_2CO_3$–$NaHCO_3$ | 17 |
| | | DIE | Nafion 117 cation | Dowex 50WX4 ($H^+$) | |
| River water | Anions | DD | RAI R-1035 anion | $Na_2CO_3$–$NaHCO_3$ | 17 |
| | | DIE | Nafion 117 cation | Dowex 50WX4 ($H^+$) | |
| Coal[c] | S (as $SO_4^{2-}$) | DIE | Nafion 117 cation | Dowex 50WX4 ($H^+$) | 17 |
| Coal[c] | Cl (as $Cl^-$) | DD | RAI R-1035 anion | $Na_2CO_3$–$NaHCO_3$ | 17 |
| | | DIE | Nafion 117 cation | Dowex 50WX4 ($H^+$) | |
| Leaves[b] | $Cl^-$, $NO_3^-$, $SO_4^{2-}$ | DIE | Nafion 117 cation | Dowex 50WX4 ($H^+$) | 17 |
| $AgNO_3$ | Cations | DIE | RAI R-1035 anion | Dowex 50WX4 ($H^+$) | 19 |
| Polyelectrolyte | Anions | DD | Homemade anion | $Na_2CO_3$–$NaHCO_3$ | 24 |
| Serum | $Ca^{2+}$ | PD | Cuprophane C1IM | $H_2O$ | 13 |

[a] DIE = dual ion-exchange, DD = Donnan dialysis, PD = passive dialysis, ME = membrane electrolysis.

[b] Sample treated by carbonate fusion.

[c] Sample treated by oxygen bomb combustion using Eschka mixture ($Na_2CO_3$–MgO, 1:2) as absorbing solution.

*Electrochemical dialysis*

Further refinement to dialysis methods can be achieved by coupling electric fields with membrane processes. For example, the transfer of ions through a membrane can be stimulated by application of an electric field across the membrane; this process is known as electrodialysis. The apparatus shown in Fig. 3 can be easily modified to include platinum gauze electrodes on either side of the membrane. This approach has been applied to the electrodialysis of metal ions using a cation-exchange membrane, $NaNO_3$ as the receiver and a 5 V/cm (peak-to-peak) sine wave potential at

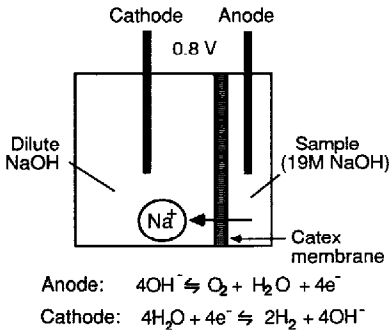


Fig. 5. Apparatus for electrodialysis of highly caustic samples[23].

TABLE III

TYPICAL PACKINGS FOR DISPOSABLE CARTRIDGE COLUMNS

| | |
|---|---|
| Silica | $C_{18}$ |
| Alumina (acidic, basic, neutral) | Anion exchange |
| Cation exchange ($H^+$ or metal form) | Polystyrenedivinylbenzene |
| Activated carbon | Polyvinylpyrrolidine |
| Chelating resins | Amino-bonded silica |

1 MHz frequency[25]. The rate of transfer through the membrane was increased by up to 2.7 times as a result of application of the potential. Electrodialysis has been reported as a sample treatment method for differential pulse polarography and has not yet been applied to IC.

A two-part electrolysis cell (Fig. 5) in which the anode and cathode compartments are separated by a cation-exchange membrane has been suggested as a method for treatment of highly caustic sample prior to IC analysis[23]. The sample is placed in the anode compartment, whilst a larger volume of dilute NaOH is used to fill the cathode compartment. During electrolysis, $OH^-$ reacts at the anode to produce $O_2$ and $H_2O$, whereas water reacts at the cathode to produce $H_2$ and $OH^-$. Thus the concentration of $OH^-$ in the anode compartment decreases, whilst that in the cathode compartment increases. Transfer of $OH^-$ through the membrane cannot occur, so sodium ions move from the anode compartment into the cathode compartment. The

TABLE IV

SOME EXAMPLES OF SAMPLE CLEANUP WITH CARTRIDGE COLUMNS

| *Matrix* | *Solute ions* | *Stationary phase* | *Ref.* |
|---|---|---|---|
| Plant extract | $NO_2^-$, $NO_3^-$, $SO_4^{2-}$ | $C_{18}$ | 26 |
| Urine | Thiosulphate | $C_{18}$ | 27 |
| Urine | Oxalate | $C_{18}$ | 28 |
| Soil extract | $SO_4^{2-}$ | $C_{18}$ | 29 |
| Cheese | $Na^+$, $NH_4^+$, $K^+$ | $C_{18}$ | 30 |
| Kraft liquor | $S^{2-}$, $S_2O_3^{2-}$ | $C_{18}$ | 31 |
| Plasma | $NO_2^-$, $NO_3^-$ | $C_{18}$ | 32 |
| Serum | $I^-$ | $C_{18}$ | 33 |
| Plant extract | $Cl^-$, $NO_3^-$, $SO_4^{2-}$ | Silica | 34 |
| Surfactants | Alkylbenzene sulfonates | Silica | 35 |
| High chloride | Anions | Cation exchange ($Ag^+$) | 36 |
| NaOH | Anions | Cation exchange ($H^+$) | 8 |
| River water | $HCO_3^-$, $Cl^-$, $NO_3^-$, $SO_4^{2-}$ | Cation exchange ($H^+$) | 37 |
| Leachate | As(III), As(V) | Cation exchange | 38 |
| Brine | Sodium | Cation exchange ($H^+$) | 39 |
| Air samples | Anions | Charcoal | 40 |
| Digests | Metal oxo-anions | Anion exchange | 41 |
| Natural waters | Anions | Amino | 42 |
| Brine | $Br^-$, $NO_3^-$, $SO_4^{2-}$ | Alumina | 43 |
| Serum | $SO_4^{2-}$ | Polymer | 44 |
| Surfactants | Anions | Polymer | 39 |
| Aromatics | Anions | Polymer | 39 |

net result of this process is that the concentration of NaOH in the sample is progressively lowered. Use of an electrolysis current of 0.15 A for 3 h lowered the NaOH concentration in the sample from 19 *M* to 0.3 *M*. The latter concentration was suitable for direct injection into a suppressed IC system.

*Chemical modification of the sample with disposable cartridge columns*

One of the most versatile and convenient means available for sample cleanup is the use of commercially available disposable cartridge columns. These devices offer rapid sample treatment and can usually be employed in tandem with disposable filters so that filtration and sample cleanup can be performed in a single operation. Some of the common stationary phases available commercially as cartridge column packings are listed in Table III.

*Modes of operation*

Cartridge columns can be employed in one of two ways. The first method is the selective removal of the solute ions from the sample matrix and in this approach, the solvent used to elute the sample through the cartridge should provide chromatographic conditions giving very strong retention of the solute ions. That is, the capacity factors for these solutes should be as large as possible. The alternative operational mode for cartridge columns is to retain selectively matrix components under conditions where the solute ions are unretained. That is, their capacity factors approach zero.

Keeping in mind that we wish the solute to be either well-retained or not retained at all, then several possibilities emerge from the stationary phases listed in Table III. Stationary phases which show some ion-exchange ability (such as silica, alumina, anion and cation exchangers, and amino phases), and stationary phases which show chelation ability should be suitable for the selective retention of ionic solutes from a matrix composed largely of neutral, organic species. Alternatively, hydrophobic stationary phases such as octadecylsilane and the polymeric phases should be useful for the removal of neutral organic components while showing little retention of ionic solutes. A further potential application of cartridge columns is their use for adjusting the pH of a sample in the same manner as that described earlier for ion-exchange resins used in the batch mode. Most of the abovementioned possibilities have been realised in practice and Table IV lists some examples of successful applications.

*Practical aspects*

Several practical aspects should receive attention when using cartridge columns, namely column pretreatment, flow-rate, method of sample application, and sample pH. First, the columns almost invariably require pretreatment in order to remove very fine particles of the packing material, to elute any contaminants, or to condition the stationary phase in order to improve the efficiency of sample binding. Significant levels of inorganic contaminants are commonly encountered in cartridge columns[1], generally as a result of residual reagents from the manufacturing process. Hydrophobic stationary phases usually require pretreatment with an organic solvent such as methanol in order to wet the stationary phase surface, so that effective binding of hydrophobic solutes is achieved from aqueous sample solutions.

The flow-rate of sample or flushing solution through the precolumn should be

TABLE V

SOME EXAMPLES OF PRE-COLUMN REACTIONS IN IC

| *Analyte* | *Additive* | *Effect* | *Ref.* |
|---|---|---|---|
| Anions | Methanol | $[CrO_4^{2-}]$ is reduced by reaction with methanol, producing formate | 46 |
| Ascorbic acid | Boric acid | Prevents oxidation of ascorbic acid (borate converted to $H_3BO_3$ in suppressor) | 47 |
| Boron | Chromotropic acid | $H_3BO_3$–chromotropic acid complex formed | 48 |
| Boron | Hydrofluoric acid | Boron converted to $BF_4^-$, and quantitated in this form | 49 |
| $Br^-$ | 2-Iodosobenzoic acid + acetanilide | 4-Bromoacetanilide formed is used as a measure of $Br^-$ | 50 |
| Cations | EDTA | Complexes some metal ions | 51 |
| HCN | Water | $CN^- + H_2O \leftrightharpoons NH_3 + HCOO^-$, with $HCOO^-$ used as an indirect measure of $CN^-$ | 52 |
| $CN^-$ | Hypochlorite | $CN^- + OCl^- \leftrightharpoons OCN^- + Cl^-$, with cyanate used as an indirect measure of $CN^-$ | 53 |
| $CN^-$ | Iodine | $I_2 + HCN \leftrightharpoons H^+ + I^- + ICN$, with iodide used as a measure of $CN^-$ | 54 |
| $H_2O_2$ | Sulfite | $H_2O_2 + SO_3^{2-} \leftrightharpoons H_2O + SO_4^{2-}$, with $SO_4^{2-}$ used as an indirect measure of $H_2O_2$ | 55 |
| $S^{2-}$ | N,N-Dimethylphenylenediamine | Reacts with $H_2S$ to form methylene blue, which is used to quantitate $S^{2-}$ | 56 |
| $SiO_3^{2-}$ | Boric acid | Fluoride converted to $BF_4^-$ to eliminate interference of $F^-$ on silica analysis | 57 |
| $SO_3^{2-}$ | Formaldehyde | $SO_3^{2-}$ converted to hydroxymethane sulfonate | 58 |
| Urea | Urease | $NH_4^+$ produced is used to quantitate urea | 59 |

kept as low as practicable so that mass transfer effects are minimised. Most column cartridges are designed for use with disposable syringes and the low packing density of the stationary phase permits very high flow-rates (*e.g.* 50 ml/min) to be easily achieved. Experience with analytical chromatographic columns suggests that such a high flow-rate is unlikely to produce the degree of selective separation required, so it is advisable to use flow-rates less than 10 ml/min.

The third important practical consideration is the manner in which the sample is applied to and eluted from the cartridge column. It is possible to apply a known volume of the sample to the head of the column and to elute the sample band through the column with a suitable eluent. However, this method is inadvisable in practice because of the difficulty in applying an accurate volume of sample using the syringes compatible with the cartridge column, and is recommended only when the sample volume is small or the concentration of the sample is high enough to quickly saturate the cartridge. It is generally more appropriate to pass sample continuously through the column, discarding the first two or three column volumes and then collecting sufficient effluent for analysis.

Finally, the sample pH has an important bearing on the selection of a suitable stationary phase. Apart from the obvious consideration that some stationary phases are intolerant of acidic or alkaline solutions, the sample pH is often a very useful indicator of the ionic strength. In cases where the ionic strength in unacceptably high, it may be necessary to use a second cartridge column, or an alternative cleanup procedure, to remove some of the ionic components from the sample.

In conclusion, it should also be noted that cartridge columns packed with hydrophobic stationary phases can also be used to retain ionic solutes (rather than neutral, organic solutes) if they are first conditioned with an ion-interaction reagent. The success of this approach is dependent on retention of the ion-interaction reagent on the stationary phase during sample elution, thus it is desirable that relatively hydrophobic ion-interaction reagents be used and the sample volume be limited. Tetramethylammonium hydroxide and pentanesulphonic acid have been employed as ion-interaction reagents for the removal of anionic and cationic surfactants, respectively, using a cartridge column packed with a polymeric divinylbenzene stationary phase[39].

*Chemical modification of the sample by pre-column reaction*

For some samples, cleanup can be best achieved using an appropriate chemical reaction to eliminate a matrix component. Alternatively, it may be necessary to derivatize a solute in order to enhance its detectability or to convert it into a form suitable for separation. Much has been written on the principles of chemical derivatization of organic solutes[45] and the same principles apply here to inorganic solutes. Table V lists some reactions which have been employed as sample treatment methods for IC, or as mobile phase reactions designed to modify the nature of the solute in an IC determination.

## CONCLUSIONS

Powerful sample cleanup procedures are available for IC and permit the analysis of very complex samples, such as those with extremes of pH or having high ionic strength. Membrane techniques are especially applicable because of their ability to transfer selectively a desired ion either into or out of the sample. These techniques will undoubtedly find increasing usage in the future as commercial devices become available for sample dialysis.

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