

## Treatment and Conditioning of Spent Ion Exchange Resin from Nuclear Power Plant

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### ABSTRACT

There are a number of liquid processes and waste streams at nuclear facilities (i.e. nuclear power plants, fuel reprocessing plants, nuclear research centers, etc.) that require treatment for process chemistry control reasons and/or the removal of radioactive contaminants. These processes may be for reactor primary coolants, the cleanup of spent fuel pools, liquid radioactive waste management systems, etc. One of the most common treatment methods for such aqueous streams is the use of ion exchange, which is a well developed technique that has been employed for many years in both the nuclear industry and in other industries. Nuclear power plant process water systems have typically used organic ion exchange resins to control system chemistry to minimize corrosion or the degradation of system components and to remove radioactive contaminants. Organic resins are also used in a number of chemical decontamination or cleaning processes for the regeneration of process water by reagents and for radionuclide removal. In this report we will describe the method to solidify this waste by cementation techniques methods. There are several techniques are available for treating and conditioning of ion exchange resins. One of such technique uses a matrix material, which can be used in the conditioning process. There is wide rang of potential materials available for the conditioning of low and intermediate level liquid wastes and at the end we will mechanically (compression strength) testify these cubes of different cement and resin composition, according to IAEA standards.

### 1. INTRODUCTION

There are a number of liquid processes and waste streams at nuclear facilities(i.e. nuclear power plants, fuel reprocessing plants, nuclear research centers, etc.) that require treatment for process chemistry control reasons and/or the removal of radioactive contaminants. These processes may be for reactor primary coolants, the cleanup of spent fuel pools, liquid radioactive waste management systems, etc. One of the most common treatment methods for such aqueous streams is the use of ion exchange, which is a well developed technique that has been employed for many years in both the nuclear industry and in other industries. [1]

Nuclear power plant process water systems have typically used organic ion exchange resins to control system chemistry to minimize corrosion or the degradation of system components and to remove radioactive contaminants. Organic resins are also used in a number of chemical decontamination or cleaning processes for the regeneration of process water by reagents and for radionuclide removal. [2]

In the past decade inorganic ion exchange materials have emerged as an increasingly important replacement or complement for conventional organic ion exchange resins, particularly in liquid radioactive waste treatment and spent fuel reprocessing applications. Inorganic ion exchangers often have the advantage of a much greater selectivity than organic resins for certain radio logically important species, such as caesium and strontium. These inorganic materials may also prove to have advantages with respect to immobilization and final disposal when compared with organic ion exchangers. However, in nuclear power plant operations the currently available inorganic exchangers cannot entirely replace conventional organic ion exchange resins, especially in high purity water applications or in operations in which the system chemistry must be controlled through the maintenance of dissolved species such as lithium ions or boric acid. [1]

The ion exchange process is very effective at transferring the radioactive content of a large volume of liquid into a small volume of solid. The treatment and conditioning of radioactive spent ion exchange materials is a complex process encompassing a detailed consideration of the materials' characteristics and their compatibility with the various processing, storage and/or disposal options. The handling of spent ion exchange media also needs to be assessed in the context of an integrated waste management system for all the radioactive waste generated; for

example, in some cases ion exchange waste may constitute such a relatively minor fraction of the total waste stream that a specialized treatment only for ion exchange media may not be cost effective. Conversely, the radiochemical characteristics of spent ion exchange media may require specialized handling, even though the volumes may represent a small fraction of a facility's waste inventory. [1]

Although inorganic ion exchange materials play an increasing role in the selective removal of specific radionuclides, organic ion exchange resins continue globally to represent the dominant form of ion exchange waste. This is largely because organic ion exchangers have proved to be reliable and effective for the control of both the chemistry and radiochemistry of water coolant systems at nuclear power plants and also for processing some liquid radioactive waste. Organic ion exchange resins have been developed over a much longer period of time than the selective inorganic ion exchangers that are now becoming available in commercial quantities and they can now meet the demands of the nuclear industry. In a number of cases, for specific physical and chemical reasons, organic resins cannot be replaced by inorganic ion exchangers. The volumes of spent organic ion exchange resins that arise from typical nuclear power plant operations are shown in Table I.[3]

Table Error! No text of specified style in document.-1 Spent organic ion exchange resin generation by reactor type

Reactor Types	Spent Ion Exchange resin Generation ( $\text{m}^3 \text{unit}^{-1} \text{a}^{-1}$ )
PWR	4-7
PHWR	5-7
BWR	20

A wide range of materials is available for the ion exchange treatment of radioactive liquids. These materials are available in a variety of forms, have widely differing chemical and physical properties and can be naturally occurring or synthetic. This section focuses on materials that are commercially available and that can be readily obtained and used for radioactive liquid treatments.[4]

## 2. MANAGEMENT OF SPENT ION EXCHANGE MATERIALS

Spent ion exchange materials represent a special type of radioactive waste and pose unique problems in the selection of their treatment options. Because of the function that they fulfill, spent ion exchange materials often contain high concentrations of radioactivity and pose special handling and treatment problems. In the past these materials were often disposed of in drums or boxes or as disposable ion exchange columns without treatment. In some operations the resins were sluiced from columns and stored in underground tanks as a bed settled in water, pending future treatment, conditioning and disposal.[3]

The selection of treatment options for spent ion exchange materials must consider their physical and chemical characteristics. Basically, there are two main methods for the treatment of spent organic ion exchange materials:

- the destruction of the organic compounds to produce an inorganic intermediate product that may or may not be further conditioned for storage and/or disposal
- direct immobilization, producing a stable end product.[4]
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Spent ion exchange materials may require interim storage to allow for radioactive decay if the activity levels in the materials exceed the treatment facility acceptance criteria or if the activity levels in the materials will decay sufficiently in a reasonable time to allow the disposal of the materials without further treatment. Storage for decay should only be used on an interim basis when the radionuclides of concern have a short half-life. Most ion exchange materials produced in nuclear power plants contain radio nuclides with sufficiently long half-lives (e.g.  $^{60}\text{Co}$ ) to preclude this option. However, in irradiated fuel reprocessing a number of fission products have half-lives

of a year or less (e.g.  $^{106}\text{Ru}$ ) and hence storage for a few years can be of benefit. [4]

Spent ion exchange materials may require storage pending a decision regarding their final treatment, conditioning or disposal. Such storage must consider the role of the materials and container integrity, gas generation (both organic and radiolytic) and material and/or container retrievability. Spent ion exchange materials are currently considered to be in retrievable storage if their treatment or disposal is deferred. Prior to their placement in storage they can be dewatered or dried to reduce the generation of radiolytic gas, to obtain some volume reduction and to improve long term container performance. If drying is employed before storage, aspects such as swelling by the reabsorption of water must be considered.[3]

In the case of wet storage, provisions are required to facilitate the retrieval of the stored waste at a future date and also to ensure that bed compaction does not take place. This latter concern is generally addressed by hydraulically or pneumatically sparging it or by agitating the resin bed to loosen it on a planned, regularly scheduled basis. Failure to agitate the resin bed regularly may result in a compaction of the resins, which can cause difficulties in removing them at a later date.[5]

Pretreatment is defined as any processing that precedes the primary treatment or conditioning of the waste for the purposes of:

- The conversion of waste materials into a form required by the subsequent treatment or conditioning step;
- The improvement of the effectiveness or economics of the subsequent treatment or conditioning step;
- or
- The enhancement of safety, especially in the case of waste placed in extended storage prior to its final treatment.

The selection of a waste pretreatment option is an integral part of the overall waste management system design. The screening and evaluation of pretreatment technologies for application to different treatment methods is described in Ref. [5]. From a technical point of view the same technique may be applied as a treatment or a pretreatment step, depending on the purpose of the process and its sequence in the overall waste management scheme. Screening and the evaluation of pretreatment technologies for application to different treatment methods is described in Ref. [3]. Available pretreatment processes include but are not necessarily limited to:

- Dewatering (organic and inorganic ion exchangers),
- Drying and heating (organic ion exchangers),
- Crushing and grinding (organic and inorganic ion exchangers),
- Foam preparation (organic ion exchangers),
- Decontamination by activity stripping (organic ion exchangers).

Immobilization is the process of incorporating waste (in this case either organic or inorganic ion exchange materials) into a matrix material for solidification or directly into a storage and/or final disposal container.[4]

The immobilization matrices currently used for spent ion exchangers are cement, bitumen and some polymers. In some countries high integrity containers are used for the storage and/or disposal of spent ion exchange media, without incorporation into a solidification matrix.[4]

The technique of immobilizing radioactive waste in cement has been used in the nuclear industry and at nuclear research centers for more than 40 years. Cement has many characteristics in its favor: it is readily available and widely used in civil engineering, the raw material is inexpensive and the processing equipment can be based on conventional technology. The resulting waste forms are strong, non-combustible and radiation resistant, have a high density (providing radiation shielding), have a reasonable chemical stability and have a moderate resistance to the release of radionuclides. The high pH conditions typical for cement results in a low solubility for many radionuclides by the formation of hydrolysed species, carbonates, etc., which provides a good resistance to leaching.[3]

The main disadvantage of the cementation of spent ion exchange materials is that the final waste volume is high compared with the initial volume, owing to the low waste loadings that are achievable. The loadings can be increased by a pretreatment, such as grinding, of the spent ion exchange materials before cementation, which improves the quality of the final cemented products.[4]

Another disadvantage of cementation for organic ion exchange materials is that a swelling of resin beads after contact with water may occur in some disposal repositories. The swelling can result in micro cracks in the cement or even in the overall cracking of the cement structure. Experience has shown that, owing to their size being less than 0.1 mm, an overall cracking of the cement structure does not occur with powder resins. The cementation of spent bead resins without a pretreatment such as grinding should therefore be avoided.[4]

The study examined the encapsulation of the oxides of titanium and manganese, the phosphates of titanium and zirconium, polyantimonic acid and copper hexacyanoferrate. It was found that, with each of these absorbers, a 33 wt% loading in the waste could be reached, which provides a good quality solidified product.[4]

Like cement, bitumen has been used for many years as an immobilization matrix for radioactive material. The processes and methods of bituminization are described in detail in the literature. The immobilization of spent ion exchange resins in polymers is practiced at many installations worldwide. Different types of polymers are used and further studies to improve cost effectiveness, process simplicity and product quality are being carried out in many countries. Among the many polymers used are epoxy resins, polyesters, polyethylene, polystyrene and copolymers, urea formaldehyde, polyurethane, phenol-formaldehyde and polystyrene.

Polymers fall into two main categories: thermoplastic polymers and thermosetting polymers. Thermoplastic polymers become soft (or melt) with the application of heat. They are generally supplied in a solid form and heated when combined with waste. Thermoset polymers are handled in a liquid form and are then polymerized to a solid form using a catalyst and/or heat after waste has been added. The use of the thermoset variety has become more popular owing to its ambient temperature processing capability. In a majority of cases a batch immobilization process in a disposable container (usually a standard drum) is used. Spent resins are generally incompatible with the polymer matrix material. Inorganic ion exchange materials and secondary process residues such as ash and liquids are generally not immobilized using polymers because they are more acceptable to other immobilization matrices such as cement. Each particle of resin is coated with the matrix material. In most cases there is no chemical bonding between the polymer and the resin.[4]

### 3. MATERIALS AND METHODS

The purpose of this project is to identify the best mechanical strength of cement resin mixture. Different compositions of resin with cement are to be made and after solidification of the specimen, the cubes made are to be tested for their strength under the compressive load. Considering the performance of the blocks under the test, the best configuration for cement and resin is identified.

Keeping view of the time frame available for the project, the scopes of the project is focused on the following:

- Preparation of Cubes with varying resin concentration
- Determination of the compressive strength of the cubes prepared earlier
- Comparison of results with the data available in literature

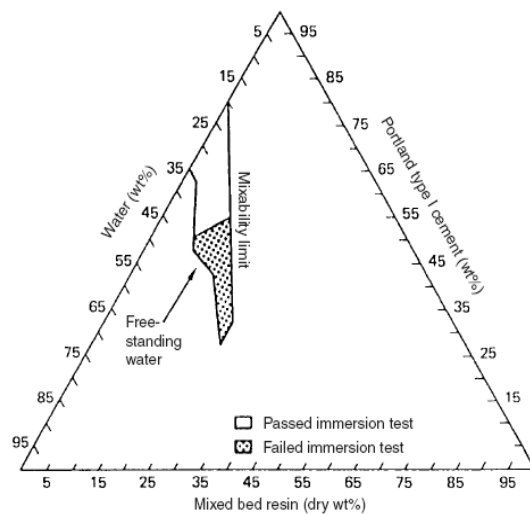
First of all the ordinary cement is tried and the best cement: resin ratio is identified. Similar tests will be conducted for cement, sand and resin. For this reason tests will be conducted in NED University in civil department.

The composition of a cemented waste form is often described by its waste content and water/cement ratio. The waste content is the amount of waste in the final waste form, which is one of the most important properties; the water/cement ratio governs the strength of the cement matrix. In selecting the composition of a mixture, workability is a decisive factor. Good workability is required in order to provide a homogeneous mixture within a reasonable time. The waste content, water/cement ratio and consistency of a waste–cement mixture are interdependent. If the

waste content is increased while the water/cement ratio is kept constant, the mixture becomes more viscous and is thus more difficult to mix. [6]

The same phenomenon occurs if the water/cement ratio is decreased while the waste amount remains constant. If too high a water/cement ratio is used the different components tend to separate in the waste mixture and there can also be free water present after the setting of the product, which is not desirable. Compositions for products that pass certain tests have been published in the literature. This information is generally given in the form of ternary composition phase diagrams, an example of which is shown in Figure 3.1. They present the limits of the composition for free-standing water, for mix ability and for the composition of the forms capable of passing a water immersion test. The weight percentages of water, cement and dry ion exchange resins are used to express the compositions. The loading of spent organic ion exchange resins in cemented products is about 20 wt% (calculated on the basis of the dry resin product), which achieves a compressive strength of about 20 MPa. With higher loadings the compressive strength of the cement product could be decreased to the extent that the acceptance criteria of storage and/or disposal are not fulfilled. [4]

Other examples of the effects of waste loading on waste form performance are given in the literature, in which Portland type III cement was used with a water/cement ratio of 1:2. The samples, containing 10 wt% dry resins, fractured upon immersion in water. To obtain higher resin loadings and more durable waste forms, the resins were coated with water extendible polyester (without an initiator). It was thus possible to obtain loadings as high as 23 wt% of dry resin. These waste forms did not crack during curing and did not deteriorate during wet and dry cycling. Special attention has to be paid to the solidification of spent resins that contain boric acid, since the boric acid affects the setting of the cement. In practice, for pressurized water reactors the boric acid content is 50 to 70 g per kg of resin, which leads to lower waste loadings in the product, as well as the need for additives such as sodium silicate.[6]



**Figure Error! No text of specified style in document.-2 Ternary Phase diagram[4]**

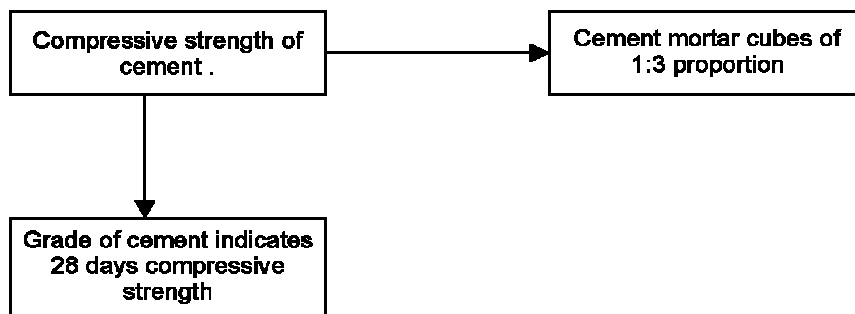
From the **Figure 3-1** the best combination is in which it is passed from immersion test is shown in Table below:

**Table Error! No text of specified style in document.-2 Cement water and resin ratio**

Sr#	Portland Cement (wt %)	Water (wt %)	Ion Exchange Resin (wt %)
1	55	30	15
2	60	30	10
3	65	30	5

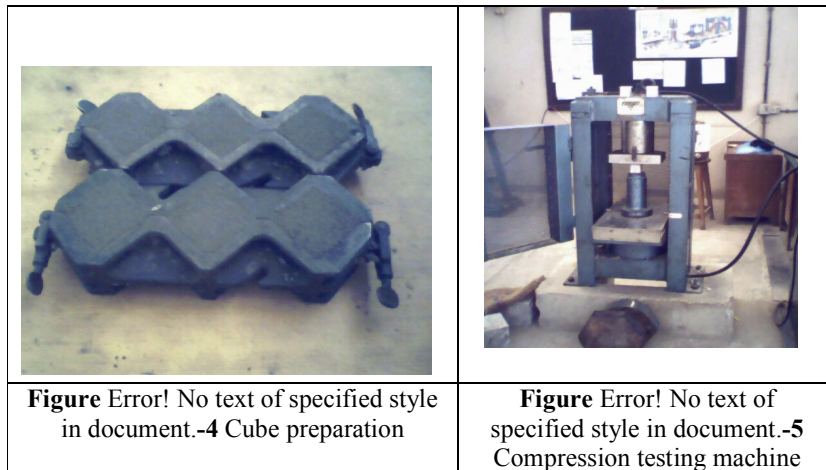
Hence, we caste the cement cube within the define composition but unfortunately the 15% resin composition with cement is not withstand, one reason may be that we have not add any additive. Similarly we caste the mortar cube with the same composition.

To determine the compressive strength of cement: resin. Compressive strength of cement indicates the compressive strength of cement mortar cubes (2inx2inx2in), using ion exchange resin, tested under compression (Grade of cement indicates their compressive strength at the end of 28 days of curing). Many other properties of mortar / concrete are related to compressive strength of cement, because cement is used in structure in the form of mortar or concrete.[6]



**Figure Error! No text of specified style in document.-3** Compressive strength

Cube mould of size 2inx 2in x 2in with base plates, weighting balance accurate up to 0.1gm, Motored cube vibration machine, Measuring cylinder, Trowel and tray etc.



#### 4. RESULTS AND DISCUSSIONS

From the experimental analysis it was found that the strength of the cement decreases with increase the concentration of Resin, as can be seen in Figure 4.1 and Figure 4.2. As Resin concentration increase it weaker the cement bonding with its molecules. The Resin particles provide an impurity in cement. Resin may contain chemical species which can affect the hydration of the cement. For conditioning of the Resin with cement, changes to normal hydration reaction are undesirable because of the potential for adverse effect on Cement: Resin strength

Similarly the experimental analysis is conducted on the cement: sand mixture i.e. so called mortar. In Figure 4.5 and Figure 4.6, on increasing the Resin concentration the strength of the mortar decreases. We see that the initially this decrease in strength is very sharp and on further increase this drop is not so much sharp. Initially the sharp decrease

is due to the effect of certain chemical species present in the resin and as well the resin acts as impurity in the mortar. These chemical species disturbed the normal hydration reaction of the cement. On further increase the concentration the resin is acting as impurity that is why the sharp is less.

In Figure 4.7 we made a comparison between the compressive strength of cement: resin and mortar: resin. As we see that the strength of the mortar is higher than cement paste. This is because in the mortar sand acts as reinforcing material as the actual strength of the cement is far less than the mortar and concrete.

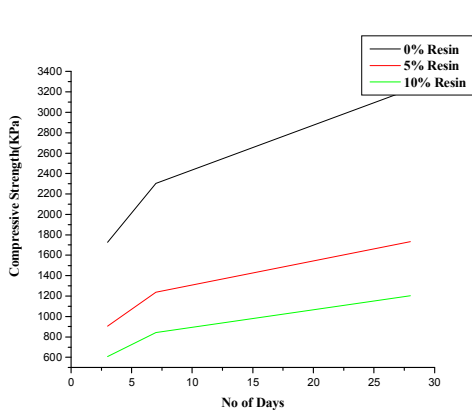


Figure Error! No text of specified style in document.-6  
 Compression Strength Vs No of Days

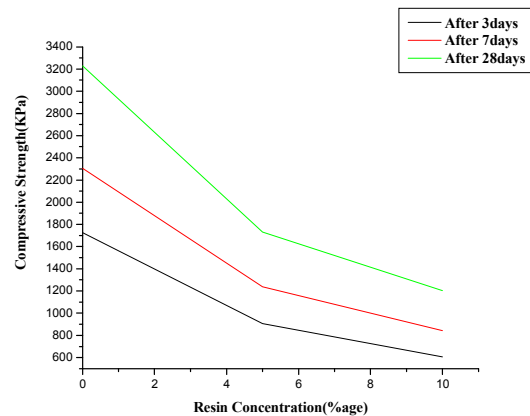


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 Compressive Strength Vs Resin Concentration

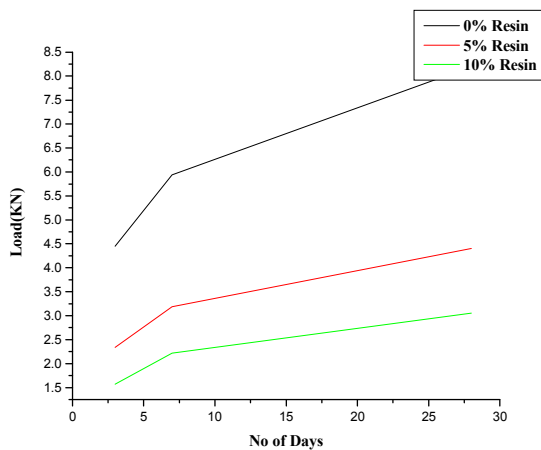


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 Load at rupture Vs No of Days

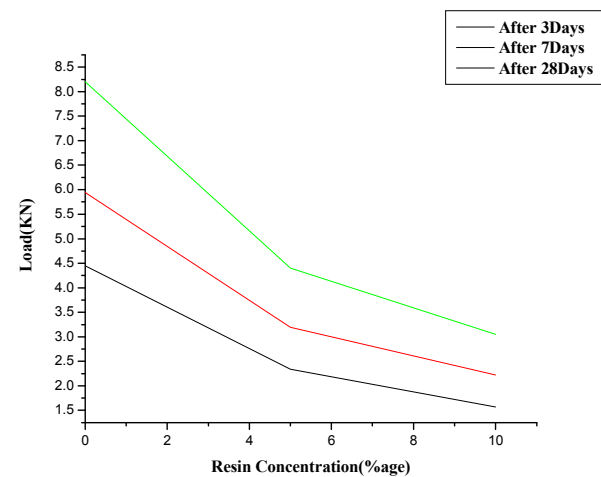


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 Load at rupture Vs Resin concentration

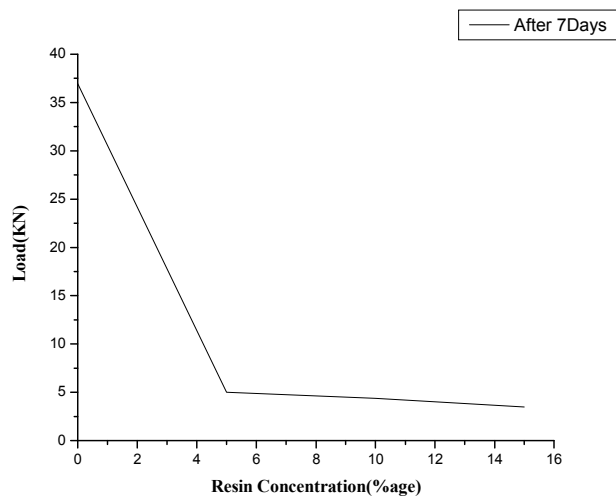
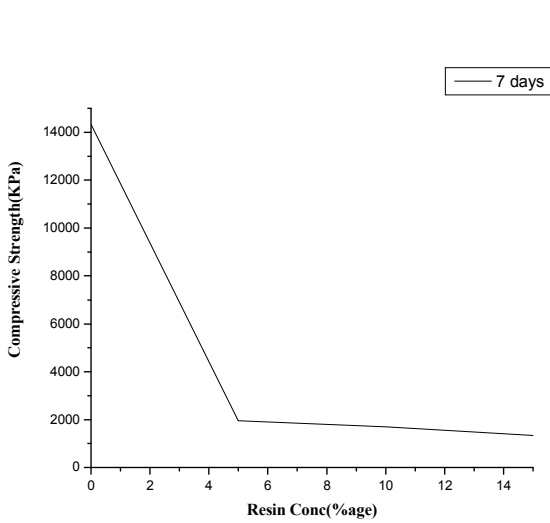


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 Compressive Strength Vs Resin Concentration

Figure Error! No text of specified style in document.-11 Load  
 at rupture Vs Resin concentration

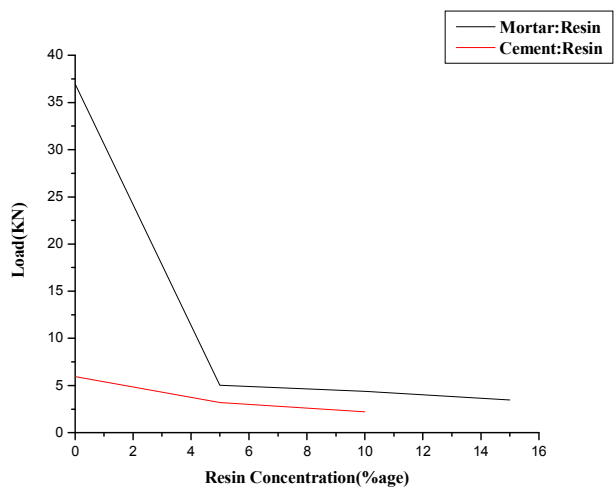
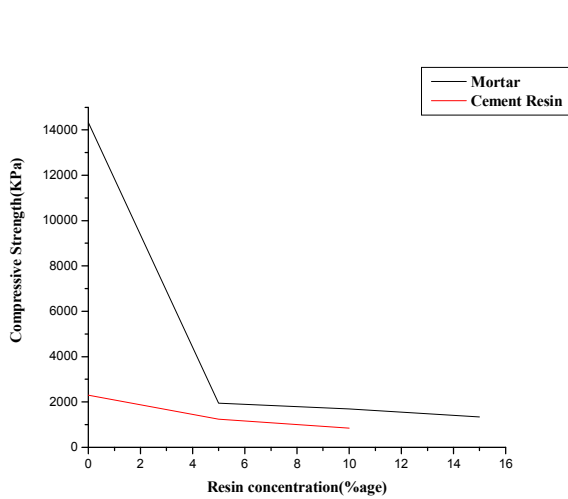


Figure Error! No text of specified style in document.-12  
 Compressive strength Vs resin concentration

Figure Error! No text of specified style in document.-13 Load at  
 rupture Vs Resin concentration



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As discussed previously, the selection of the treatment methods and packaging for spent ion exchange materials must take account of their ultimate disposal. The final waste form must meet all applicable regulatory and facility waste acceptance requirements. In addition to the general waste form concerns, there are some related specifically to ion exchange waste forms, owing to the higher concentration of radionuclides generally found on this type of waste, their associated radiation fields and the nature of the ion exchange materials themselves.[3,4]

Conditioning processes applicable to ion exchange media have been the requirements for a given storage or disposal facility in a country can influence the choice of conditioning process in a number of ways, as outlined below. Some countries require ion exchange media to be immobilized in a matrix such as cement, bitumen or a polymer, while others will accept media that have been dewatered and enclosed in a high integrity container. In Sweden and the UK cement is preferred as the immobilization matrix for low and intermediate level waste, in part due to its ability to retard the mobility of the transuranium elements (such as plutonium) as well as  $^{14}\text{C}$ . [4]. At present, in many countries, owing to the fact that no final repository is available at present, the long term interim storage of unconditioned spent ion exchangers is preferred. A planned interim storage time in excess of 50 years is an option in some countries. An advantage of long term interim storage is an improvement in radiation protection, owing to the decay of short lived radionuclides such as  $^{60}\text{Co}$ . The disadvantage with this procedure may be the degradation of organic ion exchangers owing to radiolysis, oxidation and other reactions, resulting in the potential release of some radionuclides, and the loss of information over time, especially if different waste batches are mixed together.

Another option that is used in countries that have a final repository, such as Sweden, is the short term interim storage of ion exchangers, either in an unconditioned or conditioned form. After the decay of short lived radionuclides and conditioning the waste is placed in the final repository. All information regarding the waste packages is stored in a durable form at the final repository. It is possible to check the radionuclide specific total nuclear inventory at any time. The main advantages are the minimization of the risk of the loss of information and the absence of stockpiled waste at unsuitable facilities. The latter is important in connection with the decommissioning of a nuclear power plant, as accumulated large amounts of radioactive waste could significantly delay the decommissioning process.[4]

The costs of storage and/or disposal will influence whether any volume reduction is performed prior to immobilization. If the cost of disposal is high compared with the volume reduction costs, processing for volume reduction is easily justified on an economic basis. If, however, the storage and/or disposal costs are lower, volume reduction may not be economical. Methods such as incineration, vitrification or plasma arc melting could, apart from reducing volume, also be used to destroy the organic complexing agents that may otherwise facilitate the migration of transuranic elements towards the biosphere.[5] The volume of waste to be treated, and its radionuclide specific properties, including its dose rate, will have an influence on the choice of conditioning process. If the country or facility concerned produces only a small amount of ion exchange media waste, then a simple process

such as in-drum cementation is preferred over more complicated processes, such as incineration, which are too expensive to operate on a small scale. The availability of facilities for the treatment of other waste types will influence the choice; for example, if a cementation plant is being used for the immobilization of liquid waste then the same plant can often be adapted for use with ion exchange media at little or no additional cost.

Treating spent inorganic sorbents, which have a high selectivity and ion exchange capacity, may allow other options for final disposal to be considered. Owing to their high exchange capacity, these materials can often be used in small columns. After use, the columns can be dewatered and disposed of in a shielded container. The container acts as a final waste package and the waste remains in a stable form in the column. If water enters the waste after a loss of integrity of both the concrete container and steel column, only very high concentrations of competing ions will cause a leaching of the absorbed radionuclides from the ion exchange material into the water. The size of the columns and of the final disposal container may differ, depending on the circumstances. Several small ion exchange columns can be encapsulated in one container. Empty space inside the container can be filled with radiation shielding or a buffer material, such as cement grout. Enclosure could also be done prior to its use by placing a column, for example, in a cement lined drum, which has the advantage of providing shielding during its operation and during the column's removal.[3] Long term stability of the waste form is generally required for storage and/or disposal. However, it can be affected by radiolytic, biological and chemical degradation processes, which can further influence the radiological, chemical and physical properties of the waste form.[4]

Another problem specific to many organic ion exchange media is that of dehydration and rehydration. An ion exchange resin bead may contain 50% or more water by weight. As discussed previously, an obvious means to reduce the volume and weight of the material to be disposed of is drying it. However, if the dried media subsequently come into contact with water, as may happen over time in a disposal repository or storage facility, they will rehydrate. The rehydration process will cause the resin beads to expand to their original volume, exerting enormous forces on the surrounding matrix or container. The pressure created by such expansion has been sufficient to cause immobilization matrices to crumble and containers of all types to split open.

With inorganic ion exchangers and composite absorbers with a high inorganic content, reswelling after drying does not normally occur. Dehydration occurs during heat based immobilization processes such as bituminization and polymer extrusion. Dehydration–rehydration may also take place to some extent in immobilization processes such as cementation. This effect can limit the amount of organic ion exchange media that can be incorporated into the cement. If the proportion of ion exchange media in the cement mixture is too high, the media may undergo dehydration and rehydration during curing, causing the cement to crack.

When a waste form containing a dehydrated organic resin is subjected to a water immersion test, the ion exchange medium on the outer edge of the matrix begins to swell, causing cracking. These cracks promote further water penetration into the matrix, causing progressively more and deeper cracking until the matrix ultimately fails. Although such failure mechanisms can be very slow, the long time periods associated with the requirements for radioactive waste storage and/or disposal allow ample time for the actions to occur.

Since the bond between the radioactive ion and the ion exchange medium is fairly weak, specifically in organic ion exchange resins, the spent medium must be kept away from materials that could break the bond, such as the calcium or sodium ions contained in many groundwater or cement materials. Therefore, when a complete isolation of waste forms from the disposal environment is required, a multiple barrier concept is employed, which considers an immobilized waste form itself as a sealed container. It is crucial for long term stability that complexing agents that could increase the mobility of radiotoxic long lived radionuclides are excluded from waste packages that may come into contact with water; such a situation could occur, for example, in an underground bedrock repository.[4]

Some countries, such as the USA, require immobilized waste forms to retain their structural integrity over long periods. This is generally to control the subsidence of near surface waste disposal facilities and applies directly to ion exchange media waste forms. Structural integrity can be provided by a solidified matrix or a container. In the event that a container is relied upon for structural strength, a supplemental container, generally a concrete shell is

sometimes placed around the primary container. This concrete shell serves both to support the load of backfill material placed over the container and also to provide supplemental radiation shielding. At a storage or disposal facility, supplemental shielding can be provided by other waste packages or in special shielded structures; for example, in Canada 3m<sup>3</sup> cylindrical steel containers of spent ion exchange media are stacked for storage in steel and concrete in-ground structures. Most of the shielding is provided by the ground surrounding the structure and by a thick concrete shield plug that is placed on top.

## 5. CONCLUSIONS

A major factor in process selection is the resource required and these include availability of matrix material, financing operating infrastructure, and the skill of the workforce. For example, with regard to personnel, it is considered that supervisors have appropriate training and experience in radioactive waste management practices to ensure that process operations meet the appropriate safety, regulatory, and quality assurance standards.

In this report we solidify the resin by two ways one was the cement paste solidification and the other was by mortar. By solidify the resin with cement paste, we can immobilizes larger volume of waste but it can only accommodate unto 10% of resin of cement volume and during experimental analysis the 15% resin of cement volume is not to be solidify and it disable the cement to made the bond as the hydration reaction of the cement is not completed. But one advantage of this process is that the resulting waste volume is less than that of the resulting volume formed by mortar solidification.

On the other hand the waste formed by mortar has good mechanical properties e.g. compressive strength, and is more stable. In mortar 15% resin of cement volume can be solidify. The one and the only disadvantage of mortar solidification is that the waste generated is larger than the original volume of the waste.

In this project I done my work on ordinary Portland cement and sand as additive, by using different type of cements i.e. Blast-furnace cement, Pozzolanic cement, and High alumina cement must be tasted. Also tested by using some additives i.e. Pulverized fuel ash, Reactive silica- silica fume, lime, cement modifiers.

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