A Primer on Powdered Ion Exchange Resins in Condensate Polishing Application

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Presented at The 23rd Annual Electric Utility Chemistry Workshop at University of Illinois, 2003
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Abstract:
This technical discussion covers the application of powdered resin technology under condensate polishing conditions with some comparison to Deep Bed systems. Emphasis is placed on the factors that effect proper powdered resin polisher operation and maintenance and how they directly impact final water quality.

A. Powdered Resin Process – General Discussion

Powdered ion exchange resins are resins, which have been ground to a particle size of approximately 30 - 150 microns. In ConPol applications, they usually consist of a strong acid cation resin, which may be in either the hydrogen or the ammonia form, and strong base anion resin, which is in the hydroxide form. Either of these resins are available as individual components, which must be combined by the user, premixed powdered resins in various cation to anion ratios, or resin fiber mixes, which contain either cellulose or man-made fiber in addition to powdered the ion exchange resin.

The cation resin possesses a negative charge and exchanges positive ions such as Na+ and Ca+², while the anion resin possesses a positive charge and exchanges negative ions such as Cl- and SO₄⁻². When they are mixed together in water, they form a floc, which is an agglomeration of particles held together by electrostatic forces. This results in flocculated particles, which provide depth filtration and rapid ion exchange capacity compared to bead form ion exchange resin. See Figure 1

The powdered resin is precoated on filter septa, which are ~50" to 80" in length and ~ 1 to ~2+ inches in diameter. Typically, one to seven hundred septa are contained in a single ion exchange vessel. Various types of septum designs will be discussed later. Precoat loadings range from 0.18 to 0.3 dry lbs/ft². During the precoat operation, the resin builds up on the surface of the septa to a thickness of about 0.25 inch. Once the precoat has been applied water flows through the septa. Powdered resin systems have sufficient surface area to allow a peak hydraulic flow rate (flux) of 4.0 gpm/ft² of surface area. For ConPol applications, it is recommended to maintain a flow rate of >1.5 to < 3.0 gpm/ft² with a peak flow of 4.0gpm/ft² for short durations if absolutely necessary.
During system operations two processes occur simultaneously. First is electrostatic/mechanical depth filtration, which removes small particles such as metal oxides and colloidal particles such as silica. Second is ion exchange, which removes ions such as sodium, calcium, magnesium, chloride and sulfate. These ions are replaced with both hydrogen or ammonium ions and hydroxide ions. These combine to form pure water (in the case of hydrogen ions) or dilute ammonium hydroxide (in the case of ammonium ions). The ammonium hydroxide helps to maintain a basic system pH. It should be noted that as the pressure drop builds you eventually move from depth filtration to surface filtration, which results in the delta P moving from a linear function to a Log function. See figure (1)

**Figure 1.0**
**Delta P vs. Run length Curve**

Depth Filtration – Linear Function: Surface Filtration – Log Function

**B. Powdered Resin vs. Deep Bed Comparison**

Powdered resin has performed well in condensate, for both filtration and ion exchange. Historically, a powdered resin system has been rated at an operating ion exchange capacity of ~2 meq/gm dry precoat. Typically, an equivalent precoat mix of resin would be 44% cation resin in the (H+) form and 56% anion resin in the (OH-) form. Deep bed condensate polishers reportedly vary between 30 - 60% utilization of the resin: the highest utilization being obtained where the resin is not regenerated but replaced by new resin after exhaustion.

The filtration capacity of powdered resin is estimated at 0.07 lbs crud per lb. of dry resin, however; this will vary with the nature of the crud as to what extent it is crystalline or amorphous. Powdered resin systems are very effective for removing colloidal solids down to a size of about 0.05 microns. They have approximately an 85 - 90 % removal rate for colloidal silica and a 90 - 95% removal rate for colloidal iron. They have a crud holding capacity in excess of 20% by dry weight. The powdered resin process will remove 80 to 99% of insoluble copper and iron. By contrast, Deep bed condensate polishers will remove approximately 50 to 80% for insoluble iron oxides and have very little removal capacity for colloidal solids.
Deep bed ion exchange resin polishers have a lot of reserve exchange capacity because of the very large volume of resin they contain. Therefore, if the condenser is being cooled with seawater or brackish water, and the probability of condenser leakage is high; a deep bed polisher would be best suited.

However, if lower TDS cooling water is being used, powdered resin has a number of advantages to offer such as:

1. Powdered Resin reacts ~100 times faster than standard whole bead ion exchange resins.
2. Superior removal of insoluble iron and copper oxides
3. An adequate deionization capability for condensate polishing applications.
4. A very short turn-around period the time required to remove an exhausted precoat, lay down a new precoat and return the vessel to service usually takes about two hours. This fast turn-around time is very helpful in handling condenser leaks and other abnormal plant conditions.
5. Flexibility - Cation to anion ratios can be changed from one cycle to another to meet changing conditions. A regenerable deep bed polisher is designed for a specific cation to anion ratio.
6. Resin fouling problems, which would affect resin kinetics, are avoided in powdered resin systems, since the precoat can be discarded after each service cycle and replaced with new resin.
7. Powdered resin polishers do not require regeneration, eliminating spent regenerate solution treatment before disposal. Deep bed resin on the other hand, need to be periodically disposed of without regeneration, very costly, or regenerated with sulfuric or hydrochloric and sodium hydroxide. These chemicals need to be stored, pump, neutralized and disposed of on a regular basis.
8. Should oil leak into condensate being polished in a deep bed system, it would be necessary to either clean the resin with a surfactant or rebed with new resin. Rebedding would be costly since typically a large volume of resin is required. Powdered resin systems can be precoated with a precoat rich in cellulose or other fibrous material and remove oil or other deleterious substance quickly and at a much lower cost.
9. Deep bed condensate polishers are nominally limited to a temperature of 120°F because at greater than 120°F the anion resins begin to degrade. Any degradation will be cumulative over time resulting in less and less overall capacity and shorter run lengths. When powdered resins runs are ended, the resin is discarded and replaced with fresh resins. This allows powdered resin units installed as condensate polishers or in other power plant applications to be operated at temperatures well in excess of 120°F. A study by Simon and presented in a paper by McGarvey reported that Type 1 Strong base resin at 140°F lost 1.3% of its strong base capacity per month and the degradation rate doubled for each 18°F rise in temperature. This means that at 194°F the
half-life is 43 days, which agreed exactly with the previous findings of Dr. Elizabeth Baumann. Since powdered resin is replaced with new resin approximately every 30 days, temperature effects are minimized. Phil D’Angelo and Stu Brown vetted this temperature issue in an IWC paper presentation in October 2002 at the International Water Conference and verified all the above data and information. Copy available upon request.

In summary, each system has advantages and disadvantages, which should be carefully weighed before choosing a condensate polishing system.

C. Powdered Resin Polisher Vessels

The two basic designs for powdered resin polishers are the bottom tube sheet and the top tube sheet design. In the bottom tube sheet design, the resin is introduced from the bottom of the vessel and begins to build up on the lower portion of the filter septa. As the differential pressure increases, the resin is pushed further up the septa until the entire septum is covered. In this design the precoat flow rate must be great enough so that the resin particles have sufficient energy to reach the top of the septa, but not so high as to create turbulence which could wash away the resin near the bottom of the septa. See figure (2).

In the top tube sheet design the resin is introduced in the top of the vessel, so it does not have to overcome gravity while precoating the septa. This system tends to give a more even precoat than the bottom tube sheet design. In either case, the proper rate of precoating and concentration of resin in the vessel must be maintained to ensure an even precoat. See figure (3)

Figure 2.0
Bottom Tube Sheet Design
D. Powdered Resin Precoat Septa

There are a large variety of filter septa available. They may be made of polypropylene, nylon, stainless steel or other materials. They are typically tube shaped, but some are disk shaped. They may be spiral wound, pleated or melt blown. Each type has its own particular set of advantages and disadvantages. They all come in a variety of micron ratings, which affect filtration ability and pressure drop characteristics. The specific application and the type of resin that may be used will influence the choice of filter septa. The following outlines properties to look for in powdered resin septa:

1. Septa must be uniformly linear from piece to piece, in order to facilitate uniform precoats.

2. Precoat uniformity is also a function of system operating parameters and housing hardware/design. Axial distribution, i.e., flow through the septum, is a function of flow patterns within the vessel, and of the size of the precoat resin floc within the vessel. Apart from the axial uniformity, the higher the radial resistance to flow of a septum the easier it is to achieve precoat uniformity.

3. Septa must prevent precoat materials from migrating downstream.

4. Septa must provide a surface, which does not contribute to loss of precoat integrity, such as pressure drop-induced cake cracking or loss of precoat during low flow conditions.

5. Septa must provide low resistance to flow when precoated.
6. Septa must release solids to a high degree when backwashed. Therefore, accumulated entrained solids should not interfere with uniform distribution of precoat and service flow nor significantly increase delta p rise rate during normal service runs.

7. Septa must be compatible and evaluated with the particular hardware system, in which they will be used. This especially true for the backwash techniques employed. The structure of the septa and the pressure and flow rate of the backwash determine the degree of cleaning. The quantity and type of solids entrained in each service cycle will also affect attainable cleaning, as does the service velocity (gpm/ft²).

8. Septa must incorporates sufficient dirt holding capacity such that it does not develop self limiting pressure drop based upon the quantity of solids which may traverse a properly applied precoat.

9. Septa should not retain any air within their inner effluent core after vessel fills or suffer precoat erosion at any point along its length. The Septa must be compatible with vessel hydraulics.

E. Powdered Resin Operational Steps

Precoating Process:
To apply powdered resin to the powdered resin septa the powdered resin vessels are by-passed and an external precoat system is valved in-line with the powdered resin vessels.

Backwashing:
The first step of the precoating process is to backwash the septa to remove the spent ion exchange resin. This is accomplished by a pressurized air bump or air scrub where the entire content of the filter is evacuated to the drain sump in approximately fifteen (15) to twenty (20) seconds. In the Top Tube Sheet system, the bump is followed by an air scour with condensate and a second bump. At this time, the filter is ready to precoat and then put into service.

Precoating:
Next, the precoat tank is filled with the appropriate quantity of resin based on the dry weight of the resin and the square feet of septa surface area. A fixed amount of cation and anion resin is mixed with water to form slurry, which requires approximately fifteen (15) minutes of mixing time.

Next, depositing a layer of powdered resins on the tubes precoats the Septa. A fixed amount of resins at a specific rate is fed into the recirculating flow through the filter to form a precoat on the filter tubes. This recirculation flow is established with the precoat pump. The resin particles bridge the openings in the filter septa and form a fine sieve, much finer than the filter tube screen itself could provide. The powdered resin is now the filter media, and the septa only serve as a support mechanism. Recirculation of the resin continues for
45 to 60 minutes (400 to 600 mg/l resin concentration) until the Septa are completely coated. *This is critical to obtain an even precoat.*

Figure (4) shows the typical Open Loop Precoat System used with bottom tube sheet vessel systems. Figure (5) shows the standard Closed Loop two-tank Precoat System used with top tube sheet vessel systems. Figure (6) a modified top tube sheet precoat system was introduced which uses one tank and is performing well in several plant applications. Figure (7) shows a Dilute Precoat System that can be used to improve upon the Open Loop Precoat systems used for Bottom tube sheet vessels.

Service Cycle:
After it is determined the precoat cycle is complete the filter demineralizer is put into service. During this filter/demineralizer cycle, the resins effectively remove substantial amounts of colloidal size materials, such as, iron, copper, and non-reactive silica.

In addition, ion exchange takes place whereby undesirable ions from the feed water are removed and replaced by ions from the resin, which combine to form water. The service cycle continues until water quality deteriorates or until a predetermined differential pressure is reached across the filter demineralizer or a predetermined quantity of feed water has passed through the filter. When any one of these three conditions occurs, the filter/demineralizer should be backwashed and the cycle starts again.

**Figure 4.0**
**Open Loop Precoat System for Top Tube Sheet Vessels**
Figure 5.0
Closed Loop Precoat System

Figure 6.0
Closed Loop Precoat with one Tank (Brown Method)

Top Tube Sheet (Brown Method)
F. Operational Considerations When Selecting a Powdered Resin Precoat

Some questions to consider before operating a powdered resin system:

- What do you want to remove and what quality of condensate does your system require?
- What is the best resin for your system? Do you want hydrogen form or ammonia form resin?
- Do you want to use individual component resins, a premixed resin without fiber, or a resin/fiber mix? If using premix or resin/fiber mix what ratio of cation to anion or resin to fiber is best? If you want a resin/fiber mix, several types of fiber with different properties are available.

For first time users these questions can best be answered by consulting with the experienced plant personnel, powdered resin supplier, septa suppliers and utility chemistry consultants. The plant and the supplier and consultants all have a role to play in providing optimal performance of the powdered resin ConPol system. The following are some things to consider:

- If your plant is operating at a near neutral pH (6.0 - 8.0) you will most likely want to consider using hydrogen form cation resin. If your plant is operating at a basic pH (8.0 - 10.0) you should be using an ammonium form cation resin. In both cases, a hydroxide form anion resin is used. Have discussions with you resin supplier. Your options are many.
Individual components vs. Premix materials? Individual components provide the greatest flexibility to deal with changing plant conditions, but they are the most difficult to precoat properly. A premix is easy to use, but you can’t change the cation to anion ratio. If you are interested in the highest ion exchange capacity, you probably want a mix with little or no fiber. If you want more crud removal capability at the expense of some ion exchange capacity, you might want a higher fiber material. Cellulose fiber is the most commonly used and is beneficial in obtaining a uniform precoat and absorbing organic material, but it is compressible to a degree and may add Δp and shorten the run to a Δp end point.

In nuclear plant operation, cellulose fiber mixes may contribute to gas formation in waste containers and make disposal difficult. Synthetic fibers such as polyacrylnitrile do not exhibit this problem and provide improved filtration characteristics but are more expensive than cellulose.

Cation exchange fibers are also available for applications where the removal of metallic impurities is highest priority.

How do you mix the powdered resin? If you are using a premixed resin or a resin/ fiber mix you can add the appropriate lbs of resin/ft² to your precoat tank, let it mix a short while (about 10 minutes) and then begin the precoat cycle. For normal operations, you should be using 0.18 to 0.30 dry pounds of resin per square foot of surface area. For example, if you have 600 square feet of surface area you would use approximately 120 pounds of resin. The precoat time should be about 40 - 50 minutes. This ensures that the resin will enter the precoat vessel as dilute slurry, which will give an even precoat along the entire length of the septa. If the precoat time is too short, the resin will be too concentrated when it enters the vessel and may not precoat the septa evenly. If your system is not set up for 40-50 minute precoats then consider adding a Dilute Slurry Precoat System. Your resin or equipment suppliers have these available.

If you are using individual components, the procedure is a bit more complicated. First, you need to know the desired cation to anion ratio; for example, we will assume approximately 1:1. Next, you need to determine the proper number of units of cation and anion resin to add. Be careful because the dry weight of one unit of cation may not be equal to the dry weight of one unit of anion. If the cation is 20 dry pounds and the anion is 12 dry pounds, you would want to use 3 cation and 5 anion. This would result in a 1:1 cation to anion ratio with dry pounds of resin. When using individual resins you may need to add a Solution “A” conditioner (Sol-A) to the resin. Sol-A, also known as Acrysol is a high molecular weight polyacrylic acid. It is added to powdered resin slurries to adjust the floc size and/or reduce the turbidity of the slurry. Sol-A is available from the resin manufacturer and should be diluted 1/10 prior to use. The amount of Sol-A to use varies according to the composition of the precoat. As a general guideline, 5 - 10 ml of 1/10 Sol-A should be used per dry pound of anion resin. This assumes a 1:1 cation to anion ratio. For a higher cation to anion ration less is needed, for a lower cation to anion ratio more may
be required. At cation to anion ratios of 2:1 or greater, little or no Sol-A is
required. Typically, ammonia form cation requires slightly more Sol-A than
hydrogen form. Sol-A may be added to the precoat tank either prior to the
resin or after the resin has been added. Significantly more Sol-A may be
required if it is added prior to the resin. Sol-A has a shelf life of 6 months
and the expiration date is clearly marked on the bottle. Sol-A should be
discarded when its shelf life has expired, fresh Sol-A should always be
used. Sol-A is generally not used with premixed resins or resin fiber
mixes.

If using individual components the V/V and turbidity of the mixture should
be checked. To do this fills a 1000 ml graduated cylinder with a sample of
the slurry. Let this sit for 15 minutes. The settled resin volume (V/V)
should be between 400 and 700 ml and the turbidity of the supernate
should be less than 10 NTU's. The V/V value assumes approximately a
4% slurry, obviously, a higher concentration will result in a higher V/V and
a lower concentration will result in a lower V/V. The V/V also depends on
the cation to anion ratio, the form of cation used, the amount of Sol-A
added and the temperature of the water. A low V/V will result in a tighter
precoat and a higher-pressure drop, while a higher V/V may result in a
poor precoat and lower water quality.

• What type of filter septa are you using? Continuous wound string
wrapped, melt blown polypropylene, segment string wrapped, stainless
steel mesh, sintered stainless or pleated septa… Remember, precoats
containing fiber are not recommended for use with pleated septa. Clean
septa are essential for a good precoat. If the septa are fouled you will get
uneven precoats, which can lead to even more septa fouling. This results
in a downward spiral of worsening precoats and water chemistry. What
about the backwash volume and pressure; is it adequate for the septa you
are using? A backwash of sufficient pressure is needed to ensure
complete removal of spent resin and removal of particles, which may have
become imbedded in the septa. Sometimes multiple backwashes and/or
air scrubbing are required. If the septa are still dirty, chemical cleaning
may be required. Even with the best of care, septa will eventually wear out
or become irreversibly fouled and need to be replaced. Good record
keeping will help determine the need for septa replacement. On the
average, a set of septa should last 4 - 6 years in condensate polishing
applications.
G. Tips on Improving Powdered Resin Performance.

- Know your system. The most important parameters are square feet of surface area, pounds of resin used, vessel flow rate, backwash wash flow rate and precoat tank clear time.
- Don’t cut your precoat time short. This will result in uneven precoats and septum fouling. Precoat clear times should be 45 to 60 minutes.
- Never exceed 4.0 gpm/ft² flow rates. Maintained ~1.5 - 3.0 gpm/ft²
- Maintain total precoat material loading at 0.18 to 0.30 Lbs/ft²
- Avoid using straight Sulka-floc as a precoat material. Sulka-floc comes in many grades and is rarely if ever analyzed for quality by the end user. Cellulose fiber used in powdered resin precoats is purchased to a tight QC specification, washed and sized for proper floc formation when mixed with powdered resin.
- Don’t use resin materials with expired shelf life. If resin is expired send a representative sample to the Powdered Resin Manufacturer for retesting and re-certification before use.
- Store Resin at >40°F and <100°F in their original sealed containers.
- Don’t continue to operate with badly fouled septa. This drives up the cost per gallon for treatment.
- Don’t assume that every precoating problem is a resin problem. Investigate other possible causes such as system component such as timers, vents, valves and pumps. In 35 years of working with on powdered resin systems I have found that 99.9% of the time problems are the result of either operational practices or mechanical failures.
- Ask for help early. More experienced plant personnel; Power Chemistry consultants, resin manufacturers, septa manufacturers and system designers may have the answers you need to solve your problem.
- Finally, “Always remember that the Septa never forget”. Once you start to foul septa with rapid precoats, poorly mixed precoats, too little or too much resin, too high system flow rates or precoats with the improper V/Vo you are on a slippery slope and septa recovery will never be 100%.

For Independent Power Chemistry Consulting or Training Support contact:
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H. Economic Comparison: Deep Beds Vs PDR Systems ConPol

- Plant Cap: Supercritical 600 MW Coal Fired Plant
- Condensate pH: 8.5 – 8.7
- MB Resin ration 1.5/1 C:A
- ConPol Pressure 550 to 600 psi
- \( \Delta p \) DB – \( \sim 50 \) psig (3.3 bar) or \( \Delta p \) PDR- \( \sim 30 \) psig (2 bar)

System Design Cost estimates 2005

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Note: Values from JoDAN file information compiled from various industry presentations.

All values are approximations and presented for general comparison purposes only.