Condensate Polishing For Nuclear And Super Critical Power Plants For The 21ST Century

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ABSTRACT: This paper provides a brief history and timeline of condensate polishing from the 1950's to the present. It then discusses the equipment, designs, process strategies, and operating techniques that are being employed and developed to address the increasingly stringent requirements of plants in the 21st century.

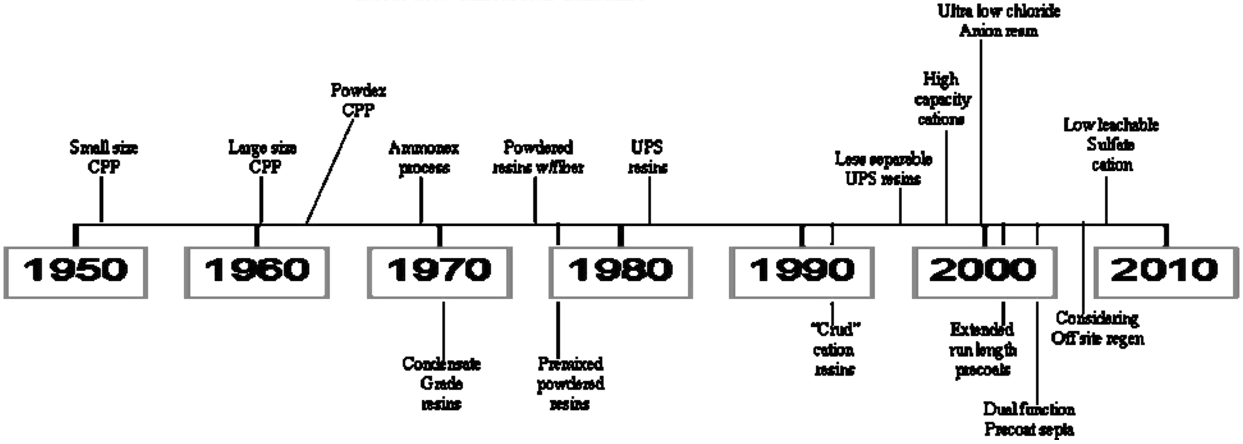
INTRODUCTION AND HISTORICAL PERSPECTIVE

Condensate polishing (CP) has a long history in critical, high-pressure power generation applications beginning with mixed- bed ion exchange demineralizer in the 1950's and followed by the introduction of powdered ion exchange precoat filter demineralizers in the 1960's. The following decades saw various operability improvements driven largely by unforeseen operating challenges and improved, more sensitive high purity water analysis capabilities. In addition, higher-pressure system designs are requiring more stringent CP water quality that is resulting in innovative technologies in order to meet those requirements. This, in turn, has also resulted in new and more stringent EPRI and INPO guidelines. Suppliers to the power generation CP market have responded with advances in ion exchange resins, equipment design, and monitoring systems.

In the framework of a renewed and global power generation growth cycle, our paper will present, briefly, the historical advances in CP systems, but more importantly advanced equipment design and operating practices that are currently available to the market. These CP system choices allow a technology to match a user's specific needs. These technologies include ion exchange technologies to maximize CP performance and minimize operating costs, combined technology systems utilizing CP filter polishing and deep bed ion exchange, advanced precoat systems, and more recently developed hollow fiber filtration. Specific CP technologies can be chosen based on a plant's individual requirements and often go hand in hand with recently developed operating strategies such as oxygenated treatment (OT) and reduced chemical costs (particularly ETA and regenerant chemicals).

Table 1.0 provides a timeline showing some of the major developments in CP technology since 1950.

Table 1.0: Historical Timeline



DEEP BED ION EXCHANGE CONDENSATE POLISHERS

Deep bed polishers typically employ a 3 to 4 foot bed of mixed ion exchange resins. The ion exchange beds can be designed with various ratios of cation exchange resin and anion exchange resin, the most typical being 2:1 or 1:1 cation to anion by volume. The systems are sized hydraulically with the accepted industry standard rating of 50-gpm/sq. ft and can have design pressures in excess of 600 psig. Figure 1.0 depicts a typical high-pressure spherical service vessel. These vessels are designed to withstand full system differential, and because of the high operational flow rates have elaborate distribution and collection systems to assure uniform flow distribution and to prevent resin mounding or bed gouging. Historically these polishers have been regenerated on-site using regeneration equipment external to the service vessels. Figure 2.0 is a simplified version of a two- (2) vessel regeneration system. The system employs a state-of-the-art bottom resin transfer system that provides an extremely high degree of resin separation and is capable of operating with variable cation to anion resin ratios with minimal mechanical modifications.

Fossil and Nuclear PWR

Standard Gaussian distributed cation and anion exchange resins were used in condensate polishing deep beds for many years. Condensate grades were introduced in the early 1970's with reduced fine particle content. These cation and anion exchange resins were somewhat easier to separate, resulting in less cross contamination. Cation fines that remain with the anion during separation are converted to the sodium form during sodium hydroxide regeneration and can lead to poor performance. Inert resins, with clearly differentiable color and a density between the cation and anion components, were sometimes added to the mixed beds to act as a buffer layer and facilitate even better separation, further reducing cross contamination. However the inert resins did not always perform consistently and in some cases became fouled, negating any further benefits. Uniform particle size resins were introduced in the 1980's as the best separating condensate polishing resins. The particle size and density differences enhance separation and subsequent regeneration quality. The uniform size allows for good flow characteristics and the lack of fine particles can mean lower differential pressure. These resins have a much narrower particle size distribution than prior grades used for condensate polishing and have become the virtual standard for condensate polishing systems.

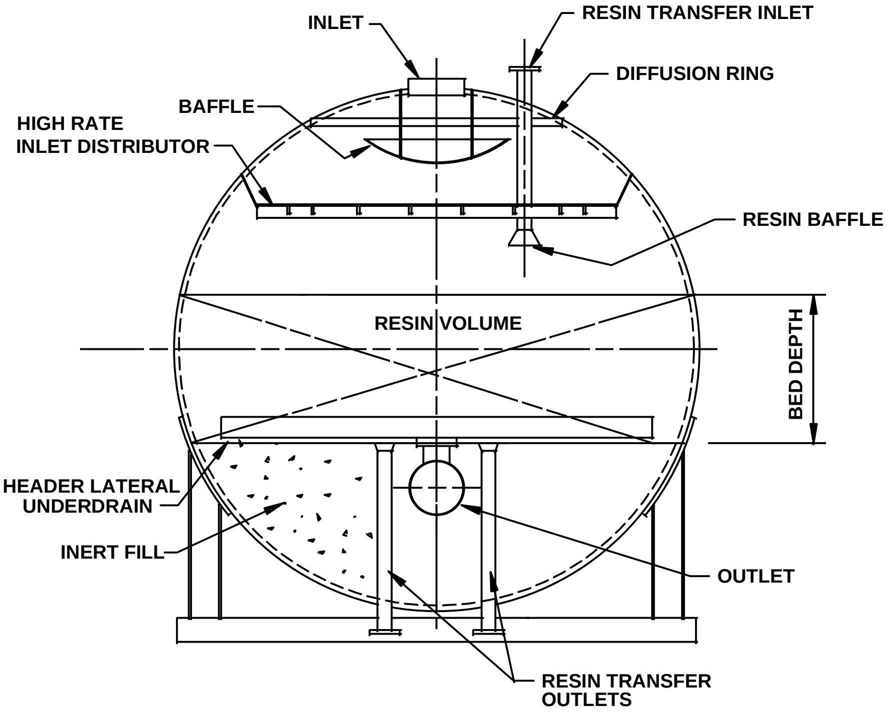
Nuclear BWR

Although early BWR deep bed plants included regeneration systems, none are operable today and only a few were ever operated. Some plants used ultrasonic resin cleaners to remove the particulate iron oxides and then return the resins to the polisher vessels. It was preferred to use mixed bed condensate polishing resins that were not easily separable. Gaussian distributed resins worked well for years. To improve the iron filtration, a new dual-morphology cation was introduced in the 1990's. This "CRUD removal" resin was installed in the condensate polishing systems at a majority of the US BWR plants. Iron removal results were excellent in all cases but elevated sulfate levels were observed in most of the systems after about nine to twelve months of operation. New opportunities were presented as iron removal remained a priority. Uniform size resin was the next step although there was some reluctance to accept the resins because of their ease of separation. In the BWR non-regenerable systems, it is desirable to keep the mixed beds intact. Smaller uniform particle size cations were developed to make mixed beds with less separable tendencies.

The process selection conditions that favor deep beds include:

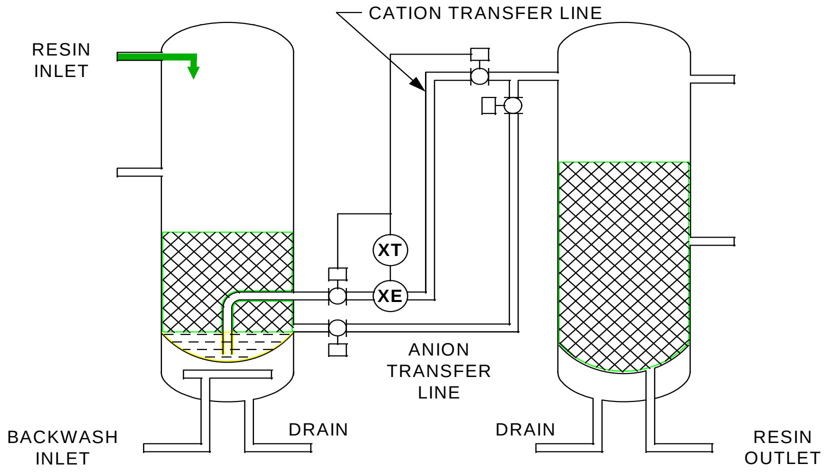
- High TDS cooling water such as sea water or high TDS cooling towers
- The requirement to operate long term with small condenser leaks
- The inability to control excessive air in-leakage

Figure 1.0



TYPICAL SERVICE VESSEL
WITH HIGH PRESSURE UNDERDRAIN

Figure 2.0:
SepraEight™ Two Vessel Bottom Transfer Regeneration System



Separation/Anion Regen. **Cation Regen/Mix & Hold**

21st CENTURY DEEP BED IMPROVEMENTS

- High capacity strong acid cation (SAC) exchange resins with higher than typical crosslinking have been evaluated in both BWR and PWR nuclear plants. These higher capacity resins can provide longer run lengths to the amine break in PWR and fossil condensate service. However, results were economically neutral when considering run length vs. resin costs. Other PWR plants evaluated the cations to reduce the phenomenon characterized as anion kinetic impairment. One thought is that the solvent properties of ethanolamine (ETA) accelerate cation leachables, which in turn begin to foul the anion resin, causing the poor kinetic performance. Many have returned to the traditional UPS cations for condensate polishing.

  The high crosslinked cations are also being used in BWR condensates in attempts to reduce the system sulfates. Small pieces of polystyrene sulfonate oligomers diffuse out of cation exchange resins over time, and form sulfates in the reactor. The higher crosslinked cations are better able to tie up these oligomers. However, all cation resins undergo some amount of polymer degradation or desulfonation over time. The high capacity cations have a greater number of sulfonated sites providing more potential for eventual degradation. Improved sulfate levels have been experienced when the cation resins are processed by the supplier prior to shipment.

  More recent specifications for TOC and sulfate extractables have been driven to some degree by improved analytical capabilities and the ability to correlate these to operating issues. Specifications may apply to both cation and anion exchange resins. As-manufactured base resins are not made specifically to meet these requirements, nor are those properties routinely evaluated. Some specifications approach the extent of electronics grade resins regarding leachable TOC and other contaminant levels. To achieve these new more stringent quality requirements often requires post manufacturing processing.

Some ion exchange resin suppliers are well qualified to perform the significant level of processing required. Multiple steps can include special cleaning techniques and UPW rinsing. Coordination of processing, shipping, and use between the customer and supplier can be key to achieving the best performance.

- A major advantage of deep bed condensate polishers is the high ion exchange capacity. However, they do have limited CRUD filtration capabilities. This is driving advances in pre filtration to the ion exchange deep beds. When combining technologies, CRUD removal is done prior to the deep beds using high flux rate filtration. This process step can consist of backwashable pleated elements, high flow rate disposable pleated elements, or powdered resin precoated elements. These technologies can be used either during the entire cycle, at start-up, or as needed at other times such as condenser leaks with high suspended solids.

  These deep bed pre-filters were also considered for plants with and without precoat filter demineralizers already installed. Various types of pleated filters have been designed and installed as new equipment, or in some cases in the existing filter demineralizer vessels. The pleated filter elements contain significant surface areas of small micron size media. Ten, five, and one micron sizes are the most frequently used. Some are specially designed as precoat septa to gain the additional advantages of powdered resin use. A more recent design employs a comparatively large diameter disposable, non-precoat, pleated filter used in a horizontal orientation.

- Highly regenerated ion exchange resins reduce ionic leakage to lower levels, extend the operating cycle, reduce regeneration periods, and extend operating life. This includes the complementary use of amine form cation resin with an ultra-low-chloride anion to achieve operational improvements. Several benefits have been realized and savings more than cover the cost of the specialty, value-added premium anion exchange resin. One goal was to reduce iron transport to a PWR’s steam generators by increasing the amine content, which raises pH and drives chloride off even a typical nuclear grade low chloride anion. A newly developed specialty regeneration process has been used to prepare the highly converted, ultra low chloride anion resin. This resin maintained low steam generator chlorides as the increased amine content reduced iron transport. The amine form cation and ultra-low-chloride anion resins have been operating for more than four years without regeneration and are expected to exceed five years. Economic benefits are realized due to a significant reduction in use of ETA and regenerant chemical savings for four years worth of regenerations. This special anion may also be used in BWR, neutral pH condensate and along with a complementary highly regenerated, very-low-sulfate specialty cation, now under development, may provide superior performance in this non-regenerable application.

- Off site regeneration can eliminate on site handling of regenerant chemicals. More recently the use of off-site regeneration service providers has become an option for plants operating deep bed condensate systems. At present, experience has been limited, and costs can be even higher than regenerating on-site when all costs are calculated. In addition to regenerant chemicals, these costs can include transportation, facility leasing or overhead, licensing site for nuclear plant resins, insurance, and others. Costs are likely to be relatively high because the volume of resin to be regenerated annually may not be sufficient to develop a regeneration facility unless multiple plants are serviced from the same facility. However, the higher cost must be weighed against potential benefits derived by plant operation improvement, time saved, and the elimination of on-site chemical handling and storage. Perhaps plants interested in discontinuing their on site regenerations should consider the non-regenerable specialty resin option to determine whether it could be their best option.

PRECOAT FILTER DEMINERALIZERS

Precoat filter demineralizers combine superior filtration, compared to deep bed polishers, with kinetically superior ion exchange by using finely ground, highly regenerated resins precoated onto septa in pressure vessels that are specially designed to provide uniform precoat application and process flow distribution. Systems of this type have been in use since the early 1960's in a variety of applications including condensate polishing in BWR, PWR, Fossil, and industrial plants; reactor water cleanup, fuel pool treatment, and radwaste processing. The first generation of precoat systems included the use of individual ionic form powdered ion exchange resins. Technology improvements have included premixed resins in various ratios of cation to anion (in several ionic forms for the cation), and sometimes combined with fibers that enhanced physical filtration and produce extended run lengths.

Precoat filter demineralizer technology has also advanced with a number of equipment and operating strategies that have improved these systems. These include advanced precoat techniques, high energy air surge backwashing in order to effectively clean septa of spent precoats and crud, internal distribution tube additions to ensure more uniform flow patterns and even distribution of precoat material along the entire surface of each septum, as well as state of the art process controls to optimize system performance. In many cases older systems have been improved by incorporating these upgrades along with evolved septa and hardware improvements that enhance filtration performance and system maintenance.

Figure 3.0 is a schematic diagram of a precoat system with an enhanced flow distribution tube, air surge type backwash, and advanced precoat system. During the service mode condensate enters the service vessel at the center of the bottom head and is directed to the chamber above the tube sheet. At this point, some of the condensate enters the filter chamber below the distribution tube while the balance enters above the distribution tube. This split assures that the condensate is distributed equally to the top and bottom of the filter elements and avoids localized high velocities that could disrupt proper distribution of the precoat material. Treated condensate passes through the filter septa and proceeds through the tube sheet to the vessel outlet.

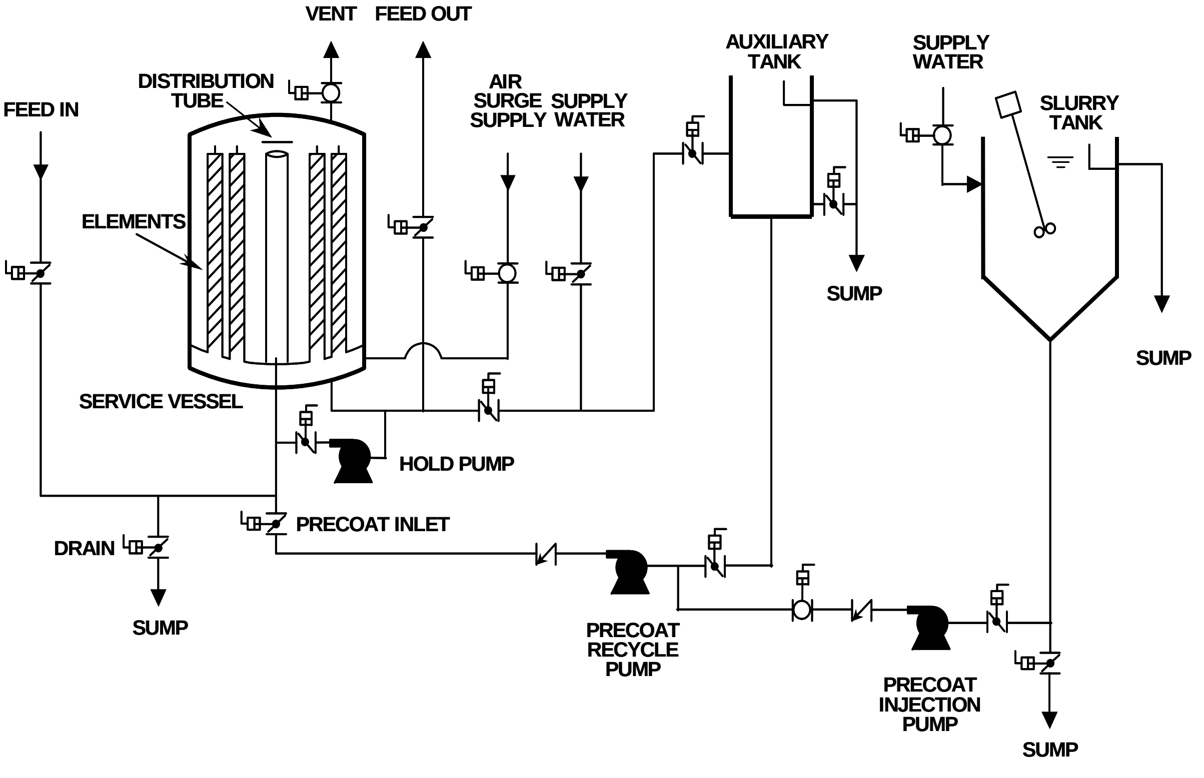
A major advantage of precoat filter demineralizers is their highly effective filtration capability. Over the years there has been considerable advancement in septa technology including improved yarn types in wound septa, absolute rated multi-media pleated filters and a combined technology of pleated filters with a precoatable surface. Other specialty filtration media exist including stainless steel wedge wire elements, carbon fiber wound septa for high temperature applications, and spun bond filters that appeal to the cost conscious user but have shown limited life when compared to other types.

Precoat filter demineralizers use a relatively small amount of ion exchange resin in the precoat, and therefore have less total ion exchange capacity than deep beds. However many of the disadvantages of bead resins, including regenerations, are avoided. In process conditions that favor precoat demineralizers they have proven to be highly flexible and effective condensate polishing systems.

The process selection conditions that favor precoat filter demineralizers include:

- Low TDS cooling water
- High temperature condensate as typically seen in air cooled condenser plants
- Titanium condensers, with welded tube sheets.
- Limited operator availability and training (regeneration of deep beds is a complex regeneration sequence and involves the use of strong acid and base)
- Desire to avoid handling and neutralizing large quantities of acid and base
- Need for frequent start ups and restarts (precoat filters provide superior crud removal and offer the most cost efficient means for controlling corrosion transport)
- Need for rapid start up
- Need to minimize pressure drop requirements for condensate polishing
- Operating policy of orderly shut down and repair in the event of a condenser leak
- Need to minimize costs including equipment, installation, and operating costs.
- Limited space availability. The footprint of a precoat dimineralizer can be as much as 50% of a deep bed installation.

Figure 3.0: Precoat Filter Demineralizer System with Advanced Precoat Feature



21st Century Precoat Filter Demineralizer Improvements

- Increased operating run lengths from one or more new equipment design upgrades: advanced precoat systems, distribution tubes, and state-of-the-art programmable logic control systems
- Precoat formulations designed to extend run lengths improving direct operating costs and reducing associated costs including the disposal of radwastes. Longer runlengths reduce the total quantity of powdered precoat usage benefitting any precoat filter demineralizer operation by reducing operating costs. For BWR plants, the volume of radwaste is reduced. This is significant because in most cases the radwaste treatment cost can exceed the purchase price.
- Fine filtration precoats for BWR particulates. Specialty precoat products are designed with improved filtration characteristics in order to remove very fine iron and copper particulates in order to meet reactor contaminant concentration guidelines.
- Layered precoat systems to target specific treatment goals such as soluble copper. One example is a specialty precoat product containing powdered weakly acidic cation that is precoated over a fiber containing mixed bed precoat to selectively remove copper in fossil condensate during startups.
- Development of extremely highly regenerated powdered ion exchange resins that combine the kinetic superiority of powdered resins with ultra low ionic contamination values that achieve low ppt levels of ionic leachables. Powdered resin analogs of ultra-low-chloride anion and the complementary very low leachable sulfate cation bead resins described earlier. High purity resins for powdered products are perhaps even more critical than for bead resins because the internal structure is exposed during the grinding process. Any contaminants that would diffuse out of the bead over time are immediately released from a powder.
- Advanced generation, dual functioning precoatable septa that combine absolute filter ratings with excellent precoatable characteristics and backwash efficiency that extend septa life.

HOLLOW FIBER FILTRATION SYSTEMS

Hollow fine fiber membrane filtration (HFF) is a filtration only technology. The use of this technology in condensate filtration was developed in Japan and it is used extensively in the Japanese nuclear industry. It also has limited application in Japanese fossil units. The first system of this type in North America was installed and has been operating for just about one year.

The filtering fibers are made of polysulfone with 1.0 mm cross-section and a 0.1 μm pore size (Figure 4.0). The fibers are potted in modules (Figures 5.0 and 6.0). The modules are then installed in tube sheets (Figure 7.0) within pressure vessels. Figure 8.0 shows an installation in Japan.

The condensate feed is introduced to the outside of the fiber, flowing through the membrane into the hollow center. Filtered condensate then flows to collection through the fiber lumen. This product is very effective for the removal of corrosion products down to <1 microgram/liter for particles greater than 0.1 micron.

The cost for an HFF system is significantly more than that of a pleated membrane filtration system. However, the membrane life has been shown to be significantly longer and can greatly reduce element replacement and disposal costs over the life of the system. Elements have been in service in Japan in excess of 10 years without needing replacement.

SUMMARY

For more than 50 years, condensate polishing systems have been used to treat the water in the power generation cycle. While the principle has remained the same, requirements have become more stringent and the condensate polishing systems and products have evolved through the joint efforts of the power industry and the dedicated suppliers who serve the needs of that industry. Countless advancements in equipment design, product development, and operational techniques have been introduced throughout these 50+ years of condensate polishing, many more than could be described in this paper.

Today more than ever, continued advancements and new technologies in condensate polishing are critical to improving plant operations in order to help produce a viable supply of power to meet the expanding needs of this country and the world. We cannot rest after 50 years of improvement, but must guide the way for the next 50 years of technology development.

At the beginning of the 21st century we are already viewing some results of continuing development through:

- Application of extensive resin cleaning to achieve the lowest possible TOC leachables.
- Coordination of the processing, shipping, loading, and use of condensate polishing resins.
- Ability to run condensate polishers without regenerations by using ultra-low-chloride anion in conjunction with operational changes, achieving both regenerant and cycle chemical savings.
- Considering an off-site regeneration option when it makes sense.
- Installation of dual function prefilters that operate effectively with precoats when necessary, and without when desired.
- Installation of new systems containing high flow rate, disposable prefilters.
- Use of custom powdered products and precoat combinations to achieve specific targeted results.
- Evaluation of low leachable sulfate products as they become available.
- Installation of parts with design improvements and control system upgrades to maximize performance of condensate polishing systems.

These are a few of the advancements already in progress, being considered, or under development for the continuous evolution of condensate polishing applications. What will the next steps be?

Figure 4.0:

Figure 5.0:

Figure 6.0:

Figure 7.0:

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Figure 8.0: