PACKED BEDS

PUROLITE
ION EXCHANGE RESINS

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1 INTRODUCTION

Ion exchange resins can treat waters of varying composition. The quality of water to be produced will depend on the particular application involved and will range from simple base exchange softening to complete removal of all the inorganic and organic species present in a raw water.

The five main factors influencing the design of a deionisation plant are :-

- **The composition of the raw water**
- **The quality and quantity of treated water required**
- **Capital cost**
- **Operation cost**
- **Plant size versus available space**

In the initial design of a plant there is a need to select the types of resin required to treat the water to the specified quality. The designer then has to evaluate the most effective use of the ion exchange resins to optimise capital and operating costs. This will entail consideration of a wide variety of design options.

The main aim of this bulletin is to review the potential of packed ion exchange beds in the treatment of raw waters. However, to do this it is essential to consider the general background to the design and operation of water treatment plants to illustrate how and why packed bed types of unit have evolved, and to compare them with other water treatment plant designs.

2 FACTORS INVOLVED IN THE DESIGN OF WATER TREATMENT PLANTS.

Before a water treatment plant is designed it is vitally important that the client considers in detail three main questions:

- **what raw waters are available, what are their compositions and how do they vary?**
- **what quality and quantity of water is required now, and in the future?**
- **what conditions will the water treatment plant have to operate under? e.g. the degree of flexibility and continuity of operation likely to be required.**

The water treatment plant designer then needs to work within the answers to the above questions to provide a plant to optimise capital and operating costs, and, at the same time, conform to safety and environmental standards. This will involve considering a large number of factors such as those listed below:

- **raw water composition and availability**
- **number of treatment stages**
- **choice of resins**
- **degree of pre-treatment required**
- **rate of production of treated water**
- **continuity of production**
- **number and sizes of service vessels**
- **regeneration techniques and facilities**
- **quantity and quality of rinse water**
- **resin cleaning facilities**
- **pumping requirements and pressure losses**
- **instrumentation**
- **control equipment**
- **waste discharge-environmental**

3 CO, AND COUNTER-FLOW SYSTEMS

In respect to ion exchange resin performance, the exhaustion and regeneration operations are the two keys factors, and at this stage it is useful to mention the ion exchange reactions occurring and how these are affected by co and counter-flow techniques.

3.1 Co-Flow

If an ion exchange bed is designed such that the flow of the water being treated and the regenerant solution are in the same direction (co-flow) during the exhaustion and regeneration cycles, respectively, then at the end of the exhaustion cycle of an hydrogen form cation resin the bed will comprise of layers of resin in differing ionic forms i.e. calcium, magnesium and sodium. On regeneration with acid, these layers will be displayed by hydrogen ions, and at the end of the regeneration period, the inlet end of the bed will be in hydrogen form, but at the outlet end of the bed sodium form resin will predominate, unless a gross excess of regenerant has been used. Consequently, during the subsequent exhaustion cycle treated water of relatively high hydrogen ion content will be contacting this high sodium band of resin at the outlet from the bed; sodium ions will be displaced into the treated water and a poor quality product will result.

3.2 Counter-Flow

By designing the bed such that the flow of water being treated and the regenerant flow are in opposite directions (counter-flow), the treated water leaving the bed during the exhaustion cycle will be contacting the most highly regenerated section of the resin bed, and extremely low concentrations of sodium will be obtained in the treated water. Similar considerations apply to the use of an anion bed.

In respect to ion exchange reactions, the use of a counter-flow technique is to be preferred. However, this entails a more complicated design. For the main cation and anion sections of a deionisation plant, therefore, there is a choice of using either co-flow operation which will have the advantage of being a simple design, but producing a relatively poor quality of treated water, or a counter-flow technique which necessitates a more complicated design, but is capable of producing an extremely high quality treated water.

Counter-flow systems have usually been designed to operate downflow during the exhaustion of a bed and with regenerant flow upwards. Fig. 1 shows a typical design of such a plant. However, the use of an upward service flow with regenerant downflow, in a packed bed design, is a viable alternative (See Fig 2)

In counter-flow operation, the high quality water obtained results from the fact that the treated water passes through the most highly regenerated section of the bed immediately before leaving the unit. For successful operation, therefore, it is essential that the bed should not be disturbed. Consequently, when operating in an up-flow regeneration mode the bed has to be held down to prevent mixing of the resin within the bed. Various plant designs have been used to overcome this risk, with the main options being air or water hold down techniques. In a typical air hold down system, the waste regenerant collector is buried just below the surface of the top of the bed. The mesh wrapped laterals are perforated top and bottom and in operation the top holes collect the downward passing air whilst the bottom holes collect the upflowing regenerant effluent, this produces a dry crust of resin on the bed which further assists the retention of the bed. An upward rinse follows the regenerant solution to displace the bulk of the effluent, and this is followed by a final downflow rinse before the unit is returned to service.

A water hold down system operates similarly but with water instead of air being passed downwards through the top shallow layer of resin before leaving through the submerged regenerant collector.

Ideally, in any counter-flow system the bed should not be disturbed. However, this is unrealistic in practice because of the need to remove any accumulated insoluble matter filtered from the incoming water by the bed, and to relieve compaction of the bed after a long period of operation both of which can result in unacceptable pressure losses arising across the bed.

In a co-flow system, the conventional backwash technique of expanding the bed by about 50% can be applied to remove such debris without a significant effect on the ion exchange process, whereas with a counter-flow system the quality of water produced would be affected adversely.

For air/water hold down counter flow systems, therefore, a backwash facility is fitted to the submerged header and lateral to provide a surface flush of the top layers of a resin bed. This provides for a partial backwash of the bed which can successfully combat the build up of high pressure losses. The technique is usually carried out prior to the regeneration stage. Therefore, the bed can be routinely maintained in an adequately clean condition, and the number of full backwashes (and the consequent need to recondition the bottom of the bed) is limited to intervals dependent on the specific operating conditions of the unit.

The vessels used in counter flow systems based on water or air hold down will have a similar freeboard space to a co-flow unit. This is in contrast to the packed bed designs where the freeboard is near to zero, and a different resin cleaning procedure has to be provided on the plant.

3.3 Packed Beds

Packed beds used in counter-flow mode.

The term ‘packed bed’ has been applied to a number of plant designs. This is unsatisfactory in that any bed of resin can be said to be ‘packed’ if it is not in suspension. It is the degree and continuity of packing that distinguishes true ‘packed’ bed designs. The specific characteristic of such a system is the very limited volume of free space available within the operating vessels, which is in direct contrast to the co-flow and hold down counter-flow systems where the free space available is a high proportion of the total volume of the vessel.

As stated previously, a counter flow system is one in which the service and regenerant flows are in opposite directions. The question then arises “which way should the system best operate?"

- **service downflow - regeneration upflow**
- **regeneration downflow - service upflow**

In either of the two options, the volume of the vessel is limited to that of the maximum expanded volume of the ion exchange resin plus any inert material used.

4 GENERAL DESIGN FEATURES OF DEIONISATION PLANTS

4.1 Size of vessels

In the design of deionisation plants the sizing of the vessels is based mainly on flow-rate, resin capacity, exhaustion cycle time, pressure loss and distribution of water and chemical solutions passing through the ion exchange bed.

For the required ion exchange reaction to take place, the water and resin must be in contact for a finite time. For this reason maximum flow rate guidelines are provided for the various types of Purolite ion exchange resins in the standard Technical Bulletins.

The process design engineer will then consult Purolite ion exchange data to select the type of resins, the regeneration mode and the quantity of regenerant required to produce water of the specified quality: also the most effective arrangement of the ion exchange units.

The ion exchange capacities can be calculated from Purolite data and from these figures the volume of resin required to obtain the specified throughput between regenerations can be obtained. In each design of deionisation plant there are options relating to capital versus running costs. For example, higher chemical efficiencies can be achieved by using smaller quantities of chemicals, but then a greater volume of resin will be required to satisfy a given exhaustion cycle time.

Vessel cost can be a significant factor in the overall optimisation procedure. For a given volume of resin, the greater the diameter of the vessel, the lower the flow velocity and pressure loss through the ion exchange bed, but distributing the water through the bed becomes more difficult the higher the diameter/bed height ratio.

The cost of a vessel of given volume will be higher the greater the diameter to height ratio, and, therefore, on cost grounds a tall narrow vessel is the preferred option. Additionally, this shape will also provide better conditions for uniform flow than a short wide vessel, and this enhances the effective use of the ion exchange resin. This particularly applies to air/water hold down counter flow plants where it is more difficult to obtain uniform distribution during the upflow regeneration stage. Note also that in such plant the height of a vessel on the straight may be up to twice that of the resin bed i.e. 100% freeboard, to allow for cleaning by backwashing. It follows that if the resin bed in a particular situation could be used without providing this method of cleaning, a shorter vessel could be used. This is the principle of the packed bed design in which the volume of resin is virtually that of the ion exchange vessel.

Frequently, modifications may be required to an existing plant, for example, a greater quantity of water may need to be produced or the raw water supplied to a site may change such that it has a higher dissolved solids content. By increasing the volume of resin used, and converting to a packed bed, these problems may be overcome. Some modification of the regeneration equipment may also be required.

4.2 Flow, Distribution and Collection

As discussed earlier, there is a need to control flow rate to provide adequate contact time between the resin and the water being treated during the service cycle, and between the chemical agents and the resin during regeneration. Additionally, the flow of water/chemical solutions through an ion exchange bed should be uniformly distributed across the whole area of the bed.
In co-flow plants the inlet water and regenerant chemicals sometimes use the same distributor, but in hold down counter flow systems two distributors may be provided, one for water, the other for regenerants.

Various types of distributor systems are used in water treatment plants ranging from simple tun dishes to sophisticated header and lateral systems or nozzle plates.

The collection of the treated water and spent effluent is arguably more important than inlet distributor systems. Two main types of collector are used.

Figure 1 NORMAL COUNTER FLOW (HOLD DOWN)

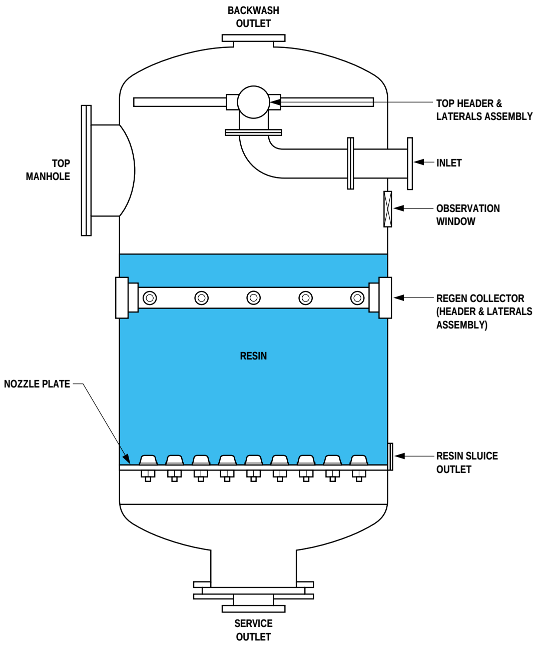


Fig. 1 shows a system in which a steel plate is fitted with nozzles. In this case the plate supports the bed and the flow of water through the nozzles passes into the dished end of the vessel. The collecting slits in the nozzles have to be small enough to prevent resin beads or fragments entering, but without producing a restriction in flow leading to high pressure losses.

A header and lateral arrangement with holes or slits in the lateral being beneath a plastic or stainless steelmesh wrapping, can be employed instead of a nozzle plate.

Various designs of nozzle are available, the main variables being size and type of slit, and construction which may allow a higher flow in one direction than another.

Pressure loss characteristics of distributor/collector systems have to be finely balanced between having a sufficient loss to promote good distribution while not jeopardising the overall unit pressure drop limit.

4.3 Resin Cleaning

In co-flow plant, disturbance of the resin by backwash is not a critical factor affecting it's performance and hence full backwashing facilities are provided within the unit for removing resin fines and any accumulated suspended solids from the incoming raw water.

In hold down counter flow systems, disturbance of the bed should be avoided; nevertheless, sufficient freeboard is usually provided to allow full backwashing to be undertaken, as and when required.

4.4. Regeneration and Exhaustion of Resins

The effectiveness of regeneration and the efficient up-take of ions during the service cycle are dictated by a number of theoretical and practical factors.

The different ion exchange reactions taking place in a bed under co and counter flow conditions have been discussed in Sections 3.1, 3.2 and 3.3

How do we maximise the effectiveness of a regeneration.
The main factors controlling the degree of regeneration are:

- **i) the quantity of regenerant used per unit volume of resin**
- **ii) the concentration of the regenerant**
- **iii) the type of regenerant**
- **iv) the contact time between the regenerant and the resin**
- **v) the uniformity of distribution of the regenerant passing through the resin.**

Factors (i) to (iv) apply generally to most designs of water treatment plants. The greater the quantity of regenerant used the higher will be the subsequent capacity of a given resin for the exchange of ions during the exhaustion stage. However, resins have a finite capacity and the chemical efficiency decreases as complete conversion of the total capacity is approached. The quantity of the regenerant employed versus the efficiency of the regeneration cycle has to be balanced in the design of a plant.

For example, a highly efficient usage of chemicals can be obtained from using low regeneration levels, but this necessitates increasing the volume of resin to obtain the required output of water between regenerations. As a result, a larger vessel may be required with a consequent increase in capital cost.

Theoretically, regeneration efficiency of a resin is favoured by using a high concentration of the chemical agent. However, in practice, the concentration is limited by several factors. For example, there has to be sufficient volume of the regenerant to allow adequate contact with the resin. In the case of regenerating with sulphuric acid there is always a risk of calcium sulphate precipitating; consequently, less effective, low concentrations have to be used in the range 1-3%, whereas with hydrochloric acid much higher strengths can be employed. Note, however that calcium sulphate is less likely to precipitate under counter flow conditions because the acid entering the bed first contacts resin in the sodium form (the bulk of the calcium being present on resin near to the acid outlet position) so there is less time for precipitation to take place from the supersaturated calcium sulphate solution before the effluent leaves the unit.

In counter flow systems a more efficient use of the chemical regenerant agent is obtained as the result of the regenerant contacting the most exhausted section of the bed last as it is positioned relatively near to the outlet of the bed, whereas in co-flow operation the ions released from the top of the bed pass through the complete depth of the bed before leaving the unit.

From the above, when figures are quoted for the regeneration efficiency of strong acid and strong base resins they should be critically examined in terms of the volume of resin used to produce a given output, the type and strength of the chemical regenerant used and the composition of the water being treated.

It should emphasised that capacity and the average leakage of ions from a bed during the exhaustion cycle are inter-related, and details are provided for individual resins in the Appendix.

5 PACKED BEDS

The two main designs of packed bed systems are :

- **Upflow regeneration with downflow service**
- **Upflow service with downflow regeneration**

Fig 2 shows the general arrangement for both options.

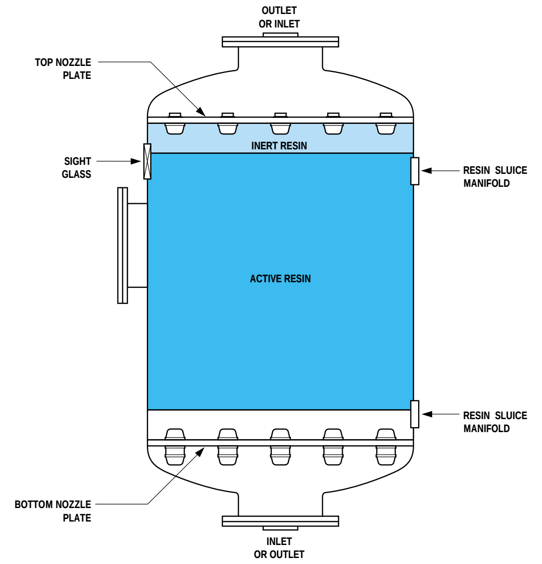
5.1 The Upflow Regenerated - Downflow Service Packed Bed

5.1.1 Vessels

For a plant designed from the outset to operate in a packed bed mode, the vessel will be of conventional cylindrical shape. The design should maximise the height to diameter ratio taking into account the various factors influencing pressure losses. i.e. the distribution and collection systems, the flow rate and the configuration of the resins (and inert) used to form the bed.

From an ion exchange viewpoint the greater the depth of bed the more effective the ion exchange processes will be.

Figure 2 PACKED BED



Moreover as indicated in Section 4.1 the greater the height to diameter ratio for a given volume of vessel the lower the cost.

The bottom support for the ion exchange resin should be of conventional design such as single nozzle plate (or header and laterals above a base plate). These systems act as the distributor/collector for the water and regenerant chemicals.

The top collector/distributor arrangement can again be either nozzle plate or a header and lateral arrangement below a head plate.

5.1.2 Resins and Inert Plastic Material

Ideally, in excess of 95% of the total volume of the vessel should be occupied by the ion exchange resin and inert material. New plant should be designed on this basis, but a retrofitted system may result in the need for a greater proportion of inert plastic material in order to top up the free space.

It is very important that the swelling and shrinking characteristics of resins are taken into account when estimating the total quantity of resin to be used. The Appendix gives reversible (and irreversible) volume changes relevant to a range of Purolite resins likely to be used in packed bed systems.

The bead size range of the resin needs to be compatible with the design of the distribution and collector systems. Accordingly, the resins should be chosen in respect to particle size. The Purolite FL range of resins have been specially graded for use in most packed bed systems, and are between 0.42mm and 1.00mm. Other size ranges can be supplied to suit specific packed bed designs.

The choice of individual Purolite resins for any treatment scheme will be based on the same criteria used for co-flow and hold down counter-flow plants. Therefore, depending on the composition of the raw water, a wide range of resins may be employed in packed beds.

In upflow regeneration, inert plastic material is used at the top of the unit. This has to be of low density so that it remains above the ion exchange bed, and of relatively large size to allow the passage of fines and any accumulated insoluble matter removed from the bed during regeneration. The standard Purolite IP4 inert material is suitable for this purpose and is cylindrical in shape with dimensions 1.2 x 1.5mm and having a density of 560g/l.

The quantity of inert material should be sufficient to completely cover the top distribution system. The use of this type of material allows relatively high slit width in the nozzles or laterals (e.g. up to 0.5mm) without any loss of whole resin beads.

The inert material remains in the unit during both the service and regeneration cycles.

5.1.3 Flow in Service

The flow conditions and limitations are similar to other types of plant operating under downflow service conditions with the bed settled and unlikely, therefore, to be disturbed. However, enhancement of the uniformity of water distribution can arise from the inert material at the top of the packed bed and contribute to the efficiency of the ion exchange process.

5.1.4 Regeneration and Rinse

The essential requirement for the upflow regeneration stage is the prevention of any disturbance of the bed, so allowing maximum uniform contact between the regenerant and the resin. Any mixing of the resin bed will cause reduction in throughput of treated water and deterioration in quality.

The types, quantities and strengths of the regenerants will be similar to those employed on conventional designs of plant.

The various stages in the regeneration procedure are as follows :

i) **A fast upflow of water to compact the bed against the top collector system. (Note that sight glasses should be fitted in the vessel to observe that satisfactory compaction has been achieved).**

ii) **Upflow of regenerant at a rate sufficient to maintain the bed in a compacted condition.**

iii) **Upflow rinse water at same rate to displace the regenerant solution.**

iv) **Short period to allow the bed to settle.**

v) Downflow rinse until the treated water is of satisfactory quality. Note a recycle rinse can be used e.g. from cation outlet to anion inlet to anion outlet to cation inlet.

It is important that the correct water quality is used for each of the regeneration stages e.g. deionised water for rinsing anion resin and decationised water for cation resin.

5.1.5 Cleaning of Resins

In packed beds, by definition the freeboard is minimal and the cleaning of the resin by backwashing cannot therefore be carried out.

In the up-flow regeneration mode inert material is installed above the resin and is graded to allow passage of resin fines and any suspended matter accumulated on the top of the bed during the service period and released during the regeneration stage. As indicated earlier, the top collector has to be suitably designed to allow the fines and suspended matter to pass from the unit. (To minimise the risk of blocking the apertures associated with the top collector will be 0.5mm compared to 0.2mm under other design conditions.

How effectively the upflow regeneration removes suspended solids will depend on a number of factors :

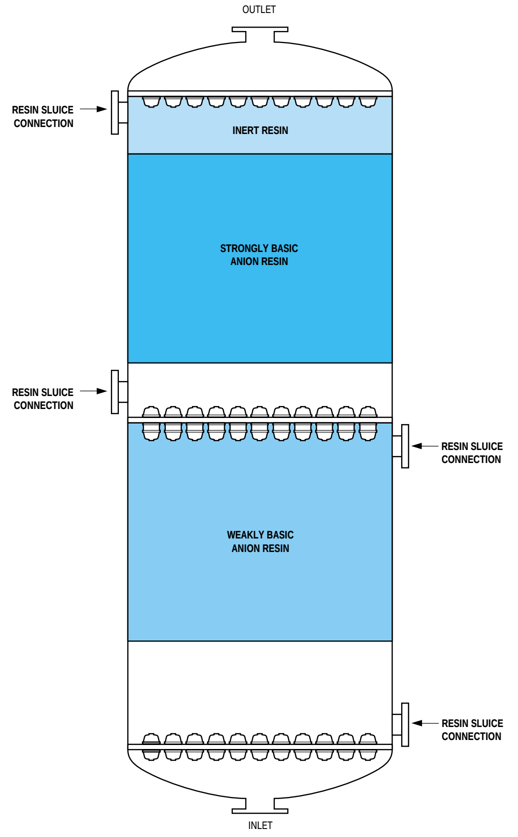
- **The degree of penetration of the suspended solid material into the bed**
- **the size and density of the suspended solids**
- **the upflow rate**
- **the physical nature of the inert overlayer.**

The regeneration procedure should help eliminate the traces of insoluble material of small particle size originating from the raw water. However, under more adverse conditions there would be a significant risk of the accumulated insoluble matter not being satisfactorily removed. The top section of the bed would then have to be removed from the unit into another vessel where it could be cleaned by backwashing.

Clearly, there is a need at the design stage to assess the extent of debris likely to enter the unit under all operating conditions to determine the provisions required for cleaning of the bed.

Removing resin from the unit would inevitably disturb the highly regenerated resin at the bottom of the bed so that after such a treatment a double regeneration sequence would be required to maintain the quality of treated water demanded.

Figure 3 TWO LAYER RESIN SYSTEM



5.2 The Upflow Service - Downflow Regenerated Pack Bed.

5.2.1 Vessel

The shape and dimensions of the vessel will be similar to those discussed in the previous section.

The distribution and collection systems employed are usually of a nozzle plate design (See Fig.2).

If a two layer resin system is required, either cation or anion, an intermediate resin separation plate should be fitted with a double nozzle system to allow the service upflow and regeneration downflow stages to be performed within the same vessel (see Fig.3). The main application of an intermediate nozzle arrangement will be when strong acid and weak acid or strong basic and weak base resins are used within a single vessel shell.The same variety of resins can be employed as for downflow service but note as stated that a more complicated process design is required where layered (stratified) beds are to be used.

5.2.2 Resins and Inert Plastic Material

The same precautions as outlined previously need to be taken on filling the unit with due regard to the swelling characteristics of the resins (see Appendix).

The upflow service type of bed can be designed with or without an inert floating layer; there is a risk, therefore, of particles of resin blocking the apertures of the nozzles which are conventionally sized with 0.2mm slits. The size of the resins used needs to be carefully considered and controlled to minimise this risk. Purolite FL grade resins are recommended for this application. It is safer however to consider the use of a floating inert in conjunction with Purolite FL.

5.2.3 Flow in Service

With upward service flow, there is a need at the beginning of the service cycle to raise the bed so that it immediately compacts against the top collector. It is essential that the bed is sufficiently compacted to maintain good contact between the water being treated and the resin. The flow-rate required to produce the initial raising of the bed will be higher than that required to maintain the bed in position thereafter i.e. 15m/h. The aim is to set the service flow rate so that compaction is maintained (again sight glasses need to be installed to confirm compaction) with a satisfactorily low pressure loss.

Flow-rates required will vary with the particular design and operating conditions of the plant, but bed stability should be obtained at flow rates as low as 10m/h.

In practice, variations in flow rate may lead to some relaxation within the bed, but depending on the quality/capacity criteria of a specific plant, this may be acceptable. However, a major disturbance of the bed will result in a deterioration in the quality of water obtained and a shortening of the service cycle.

If intermittent operation of a plant or excessive variations in flow are likely to arise an automatic recycling system can be installed which is activated when the flow rate approaches an unacceptably low level.

5.2.4 Regeneration and Rinse

Downflow regeneration mode ensures stability of the bed and good distribution of the chemical agents. Furthermore, with a packed bed dilution of regenerant is minimised. The general regeneration conditions are similar to those for conventional plant e.g. the regenerants should be of a concentration so that the volume of the regenerant, and flow rate is controlled to allow an adequate contact time between the regenerant and the resin. The standard technical literature gives the general conditions used in a typical regeneration.

As previously, the packed bed reduces the quantity of rinse water required. Furthermore, with the upflow service design a recycle facility is frequently installed for maintaining the bed in a compacted condition ready for the next upflow service period.This procedure can be used to advantage towards the end of the rinse period to reduce the quantity of fresh rinse required and to shorten the regeneration procedure.

5.2.5 Cleaning of Resins

In the upflow service system the top nozzle arrangement needs to be protected from resin fines (see 5.2.2). Any suspended solids entering with the raw water will be filtered at the bottom of the cation bed and cannot, therefore, be easily removed from the unit. These factors dictate that an external cleaning system should be installed. However, a single cleaning facility can be designed to serve a number of units, and can be constructed relatively cheaply to a simple design.

It is unnecessary to transfer the whole of the bed from the unit for cleaning. It is the two ends of the bed that require cleaning so facilities should be provided for transferring resin from the top and bottom of the unit for fines and suspended solids removal, respectively.

The design of a separate backwash vessel and the frequency with which it is used will depend on the quality of the raw water and to a lesser extent on the production of resin fines. On this basis, the quantity of resin likely to need backwashing can be estimated and the backwash vessel sized accordingly. If the whole of the bed needs to be backwashed this can be done by progressively transferring resin over a number of service cycles and removing a fraction of the bed from the top of the unit and returning it to the bottom of the unit.

Care needs to be taken in the quality of water used for the backwashing operation, particularly if the resin is to be returned to the top of the unit where the most highly regenerated resin should be. In this case deionised water would be the preferred option.

5.3 Comparison of Packed Beds and Their Usage -

5.3.1 Packed beds versus ‘hold down’ Counterflow Beds

Advantages of Packed Beds

- **Simple design of units without the need for intermediate collection and distribution systems.**
- **Shorter units of lower cost arising from the elimination of freeboard**
- **Easier to operate automatically**
- **More stable conditions during regeneration leading to improved quality of treated water and more effective use of chemicals**
- **Savings in rinse requirements and waste water.**

Disadvantages

- **Additional plant facility may be required for the removal of resins from vessels for cleaning**

5.3.2 Downflow Service Packed Bed versus Upflow Service Packed Bed.

Any performance difference related to these two alternatives designs will be minimal. Comments below are therefore limited to a consideration of the two designs in terms of operational risk in achieving the specified quality and quantity of treated water.

In all counter flow plant the degree of compaction of the bed during the exhaustion and regeneration cycles is a major factor controlling the quality of water produced and the capacity obtained from the ion exchange resins.

Both of the packed bed designs described carry a slight risk of some ‘de-compaction’ of the bed and the degree of risk is dependent on the volume of free space in the unit. (This ‘de-compaction’ could occur either during the upflow exhaustion stage or upflow regeneration).

The presence of suspended solids in the raw water may present problems to both categories of packed bed. Suspended matter will be filtered out on the top and bottom of a bed with downflow and upflow service conditions, respectively. (Accumulated material has to be removed from the bed to relieve pressure losses).

On reversing the flow during the regeneration stage some of the solids will be released (see Sections 5.1.5 and 5.2.5).

6 USE OF PACKED BEDS

Plants based on the packed bed principle can be designed to treat water for a range of applications ranging from softening to complete deionisation. It is possible to retro fit conventional plants to work as packed beds, but this is more feasible with downflow service upflow regeneration packed bed designs.

In the deionisation of water, packed beds can function as the primary deionisation section, i.e., as cation-anion units.

A counter flow packed bed system provides a means of obtaining a very high quality water from a cation-anion plant with optimum use of regenerant chemicals. For example, conductivities of treated water leaving the anion unit can be <0.5 uS/cm, therefore a final mixed bed stage may not be required. Note, However, that should water of the highest quality be required (<0.1uS/cm) the installation of a conventional mixed bed should be considered.

Packed beds can also be used in other fields where ion exchange techniques are employed such as :

- **Effluent treatment**
- **Recovery of reusable products from process**
- **Decolourisation of sweetener syrups**
- **Adsorption processes**

7 CONCLUSIONS

- **Packed beds properly designed, engineered and operated will compete with Counter Flow Hold Down Systems in terms of throughput and quality.**

- **Packed beds have advantages in terms of overall reduction in size of vessels and total space requirement. Reduction in waste water and regeneration chemicals is also an important factor.**

- **With an increase in the employment of packed bed technology the purpose of this bulletin is to assist those people routinely engaged in the design of ion exchange systems.**

The general physical and chemical characteristics of the Purolite resins used in packed systems are given in the standard product Technical Bulletins. (These can be supplied on request).

These Bulletins can be read in conjunction with the specific data given in the Appendix to this publication.

PUROLITE C100FLH (Sulphuric acid regeneration)

Operating capacity and leakage characteristics for varying water analysis and regeneration levels are given below.

Capacities are calculated in terms of g/l $CaCO_3$ and are to a 500 ppb sodium end point (as Na).

CAPACITY

Regeneration level g/l 98% H_2SO_4	0-50% Sodium			75% Sodium		
	0% Alk.	50% Alk.	100% Alk.	0% Alk.	50% Alk.	100% Alk.
40	25.0	28.5	30.0	32.5	35.0	36.5
64	30.0	32.5	36.0	41.0	43.0	46.5
98	36.0	40.0	43.5	49.0	52.5	57.5
128	40.0	44.0	47.5	55.0	57.5	64.0

SODIUM LEAKAGE

Figures given in table are average sodium leakage as Na in ppb

Regeneration level g/l 98% H_2SO_4	% Sodium of total cations		
	75	50	20
40	220	200	170
64	62	50	35
98	27	22	15
128	18	16	8

PUROLITE C100FLH (Sulphuric acid regeneration)

Operating capacity and leakage characteristics for varying water analysis and regeneration levels are given below.

Capacities are calculated in terms of Kilograins/cu.ft. $CaCO_3$ and are to a 500 ppb sodium end point (as Na).

CAPACITY

Regeneration level lbs/cu.ft. 98% H_2SO_4	0-50% Sodium			75% Sodium		
	0% Alk.	50% Alk.	100% Alk.	0% Alk.	50% Alk.	100% Alk.
2.5	10.9	12.5	13.1	14.5	15.3	15.9
4.0	13.1	14.2	15.7	17.9	18.8	20.3
6.0	15.7	17.5	19.0	21.3	22.9	25.1
8.0	17.5	19.2	20.7	24.0	25.1	27.9

SODIUM LEAKAGE

Figures given in table are average sodium leakage as Na in ppb

Regeneration level lbs/cu.ft. 98% H_2SO_4	% Sodium of total cations		
	75	50	20
2.5	220	200	170
4.0	62	50	35
6.0	27	22	15
8.0	18	16	8

PUROLITE C100FLH (Hydrochloric acid regeneration)

Operating capacity and leakage characteristics for varying water analysis and regeneration levels are given below.

Capacities are calculated in terms of g/l $CaCO_3$ and are to a 500 ppb sodium end point (as Na).

CAPACITY

Regeneration level g/l 100% HCl	0-50% Sodium			75% Sodium		
	0% Alk.	50% Alk.	100% Alk.	0% Alk.	50% Alk.	100% Alk.
32	40.0	43.5	44.5	45.0	46.0	48.5
64	55.0	60.0	64.5	62.0	64.5	68.0
96	64.0	69.5	74.5	72.0	74.5	79.0
128	69.0	75.0	79.0	75.0	79.5	84.5

SODIUM LEAKAGE

Figures given in table are average sodium leakage as Na in ppb

Regeneration level g/l 100% HCl	% Sodium of total cations		
	75	50	20
32	110	70	25
64	25	19	14
96	16	12	8
128	10	7	6

PUROLITE C100FLH (Hydrochloric acid regeneration)

Operating capacity and leakage characteristics for varying water analysis and regeneration levels are given below.

Capacities are calculated in terms of Kilograins/cu.ft. $CaCO_3$ and are to a 500 ppb sodium end point (as Na).

CAPACITY

Regeneration level lbs/cu.ft. 100% HCl	0-50% Sodium			75% Sodium		
	0% Alk.	50% Alk.	100% Alk.	0% Alk.	50% Alk.	100% Alk.
2.0	17.5	19.0	19.4	19.6	20.0	21.1
4.0	24.0	26.2	28.1	27.0	28.1	29.7
6.0	27.9	30.3	32.5	31.4	32.5	34.5
8.0	30.1	32.7	34.5	32.7	34.7	36.9

SODIUM LEAKAGE

Figures given in table are average sodium leakage as Na in ppb

Regeneration level lbs/cu.ft. 100% HCl	% Sodium of total cations		
	75	50	20
2.0	110	70	25
4.0	25	19	14
6.0	16	12	8
8.0	10	7	6

PUROLITE A200 FL

The following information on capacity and silica leakage is for ambient regeneration conditions.

Capacities are based on an SiO_2 end point of 200 ppb and it is assumed that the water has been decationised through a packed bed counterflow regeneration system.

All capacity figures are relevant to decationised water having silica levels between 0 and 25% of total anions and are presented in terms of g/l as $CaCO_3$.

CAPACITY

Regeneration level g/l 100% NaOH	100% Sulphate	50% Sulphate	20% Sulphate
48	42.0	40.0	37.5
64	44.5	42.5	40.0
96	48.0	45.5	43.0
128	49.0	48.0	44.0

SILICA LEAKAGE

Silica leakage figures are given in the Table below as a ppb and are relevant providing that the sodium level in the decationised water is < 100ppb.

Regeneration level g/l 100% NaOH	Silica as % of total anions		
	5%	10%	25%
48	<5	15	60
64	<5	<5	32
96	<5	<5	9
128	<5	<5	<5

PUROLITE A200 FL

The following information on capacity and silica leakage is for ambient regeneration conditions.

Capacities are based on an SiO_2 end point of 200 ppb and it is assumed that the water has been decationised through a packed bed counterflow regeneration system.

All capacity figures are relevant to decationised water having silica levels between 0 and 25% of total anions and are presented in terms of Kilograins/cu.ft. as $CaCO_3$.

CAPACITY

Regeneration level lbs/cu.ft. 100% NaOH	100% Sulphate	50% Sulphate	20% Sulphate
3.0	18.3	17.5	16.3
4.0	19.4	18.5	17.5
6.0	20.9	19.8	18.7
8.0	21.4	20.9	19.2

SILICA LEAKAGE

Silica leakage figures are given in the Table below as a ppb and are relevant providing that the sodium level in the decationised water is < 100ppb.

Regeneration level lbs/cu.ft. 100% NaOH	Silica as % of total anions		
	5%	10%	25%
3.0	<5	15	60
4.0	<5	<5	32
6.0	<5	<5	9
8.0	<5	<5	<5

PUROLITE A850 FL

The following information on capacity and silica leakage is for ambient regeneration conditions.

Capacities are based on an SiO_2 end point of 200 ppb and it is assumed that the water has been decationised through a packed bed counterflow regeneration system.

All capacity figures are relevant to decationised water having silica levels between 0 and 25% of total anions and are presented in terms of g/l as $CaCO_3$.

CAPACITY

Regeneration level g/l 100% NaOH	100% Sulphate	50% Sulphate	20% Sulphate
48	37.5	35.0	32.5
64	40.5	38.0	35.0
96	44.5	42.0	40.0
128	46.5	44.0	42.0

SILICA LEAKAGE

Silica leakage figures are given in the Table below as ppb and are relevant providing that the sodium level in the decationised water is <100ppb

Regeneration level g/l 100% NaOH	Silica as % of total anions		
	5%	10%	25%
48	<3	5	40
64	<2	<5	23
96	<2	<2	6
128	<2	<2	<3

PUROLITE A850 FL

The following information on capacity and silica leakage is for ambient regeneration conditions.

Capacities are based on an SiO_2 end point of 200 ppb and it is assumed that the water has been decationised through a packed bed counterflow regeneration system.

All capacity figures are relevant to decationised water having silica levels between 0 and 25% of total anions and are presented in terms of Kilograins/cu.ft. as $CaCO_3$.

CAPACITY

Regeneration level lbs/cu.ft. 100% NaOH	100% Sulphate	50% Sulphate	20% Sulphate
3.0	16.3	15.2	14.5
4.0	17.7	16.6	15.2
6.0	19.4	18.3	17.5
8.0	20.3	19.2	18.3

SILICA LEAKAGE

Silica leakage figures are given in the Table below as ppb and are relevant providing that the sodium level in the decationised water is <100ppb

Regeneration level lbs/cu.ft. 100% NaOH	Silica as % of total anions		
	5%	10%	25%
3.0	<3	5	40
4.0	<2	<5	23
6.0	<2	<2	6
8.0	<2	<2	<3

PUROLITE A510 FL

The following information on capacity and silica leakage is for ambient regeneration conditions.

Capacities are based on an SiO_2 end point of 200 ppb and it is assumed that the water has been decationised through a packed bed counterflow regeneration system.

All capacity figures are relevant to decationised water having silica levels between 0 and 25% of total anions and are presented in terms of g/l as $CaCO_3$.

CAPACITY

Regeneration level g/l 100% NaOH	100% Sulphate	50% Sulphate	20% Sulphate
48	37.0	34.5	32.0
64	40.0	37.5	34.5
96	44.5	42.0	39.5
128	46.0	43.5	41.0

SILICA LEAKAGE

Silica leakage figures are given in the Table below as a ppb and are relevant providing that the sodium level in the decationised water is < 100ppb.

Regeneration level g/l 100% NaOH	Silica as % of total anions		
	5%	10%	25%
48	<5	15	60
64	<5	<5	32
96	<5	<5	9
128	<5	<5	<5

PUROLITE A510 FL

The following information on capacity and silica leakage is for ambient regeneration conditions.

Capacities are based on an SiO_2 end point of 200 ppb and it is assumed that the water has been decationised through a packed bed counterflow regeneration system.

All capacity figures are relevant to decationised water having silica levels between 0 and 25% of total anions and are presented in terms of Kilograins/cu.ft. as $CaCO_3$.

CAPACITY

Regeneration level lbs/cu.ft. 100% NaOH	100% Sulphate	50% Sulphate	20% Sulphate
3.0	16.1	15.1	14.0
4.0	17.5	16.3	15.1
6.0	19.4	18.3	17.2
8.0	20.0	19.0	17.9

SILICA LEAKAGE

Silica leakage figures are given in the Table below as a ppb and are relevant providing that the sodium level in the decationised water is < 100ppb.

Regeneration level lbs/cu.ft. 100% NaOH	Silica as % of total anions		
	5%	10%	25%
3.0	<5	15	60
4.0	<5	<5	32
6.0	<5	<5	9
8.0	<5	<5	<5

PUROLITE A400 FL

The following information on capacity and silica leakage is for ambient regeneration conditions.

Capacities are based on an SiO_2 end point of 200 ppb and it is assumed that the water has been decationised through a packed bed counterflow regeneration system.

All capacity figures are relevant to decationised water having silica levels between 0 and 25% of total anions and are presented in terms of g/l as $CaCO_3$.

CAPACITY

Figures given are for strong anion compositions of 100% sulphate in the decationised water.
See correction table for variation.

Regeneration level g/l 100% NaOH	Silica %		
	10	20	50
64	31.5	30.5	28.0
96	35.5	35.0	33.5
128	39.0	38.5	37.0
160	42.0	41.5	40.0

SULPHATE/CHLORIDE RATIO CORRECTION

% Sulphate	100	90	80	70	60	50	40	30	20	10	0
Correction Factor	1.0	0.98	0.97	0.95	0.94	0.93	0.92	0.90	0.88	0.87	0.86

SILICA LEAKAGE

Regeneration level g/l 100% NaOH	Silica as % of total anions		
	10	20	50
64	<3	22	43
96	<2	10	25
128	<2	3	7
160	<2	<2	<3

PUROLITE A400 FL

The following information on capacity and silica leakage is for ambient regeneration conditions.

Capacities are based on an SiO_2 end point of 200 ppb and it is assumed that the water has been decationised through a packed bed counterflow regeneration system.

All capacity figures are relevant to decationised water having silica levels between 0 and 25% of total anions and are presented in terms of Kilograins/cu.ft. as $CaCO_3$.

CAPACITY

**Figures given are for strong anion compositions of 100% sulphate in the decationised water.
See correction table for variation.**

Regeneration level lbs/cu.ft. 100% NaOH	Silica %		
	10	20	50
4.0	13.7	13.3	12.2
6.0	15.5	15.2	14.6
8.0	17.0	16.8	16.1
10.0	18.3	18.1	17.5

SULPHATE/CHLORIDE RATIO CORRECTION

% Sulphate	100	90	80	70	60	50	40	30	20	10	0
Correction Factor	1.0	0.98	0.97	0.95	0.94	0.93	0.92	0.90	0.88	0.87	0.86

SILICA LEAKAGE

Regeneration level lbs/cu.ft. 100% NaOH	Silica as % of total anions		
	10	20	50
4.0	<3	22	43
6.0	<2	10	25
8.0	<2	3	7
10.0	<2	<2	<3

CHANGE IN VOLUME PUROLITE RESINS

All ion exchange resins swell and shrink relative to their active ionic forms. This category of property is defined as 'reversible volume change'.

In certain cases the resin, as first delivered, will undergo a non-reversible swelling when initially cycled as well as have reversible volume change properties.

The table below illustrates these properties for the Purolite resins included in this bulletin. For reversible volume change numbers please note that the percentages relate to complete conversion from one ionic form to another.*

Resin	Irreversible volume change	Reversible volume change
Purolite C100FLH	NIL	H^+ -->Na^+, - 5%
Purolite A200FL	NIL	$C1^-$ -->OH^- + 15%
Purolite A400FL	NIL	$C1^-$ -->OH^- + 20%
Purolite A510FL	NIL	$C1^-$ -->OH^- + 10%
Purolite A850FL	8%	$C1^-$ -->OH^- + 15%

* For the purpose of calculating volume change in any particular instance, a proportion of the total volume change figure should be taken representing the percentage of the total intrinsic capacity utilised in carrying out the plant calculation.

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The Purolite Company and Purolite International Limited have one of the most complete ranges of ion exchange resins worldwide. For further information please contact your local Purolite office.

PUROLITE
ION EXCHANGE RESINS

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