EXECUTIVE SUMMARY

Pentair Porous Media has worked with a major global oil & gas producer to optimize the performance of the filtration and separation at their United States mid-continent operations located in the Wind River Basin of Central Wyoming. Their operations cover more than 42,500 net acres in Wyoming. Net gas production averages greater than 100 MMSCFD from multiple formations ranging in depth from 5,000 feet to more than 25,000 feet. The gas production wells are scattered across a large area in the Wyoming highlands. The area is a remote, high plains desert experiencing temperatures up to 100 F (38 C) in the summer and as low as -30 F (-34 C) in the winter months. The produced gas is gathered from multiple wells and treated locally at a 300 MM scfd gas processing facility. The gas plant and general topography of the production site are illustrated in Figure 1.

Pentair Porous Media optimized the produced water filtration across the entire production site (~ 25,000 bbl/day produced water) to reduce filter change out frequency from up to twice a day to approximately once per month during normal operations, reducing direct filtration costs by 63%, resulting in savings of $88,320 per year. The optimization reduced operator hours dedicated to filter maintenance by 95%, saving an additional $179,520 per year in direct labor, allowing those assets to be redeployed more productively at the production site. Additionally, the solid filter waste generated was reduced by 93% eliminating over 80 cubic yards (61 m3) of waste and $4,800 in solid waste disposal costs. Total realized savings amounted to $272,604.

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ABOUT PENTAIR POROUS MEDIA

Pentair Porous Media designs and manufactures advanced technologies for the high performance separation of solids, liquids and gases. These technologies are used to help facilitate balanced systems that are highly stable, reliable and robust, thereby increasing throughput, reducing operating cost and minimizing waste. The company’s technologies help solve the most critical separation and extraction issues for the gas, refining, chemical and power generation industries.
PRODUCE OVERVIEW & OPERATIONAL CHALLENGES

Produced liquids are separated from the natural gas brought in from the various wells. The liquids are captured in a large skim tank and gravity separate into water and hydrocarbon condensate. The condensate is recovered and the water is pumped down a disposal well at ~1,600 psi. There are multiple produced water injection wells spread throughout the production field. Each well disposes of 2,000 bbl/day to 4,000 bbl/day of produced water. Each remote well site collects the produced water in a skim tank located at the produced water gathering and injection site. The produced water is pumped from the skim tanks through two bag filter vessels operating in parallel. Each of the vessels contains either 5 or 6 bag filters, depending on the system design. The filtered produced water is then sent to a high pressure piston style pump which generates a 1,600 psi (110 bar) discharge pressure prior to injection at the wellhead.

Due to the geology of the producing wells, the produced water contains considerable amounts of kaolinite as suspended solids (>20 mg/L). The produced water also contains considerable entrained hydrocarbon condensate. The hydrocarbon condensate interacted with the molded polypropylene sealing surface of the filter bags causing swelling and distortion of the filters in service. As a result, the bag filters experienced significant bypass of contaminants which accumulated as 4 – 6 cm of sediment in the lower section of the filter vessels (Figure 3).
PRODUCED WATER CASE STUDY

Figure 3. Prior to Pentair Porous Media upgrade: Originally installed bag filters (left) and accumulated solids on the “clean” downstream side of the filters (right) due to bypass

The elevated solids in the produced water downstream of the filters led to elevated erosional wear in the high pressure injection pumps, caused reliability issues with valves and entered the formation adding to the potential for plugging. Operationally, the produced water filters caused maintenance and labor challenges. Due to the limited capacity of the bag filters, the filters experienced short operating life. The operating life was further constrained by the differential pressure limitations presented by the bag filters. The maintenance personnel were restricted to changing the filters at a differential pressure limit of 5 psid. Above 5 psid, the bags became stuck in the vessel as the filters extruded into the support baskets, making removal by maintenance personnel very difficult and time consuming. Consequently, the filters for each disposal well were changed out every two days during normal operation and up to twice a day during frequent process excursions. This resulted in not only high costs and excessive maintenance, but also generated significant waste volumes associated with spent filters.

Figure 4. Spent filter waste from one 2,000 bbl/day disposal well after several days of operation
The disposal wells were located at remote sites requiring the use of pager notification of maintenance personnel when the pre-determined high level alarm was reached on the filter vessel pressure transmitters. This alerted the maintenance personnel of the need to change filters. The maintenance personnel would then drive to the well site to replace the filters. Due to the remote locations of the wells and the frequent filter changes, filter maintenance required the full time dedication of at least one operator every day. The filter challenges culminated eventually in an episode which led to an environmental release and temporary shut down of one injection well facility and the associated production wells. On this occasion, the maintenance burden overwhelmed the ability of the maintenance personnel to respond. Normally, in the event of the produced water filters exceeding their set high level alarm, the system would shut down the injection well and production would continue until the capacity of the skim tank was reached, at which point the fail-safe systems would shut down the producing wells until the filters could be changed, the injection well could be re-started and the tank level could be lowered; at which point production would resume. On this occasion, the high level fail-safe on the skim tank failed, resulting in overflow of the tank into the surrounding retaining dike area. By the time the maintenance personnel arrived the following morning, both the skim tank and the dike had overflowed, discharging raw produced water and condensate onto the surrounding ground. This prompted shut down of the disposal well and associated producing gas wells until the environmental remediation could be completed and regulatory authorities approved re-start of the facility.

PENTAIR POROUS MEDIA UPGRADE & OPTIMIZATION OF THE PRODUCED WATER FILTRATION

Pentair Porous Media was engaged to remedy the operational challenges and high costs associated with the produced water filtration at the production site. Initial site visits provided an opportunity for Pentair Porous Media’s field service personnel to perform a site survey and determine the water quality at the production site. During this visit, Pentair Porous Media also evaluated the existing filtration systems and performed an engineering review of the existing bag filter vessels. Based upon the site survey and engineering review, Pentair Porous Media recommended that the bag filter vessels be upgraded to utilize Porous Media’s proprietary VMAX coreless element design.

The VMAX element design makes use of a tapered, high surface area element utilizing very high capacity media and an o-ring sealing mechanism. The tapered shape allows the element to release from the support cage once the o-ring seal is dislodged. Removal of VMAX elements is very easy, even when operated to differential pressures of 50 psid or greater. A conventional, cylindrical bag filter, by contrast, is difficult to remove from the support basket because the element contacts the entire length of the basket, providing significant resistance upon removal. Consequently, the VMAX design provides efficient operation across a much wider window of differential pressure relative to a bag filter, significantly increasing filter life and contaminant capacity.

Figure 5. Installed VMAX support cages (left). VMAX element (right)
The VMAX upgrade of a bag filter vessel employs the fabrication and installation of a VMX cage, engineered to seal to the specific requirements of a given vessel. The VMAX support cage installs within the same envelope occupied by the bag filter support basket. In contrast to a bag filter basket, however, the VMAX cage relies on a high efficiency o-ring seal between the support cage and the filter vessel eliminating the opportunity for contaminant bypass. This seal mechanism is typically absent in conventional bag filter designs.

Successful implementation of the VMAX coreless element design at the initial produced water disposal site provided the rationale for upgrading the remaining produced water disposal well filtration systems. Prior to the upgrade to VMAX, the produced water filters were changed every two days during normal operation and every 12 – 24 hours during frequent process excursions. The result was annual consumption of greater than 35,000 bag filters per year across the entire production site at an annual operating cost of $140,160 in direct filtration costs. The spent filters created over 86 cubic yards of solid waste annually. The filter maintenance required over 3,600 hours per year, resulting in an associated labor cost of $179,520.

After successful upgrade of the produced water filtration to Pentair Porous Media’s VMAX coreless element technology at eight disposal well sights in the production field, the filters required replacement on only a monthly basis, reducing direct filtration costs by 63% annually ($88,320) and reduced solid waste generation by 80 cubic yards (61 m3). The labor associated with filter maintenance was reduced by over 95% resulting in the recovery of a full time equivalent maintenance operator, which could be redeployed to more productive activities within the production site. The cumulative filter, labor and waste disposal cost reductions amounted to $272,604 annually. The implementation of the VMAX technology also increased the reliability of filter maintenance scheduling and dramatically decreased the potential for production interruptions due to shut-down of the produced water processing facilities and reduced the potential for environmental releases associated with the produced water operation.

Table 1. Summary of Produced Water Filtration - Operational Costs

<table>
<thead>
<tr>
<th></th>
<th>Conventional Bag Filtration</th>
<th>Pentair Porous Media Coreless Filter Upgrade</th>
<th>Cost Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average filter Life (days)</td>
<td>1</td>
<td>30</td>
<td>--</td>
</tr>
<tr>
<td>Number of Filters Annually</td>
<td>35,040</td>
<td>1,152</td>
<td>--</td>
</tr>
<tr>
<td>Annual Waste Disposal Volume (yd$^3$)</td>
<td>86</td>
<td>6</td>
<td>--</td>
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<tr>
<td>Annual Labor Cost</td>
<td>$185,640</td>
<td>$6,120</td>
<td>$179,520</td>
</tr>
<tr>
<td>Annual Filter Cost</td>
<td>$140,160</td>
<td>$51,840</td>
<td>$88,320</td>
</tr>
<tr>
<td>Annual Waste Disposal Cost ($60 / yd$^3$)</td>
<td>$5,160</td>
<td>$360</td>
<td>$4,800</td>
</tr>
<tr>
<td><strong>Total Annual Savings after Pentair Porous Media Upgrade</strong></td>
<td></td>
<td></td>
<td><strong>$272,604</strong></td>
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</tbody>
</table>

Currently, Pentair Porous Media provides produced water filtration across the entire gas production site, as well as gas / liquid separation for the inlet separator to the glycol dehydration system and the lean glycol filtration loop at the production site. Pentair Porous Media also provides all of the process filtration and gas conditioning for the adjoining 300 MM scfd gas processing plant.