

DuPont Water Solutions for Oil & Gas – Produced Water

Addressing pressing needs for produced water treatment
with DuPont innovative technologies



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About DuPont Water Solutions

Companies, communities and homes around the world choose DuPont Water Solutions to help make water safer and more accessible. Industries and markets count on us to become more efficient. Our innovation and collaboration with the world's best water experts enables ecosystems of innovation to deploy vital technologies in new, market-shaping ways.

With a global network of accessible knowledge and a market-leading portfolio of purification and separation technologies, we enable the water productivity from which health, profits, and possibilities spring. In a world of increasing water scarcity, we provide a proven path that balances resource productivity and responsibility.



Our products are based on decades of industry leadership, and include ion exchange resins, reverse osmosis nanofiltration technology, ultrafiltration membranes, degasification modules and wastewater treatment products, with globally recognized brands like FilmTec™ Fortilife™, Memcor™ and the Amber series to meet your water, waste and other separation needs.

We provide support to markets and industries across the globe, including residential, municipal, power generation, oil & gas, healthcare, commercial industries, chemical & petrochemical, food & beverage and microelectronics, for a wide range of applications as well as minimal liquid discharge (MLD) consultancy.

Unmatched in our global reach, industry experience and expertise, our focus and dedication places us in a unique position to help industries, organizations, and communities prosper. We offer the broadest portfolio in the water treatment technology industry and provide leading innovations.

The broadest Portfolio in the industry

Water is the largest volume by-product of Oil & Gas production and requires treatment for use, reuse and discharge. To improve productivity, water with specific quality requirements is injected into the well for secondary and tertiary recovery. For discharge, the organic load (expressed as BOD, COD, TOC or oil & grease) is usually a limit for wastewater disposal permits.

Like no other supplier, we can provide ultrafiltration (UF), reverse osmosis (RO) elements, sulfate-removal nanofiltration (NF) membranes, degassing membranes and Wastewater solutions like membrane bio-reactor (MBR), polymeric adsorbents and selective ion exchange resins (IX). The use and details of these products are further described in this brochure, providing a sample of our expertise and growing portfolio of technologies that targets the unique needs of hydrocarbon exploration and production.

From injection to produced water, we provide a complete set of treatment technologies to handle oil and gas production

| | | | | | |
|-------------------|----------------------------|--|--|---|------------------------------------|
| | Memcor® MBR & UF | inge® Multibore® UF Membranes | DesaliTec™ CCRO | DuPont™ Ligasep™ Degasification Modules | |
| Wastewater | | | | | Ultrapure Water |
| | | | | | |
| | OxyMem MABR | DuPont™ IntegraFlux™ Ultrafiltration | FilmTec™ Reverse Osmosis Nanofiltration | Amber Series Ion Exchange Resins | DuPont Electro-deionization |

Produced Water and Petrochemical Wastewater

Preserving and restoring the world's water supply remains as one of the world's top environmental challenges. Minimizing waste is one of the principles behind any circular economy initiative. Failing to purify water before discharging it back into the environment has dire consequences. More stringent legislation across the globe as well as an increased awareness of corporate social responsibility towards sustainability are leading corporations to enforce and implement new solutions to tackle some of the issues that an uncontrolled disposal of these pollutants causes to our planet.

DuPont helps to solve some of the Oil & Gas industry's most challenging environmental problems. We provide the right industrial water treatment options to handle oil and gas production needs.

Effective removal of critical contaminants can help avoid:

- 1) Hindering downstream unit operations
- 2) Fines/penalties for exceeding discharge permits
- 3) Polluting the environment

In the end, it can be costly to ignore the importance of effectively removing certain contaminants. Finding cost-effective solutions is as important as ever.

Product Portfolio

DuPont Water Solutions offers a broad spectrum of proven technologies for a wide variety of treatment schemes – allowing customers to mix and match technologies to achieve their waste and process stream treatment objectives.



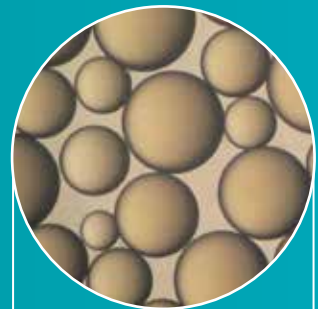
Biological treatment options such as **MBR** and **MABR** for ...



Ultrafiltration (UF) Modules for suspended solids removal



Fouling resistant **Reverse osmosis and Nanofiltration Membrane Elements** for dissolved salts removal



Polymeric Adsorbents and Ion exchange Resins for selective and non-selective removal





Organics removal

Wastewater treatment capabilities in Oil & Gas requires a focus on organic compound removal. The organic composition of a wastewater stream is often the key parameter for meeting discharge limitations or recycling the water:

- For discharge, the organic load expressed as BOD, COD, TOC or Oil concentration is usually a limit for wastewater discharge permits. Municipal or public wastewater treatment plants (WWTP), may add surcharges on the cost of treating effluents based on the organic load.
- Downstream water recycle and recovery processes (such as reverse osmosis) are often sensitive to the organic load so pretreatment is required. In the case of environmental remediation of contaminated soils, the removal of the organic/solvent/fuel is a must to meet overall standards.



Oil contamination in Oil & Gas Effluents

The organic contamination most common in water in O&G industry is obviously in form of oil. This is mainly found in the water from distillates in refineries, chemical processes or associated with hydraulic fracturing and drilling, also commonly known as produced water which presents an opportunity to recover valuable hydrocarbons as well as to make water suitable for recycling or disposal. Oil-in-water may appear in several different forms:

Free Oil

The free oil rises rapidly to the surface of the water tank under calm conditions when the oil drops are large enough, usually over 150 μm . In this case, the oil can be removed by an overflow weir in the tank and a skimmer.

Emulsified Oil

Emulsified oil appears as small oil droplets in the water (from

1 to 150 μm). They are stabilized by electrical charges due to the shear resulting from travelling through pumps, splashing into a tank, or anything that will break up and disperse larger oil drops. These droplets can be very difficult to remove with conventional mechanical techniques. Unless absorbed onto solid particulates, paraffins can be considered part of emulsified oil.

Dissolved Oil

Dissolved oil is comprised of water-soluble members of the oil. These are uncharged non-polar carbon-containing compounds such as:

- Benzene, ethylbenzene, toluene, and xylenes – collectively known as "BTEX".
- Gasoline range organics (GROs) – typically C6 – C12 compounds
- Total petroleum hydrocarbons (TPH)
- Phenols and naphthenic acids.

Organics Removal Portfolio for Onshore and Offshore Application

| Product | Polymer | Best For |
|--|-------------|---|
| DuPont™ AmberLite™ ROC110 Oil-Coalescing Media | Styrene-DVB | Removal of emulsified oil with excellent physical stability |
| DuPont™ AmberSorb™ L493 Polymeric Adsorbent | Styrene-DVB | Removal of dissolved organic non-polar components |
| XAD™ 4 Polymeric Adsorbent | Styrene-DVB | Removal of dissolved organic polar components |
| XAD™ 16 Polymeric Adsorbent | Styrene-DVB | |
| DuPont™ AmberLite™ SCAV1 Ion Exchange Resin | Acrylic | Removal of hydrophobic and hydrophilic NOM species |
| DuPont™ AmberLite™ SCAV2 Ion Exchange Resin | Acrylic | |

Emulsified Oil

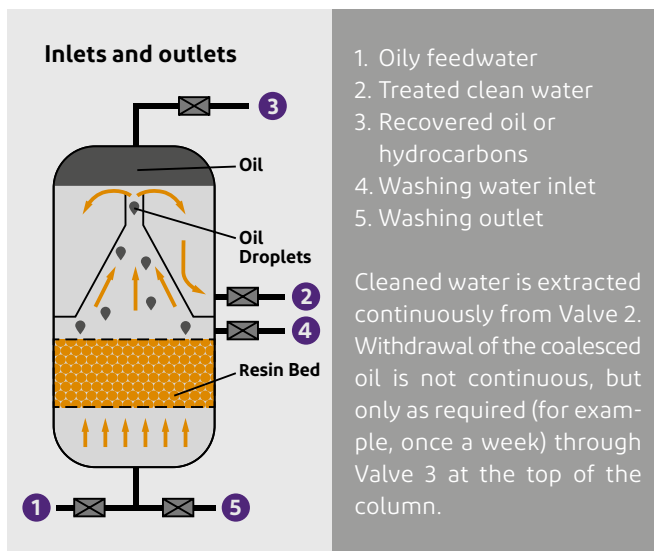
Emulsified oil can be removed by coalescing and decanting, using an ion exchange resin bed containing **DuPont™ Amberlite™ ROC110 Oil-Coalescing Media**. This product has oleophilic properties that attract oil molecules very efficiently usually greater than other coalescer technologies. The media resizes the small oil droplets from micron to millimeter size, becoming easily separated. Key features of a coalescer packed bed system includes:

- Continuous operation;
- No regeneration is required;
- No chemicals or coagulants needed;
- Can hold high concentrations of oil
- Resistant to elevated temperatures (up to 150 C) – beneficial for heavy oils processing.
- Very long resin lifetime.
- Systems can be designed for up-flow or down-flow operations.

Emulsified Oil Removal System:

Oily water passes through the ion exchange fixed resin bed from bottom to top. The resin beads are coated with a layer of oil, leading to saturation and then supersaturation such that the oil can now slough off the beads as large drops that can easily

rise to be skimmed off. There is no regeneration procedure. The oil is removed periodically from the top of the column. If proper filtration has been performed, backwashing is an infrequent event. The diagram illustrates an up-flow operation, but the system could be designed for down-flow:



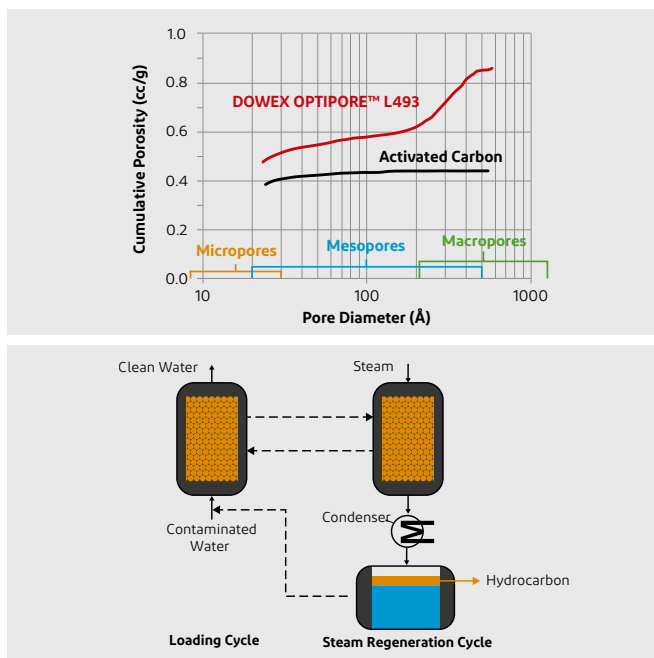
Dissolved Oil

Polymeric adsorbents offer an alternative to activated carbon for the removal of a wide variety of organic compounds from industrial wastewater and produced water such as light hydrocarbons, volatile organics, aromatic and phenolic compounds.

Most of the compounds found in dissolved oil can be removed by adsorption. Products such as **DuPont™ AmberSorb™ L493** and **AmberLite™ XAD™** can effectively remove a wide variety of these organic compounds.

Macroporosity comprises a sizable portion of the DOWEX OPTIOPORE™ Polymeric Adsorbent compared to activated carbon, and these larger pores help to facilitate more effective adsorption and desorption kinetics.

Schematic of a Typical Steam-Regenerated System with DOWEX OPTIOPORE™ Polymeric Adsorbent: A two-bed system in which one bed is in service removing hydrocarbons and clean treated water exits the bed. When the bed in service is loaded, it is swapped out for steam regeneration.



Measurements for Organic Load

BOD (biological oxygen demand)

is based on the principle that if enough oxygen is available, aerobic biological decomposition by microorganisms will consume all of the organic material present. It is a test that measures the consumption of oxygen over a 5-days period under prescribed conditions.

COD (chemical oxygen demand)

is the most popular alternative to BOD because it can be performed in a few hours. The test uses a chemical (potassium dichromate in 50% sulfuric acid) to chemically oxidize the organics and inorganics in the water sample. Because inorganics are measured, a COD result is often higher than a BOD measurement.

TOC (total organic carbon)

is gaining popularity because the test can be performed in 5–10 minutes. A TOC measurement is like a COD measurement in that it uses oxidation methods to break down the organics to CO₂, followed by quantification.

O&G (oil & grease)

measures the hydrophobic components of wastewater (fat, oil, grease, and petroleum hydrocarbons) and can exist as emulsions which are tiny particles of the O&G suspended in water.

BTEX (benzene, toluene, ethylbenzene and xylene)

is a specific group of petroleum hydrocarbons that can be called out for specific quantification and restrictions on discharge. Levels are typically measured by GC or GC-MS. Limits on benzene can be in the parts-per-billion range.

Biodegradable organics and nutrients

Membrane-based biological treatment technology such as MBR and MABR harness the action of bacteria and other microorganisms to clean water, coupled with the filtration power of Ultrafiltration (UF) membranes. This type of process is ideal for the removal of biodegradable organics (BOD, COD) and nutrients (Nitrogen and ammonia) from wastewater.

Membrane Bioreactor (MBR)

A membrane bioreactor (MBR) is the combination of a suspended growth biological treatment method, usually activated sludge, with membrane filtration equipment. Proven to deliver greater effluent and productivity, while reducing the lifecycle cost, Memcor® MBR technology uses a fully automated process that provides liquid/solid separation by combining biological waste oxidation and membrane separation. In turn, this eliminates the need for any secondary clarification. It helps provide:

- A biological process apt for heavy COD loads.
- MBR includes a reduced footprint, usually 30-50% smaller than the equivalent conventional active sludge with secondary clarifiers and media tertiary filtration.

- Flexible, modular rack design.
- Provides effluent water of improved quality, with low amounts of suspended solids, allowing water to be re-used.
- Allows for plant expansions in the same footprint.
- A solution that can be implemented with low CAPEX.
- Pulsed, plug flow aeration, with reduced energy consumption compared to bubble aeration.
- Easy to use with existing infrastructure.
- Fully automated.



MBR and MABR Portfolio for Onshore and Offshore Application

| Product | Best For | |
|-------------|--------------------------------------|--|
| Memcor® B40 | Municipal and Industrial waste water | - To reduce foot print - Lower sludge production - High loading rate capability - High effluent quality |

Salinity management

Oilfield produced water can often contain high levels of total dissolved solids (TDS) in addition to hydrocarbons, precipitates, and suspended particles. The dissolved solids mainly consist of sodium, calcium, and magnesium salts. The combination of the high salinity and hardness in produced water can be very detrimental.

FilmTec™ membrane elements can help address produced water hyper-salinity regulatory challenges with FilmTec™ minimal liquid discharge (MLD) solutions. High-recovery reverse osmosis systems have the potential to minimize operating costs and maximize water recovery while reducing the amount of energy required to operate.

Low-energy reverse osmosis (RO) are suitable for produced water treatment. **FilmTec™ SW30HRLE Elements** are used in produced water treatment facilities. These durable, high-rejection and high-productivity reverse osmosis elements are designed for use in high-fouling or challenging feedwater conditions. **FilmTec™ SW30XHR Series** are the highest rejection membrane in the produced water portfolio, for high quality permeate water needs.

The **FilmTec™ Fortilife™ XC** product family is designed for facilities that need an industry-leading nanofiltration (NF) and reverse osmosis (RO) water treatment that's reliable, easy to clean, and that would benefit from a durable, robust membrane.

The high temperatures often associated with produced water is the greater challenge for the treatment of high-salinity produced water. New solutions that allow membrane systems to operate at high pressures and temperatures offer a promising alternative to conventional thermal based alternatives for oil and gas wastewater. The **DuPont Ultra High-Pressure** Reverse Osmosis Elements can operate continuously at pressures up to 120°C.



Reverse Osmosis Membranes Portfolio for Onshore and Offshore Application

| Product | Best For |
|------------------------------|--|
| FilmTec™ SW30 Series | Treatment of high-salinity feedwater with challenging conditions. |
| FilmTec™ Fortilife™ Series | Treatment of high-salinity feedwater with challenging conditions in high-recovery systems. |
| DuPont XUS180808 | Treatment of extremely high-salinity water, typically concentrate, requiring pressure up to 120 bar. |
| FilmTec™ Low Energy Products | Treatment of moderate salinity wastewater with challenging conditions. |



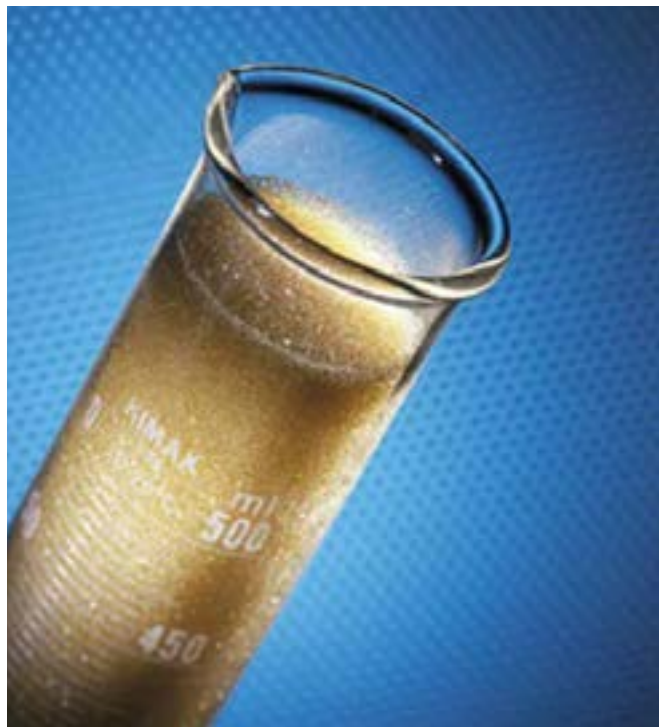


Hardness Removal

In many cases where the removal of scale-forming divalent ions such as hardness and silica is more important than NaCl removal. Ion exchange softening resins can remove scale-forming cations, such as Ca^{2+} , Ba^{2+} and Sr^{2+} , with removal efficiency greater than 99.5%. This usually eliminates any risk of carbonate or sulfate scaling. Additionally, the resin is easily regenerated with NaCl at hardness breakthrough.

DuPont ion exchange resins (IX) are designed for use in industrial demineralization and softening applications offering high operating performance, long resin life, simplified and cost-effective operation. **DuPont™ AmberLite™ IRC83 H** Ion Exchange Resin is widely used in the treatment of unconventional oil and gas wastewater streams because of its high capacity and stability.

Additionally, – depending on feedwater characteristics, and existing pre-treatment – nanofiltration (NF) membranes are another good candidate for water softening: they provide a high water flux and a lower rejection of monovalent ions (<90%) compared to reverse osmosis (RO) membranes. Membranes like **FilmTec™ NF90-400/34i**, **FilmTec™ NF270-400/34i** or **FilmTec™ Fortilife™ XC-N** can be used for industrial water softening.



Ion Exchange Resins and Reverse Osmosis Membranes Portfolio for Onshore and Offshore Application

| Product | Type | Best For |
|------------------------------------|------|--|
| DuPont™ AmberLite™ IRC83 H | IX | Very high-capacity de-alkalization and softening WAC resin for Oil sand application and high salinity waters |
| DuPont™ AmberLite™ HPR8300 H | IX | High-capacity de-alkalization and softening resin (WAC) for high salinity waters. |
| DuPont™ AmberLite™ HPR1100 Na | IX | Uniform Particle Size Gel, SAC resin for de-alkalization of low-salinity waters. |
| DuPont™ AmberSep™ Chelating Resins | IX | Softening of waters with a salinity > 30.000 ppm of dissolved salts. |
| FilmTec™ Fortilife™ XC-N | NF | NF element for sulfate removal in industrial wastewater streams. |
| FilmTec™ NF270 | NF | NF element for energy-efficient hardness removal. |
| FilmTec™ NF90 | NF | NF element for hardness removal requiring high rejection rates. |

Heavy Metals

Among the wastes identified in the Oil & Gas industry, produced water containing heavy metals is amongst the most dangerous given their toxicity, and it is also strictly regulated. Produced waters are often enriched with:

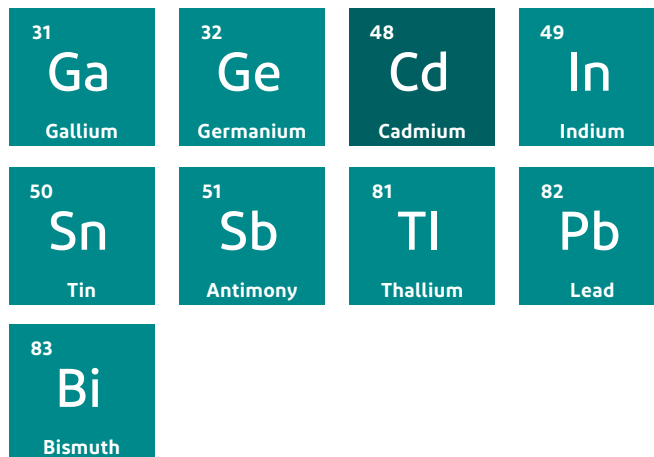
- Iron (Fe)
- Copper (Cu)
- Manganese (Mn)
- Cadmium (Cd)
- Lead (Pb)
- Nickel (Ni)
- Chromium (Cr)
- Mercury (Hg)

They are usually found in concentrations that exceed safe discharge limits and regulations.

Heavy metals can be removed from water with neutral pH as cations. For this, DuPont recommends the use of a weak acid cation (WAC) exchanger. Several products exist that can be recommended, such as **DuPont™ AmberLite™ IRC83 H** and **AmberLite™ HPR1100 Na**. Both resins can be regenerated with NaCl brine or disposed of in accordance with local requirements once they are loaded with metals.

In acid conditions, heavy metals can form anionic complexes that can be removed with anion exchange resins. For these the recommended solution is the use of a strong base anion resin (SBA) such as **DuPont™ AmberSep™ 21K XLT** or **AmberLite™ HPR9200 Cl**.

Most of these metals can also be selectively removed from solution with chelating resins such as **DuPont™ AmberSep™ IRC748 Resin, AmberSep™ GT74, or AmberSep™ 43600**.



Mercury can also form colloidal complexes that can be reliably removed with **DuPont Ultrafiltration SFP Modules**.

Since multiple types of metals can be in the same stream, multiple removal techniques may need to be employed in series. Contact your DuPont™ expert for more information.

Metals Removal Portfolio for Onshore and Offshore Application

| Product | Best For |
|--|---|
| DuPont™ AmberSep™ IRC748 UPS Chelating Resin | Selective removal of heavy metals. |
| DuPont™ AmberSep™ 43600 Chelating Resin | Selective removal of heavy metals. |
| DuPont™ AmberSep™ GT74 Ion Exchange Resin | Selective removal of heavy metals. |
| DuPont™ AmberSep™ 21K XLT Ion Exchange Resin | Selective removal of Cr(VI) and metals forming an anionic complex. |
| DuPont™ AmberSep™ G26 H Ion Exchange Resin | Selective removal of Cr(III). |
| DuPont™ AmberLite™ IRC83 H Resin | Non-selective weak acid cation exchanger. |
| DuPont™ AmberLite™ HPR1100 Na Resin | Non-selective strong acid cation exchanger. |
| DuPont™ AmberLite™ HPR9200 Cl | Non-selective weak base anion exchanger resistant to organic fouling. |
| DuPont™ AmberLyst™ A21 | Non-selective weak base anion exchanger. |
| DuPont Ultrafiltration SFP Modules | Removal of colloidal complexes containing mercury. |



Powering performance worldwide

With a large global manufacturing footprint, strong R&D expertise and technical support services and systems, we supply high market volumes with high quality. DuPont partners with you, our customer, to understand unmet needs and develop tailored solutions. With a large global manufacturing footprint, strong R&D expertise and technical support services and systems, we supply high market volumes with high quality. DuPont partners with you, our customer, to understand unmet needs and develop tailored solutions.

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*Global Water
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Water Solutions
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