DIGITAL ADDENDA 6A – 6B

Addendum 6A: Tabulated detailed information

Table 1: Chemical components of concern present in Produced water (Hammer and Van Briesen, 2012)

Chemical component used 2005-2009	Chemical category	Detected in at least one produced water sample (MSC report)
Methanol	HAP	Not tested
Ethylene glycol (1,2-ethanediol)	HAP	Yes
Diesel	Carcinogen, SDWA, HAP	Not tested
Naphthalene	Carcinogen, HAP, PC	Yes
Xylene	SDWA, HAP	Yes (total xylene)
Hydrochloric acid	HAP	Not tested
Toluene	SDWA, HAP	Yes
Ethylbenzene	SDWA, HAP	Yes
Diethanolamine	HAP	Not tested
Formaldehyde	Carcinogen, HAP	Not tested
Sulfuric Acid	Carcinogen	Not tested
Thiourea	Carcinogen	Not tested
Benzyl chloride	Carcinogen, HAP	Not tested
Cumene	HAP	Not tested
Nitrilotriacetic acid (NTA)	Carcinogen	Not tested
Dimethyl formamide	HAP	Not tested
Phenol	HAP	Yes
Benzene	Carcinogen, SDWA, HAP	Yes
Di (2-ethylhexyl) Phthalate	Carcinogen, SDWA, HAP	Not tested
Acrylamide	Carcinogen, SDWA, HAP	Not tested
Hydrofluoric acid	HAP	Not tested
Phthalic anhydride	HAP	Not tested
Acetaldehyde	Carcinogen, HAP	Not tested
Acetophenone	HAP	Yes
Copper	SDWA	Yes
Ethylene oxide	Carcinogen, HAP	Not tested
Lead	Carcinogen, SDWA, HAP, PC	Yes
Propylene oxide	Carcinogen, HAP	Not tested
p-xylene	HAP	Yes (total xylene)

Table 2: List of operational municipal waste disposal sites in the study area (DEAT, 2007)

Province	Municipality	Landfill site	Class	Airspace estimate 2007 (years)
Eastern Cape	Lukhanji	Queenstown	GCB-	25
	Baviaans	Willowmore	GSB+	10
	Blue Crane Route	Cookhouse	GSB-	3
		Pearston	GCB-	6
		Somerset East	GMB-	
	Camdeboo	Nieu-Bethesda (Jakkalshoek)	GCB-	10
		Aberdeen	GCB-	30
	Gariep	Burgersdorp	GCB-	15-20
	Tsolwana	Tarkastad	GSB-	4
		Britstown	GCB-	10
		Hanover	GCB-	20
	Emalahleni	Dordrecht	GCB+	5-10
		Indwe	GCB+	5
Northern Cape	Hantam	Nieuwoudtville	GCB-	20
		Middelpos	GCB-	10
	Kareeberg	Vosburg	GCB-	20
		Vanwyksvlei	GCB-	20
	Karoo Hoogland	Williston	GCB-	10
		Sutherland	GCB-	8
	Ubuntu	Loxton	GCB-	15
		Richmond	GCB-	15
	Umsobomvu	Norvalspont	GCB-	20
Western Cape	Beaufort West	Merweville	GCB-	10
		Nelspoort	GCB-	30
	Laingsburg	Laingsburg	GSB^-	
	Prince Albert	Klaarstroom	GCB-	20
		Prince Albert Road	GCB-	6
		Leeu Gamka	GCB-	8

Table 3: The number of waste water treatment plants per municipality in the study area and technologies employed

Province	Municipality	No of WWTW	Technologies in use	Cumulative Risk Rating (DWS, 2014)
Eastern Cape	Lukhanji	2	Activated sludge Drying beds Oxidation ponds Anaerobic digestion Biological filters Maturation ponds Sedimentation Chlorination	High
	Baviaans	3	Drying beds Oxidation ponds Chlorination	High
	Blue Crane Route	3	Oxidation ponds	High
	Camdeboo	3	Activated sludge Drying beds Oxidation ponds Chlorination	Medium
	Gariep	4	Activated sludge Drying beds Oxidation ponds Maturation ponds Sedimentation Chlorination	Medium
	Maletswai	2	Activated sludge Drying beds Maturation ponds Chlorination	Medium
	Sundays River Valley	4	Activated sludge Drying beds Oxidation ponds Chlorination	High
	Tsolwana	2	Oxidation ponds Maturation ponds Chlorination	High
	Ngqushwa	2	Activated sludge Drying beds Belt press dewatering Sedimentation Chlorination Filtration	Medium

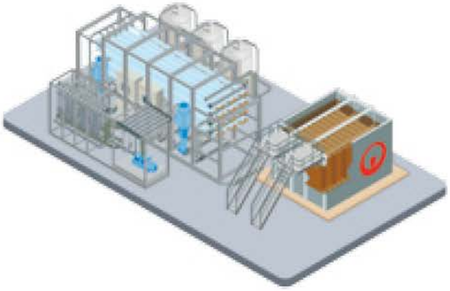
Province	Municipality	No of WWTW	Technologies in use	Cumulative Risk Rating (DWS, 2014)
	Nkonkobe	3	Activated sludge Drying beds Maturation ponds Sedimentation Chlorination	Medium
	Emalahleni	2	Oxidation ponds Maturation ponds	High
	Inkwanca	2	Activated sludge Oxidation ponds Maturation ponds Chlorination	High
	Inxuba Yethemba	2	Activated sludge Drying beds Oxidation ponds Anaerobic digestion Biological filters Chlorination	High
	Nxuba	2	Activated sludge Drying beds Oxidation Maturation ponds Chlorination	Medium
	Ikwezi	2	Oxidation ponds Maturation ponds	High
	Makana	3	Activated sludge Oxidation ponds Anaerobic digestion Biological filters Sedimentation Chlorination	High
Northern Cape	Hantam	5	Oxidation ponds Anaerobic ponds Maturation ponds	Low
	Kareeberg	3	Drying beds Oxidation ponds	Medium
	Karoo Hoogland	3	Oxidation ponds Chlorination	High
	Emthanjeni	3	Activated sludge Drying beds Oxidation ponds Maturation ponds	Low

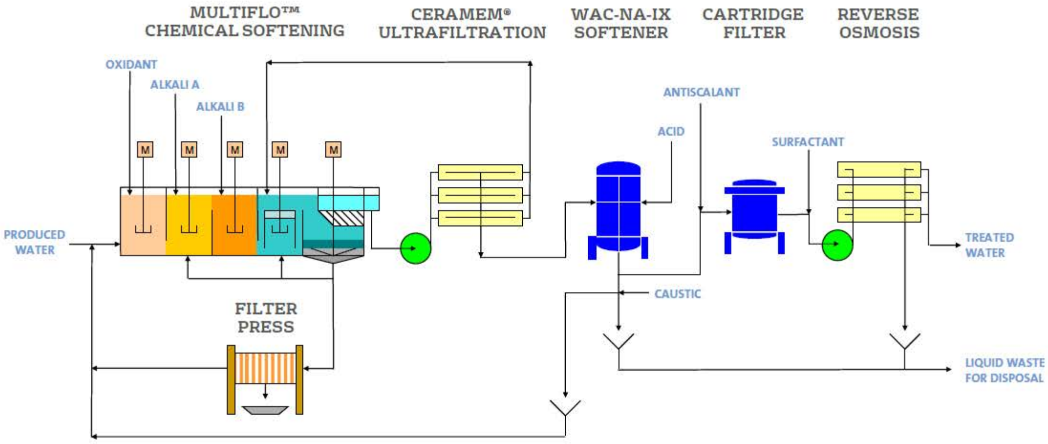
Province	Municipality	No of WWTW	Technologies in use	Cumulative Risk Rating (DWS, 2014)
	Ubuntu	3	Activated sludge Drying beds Oxidation ponds Chlorination	Medium
	Umsobomvu	3	Activated sludge Oxidation ponds Anaerobic digestion Maturation ponds	High
Western Cape	Beaufort West	4	Activated sludge Drying beds Oxidation ponds Biological filters	Low
	Witzenberg	4	Activated sludge Oxidation ponds	Low
	Laingsburg	1	Oxidation ponds	High
	Prince Albert	3	Aerated lagoons Oxidation ponds Anaerobic digestion	High
	Breede Valley	4	Activated sludge Drying beds Anaerobic digestion Biological nutrient removal Biological filters Maturation ponds Sedimentation	Medium

Addendum 6B: Examples of Commercially available Modular Water Treatment Technologies

OPUS® II technology is a proprietary Optimized Pretreatment Unique Separation technology developed to achieve high recovery of clean water for reuse or discharge. This new generation of OPUS technology is a compact design that results in lower installed costs than comparable systems.

Developed by Veolia Water Technologies, this unique technology utilizes our proprietary CeraMem® ceramic membranes with chemical and ion exchange softening as pretreatment to a reverse osmosis (RO) process operated at an elevated pH. The result is a compact treatment system that provides high quality water suitable for reuse in industrial processes or replenishment of raw water sources.



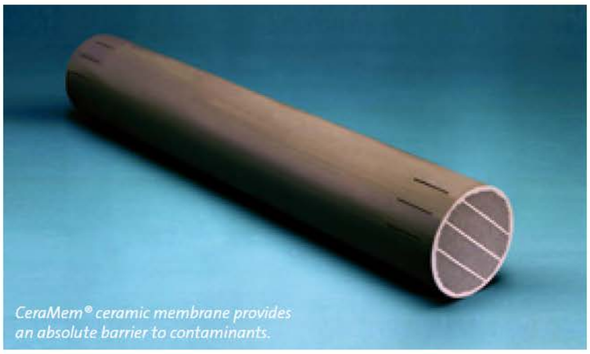


Technology Description

OPUS II technology consists of multiple treatment processes involving chemical softening, membrane filtration, ion exchange softening and reverse osmosis operated at an elevated pH. The pretreatment processes ahead of the RO are designed to reduce free oil, hardness, metals and suspended solids in the feed water. The RO process operates at an elevated pH, which effectively controls biological, organic and particulate fouling, eliminates scaling due to silica and increases the rejection of silica, organics and boron.

In the OPUS II technology, the feed water is subjected to chemical softening, free oil and solids removal in a pretreatment process that uses CeraMem ultrafiltration technology. This process consists of a series of reaction tanks followed by a crystallization tank fitted with our patented Turbomix® mixing technology, which facilitates precipitation of hardness and metals in the feed water and crystallization of the solids generated by precipitation. The softened water and crystalline solids are then processed through the ceramic membrane ultrafiltration system operated in cross-flow mode for removal of free oil, total hardness and suspended solids to lower concentrations. The solids waste from the CeraMem process is continuously recycled to the crystallization tank and purged intermittently for dewatering and subsequent hauling to landfill for disposal.

The filtrate from the CeraMem process is further treated with ion exchange softening utilizing Weak Acid Cation (WAC) resin in sodium form for further removal of hardness and metals to lower concentrations, without pH correction. Any remaining particulates are removed by cartridge filtration. The pretreated water is then pressurized through the RO, operated at an elevated pH in single or double pass mode, to reduce the TDS, boron and organics.



CeraMem® ceramic membrane provides an absolute barrier to contaminants.

Our mobile pilot systems are available for deployment.

Technology Benefits

- >90% recovery rate up to 7,500 ppm influent TDS
- Compact, modular systems with low field installation costs
- Prevents scaling caused by silica, calcium and metal salts
- Controls fouling due to organics and particulates
- Achieves salt rejection removal rates of >99.4% boron, >99.7% silica and >99% TOC
- Continuous Clean-In-Place (CIP) process minimizes RO cleaning frequency
- 3-year, pro-rated membrane life warranty
- Robust treatment approach with minimal system downtime
- Effectively handles variations in feed water quality

Applications

- Oil and Gas Field Produced Water
- Power Plant Cooling Tower Blowdown
- Reuse of Industrial Wastewater to Achieve Zero Liquid Discharge

Guaranteed Performance

Veolia Water Technologies offers a performance guarantee after testing OPUS II technology using our mobile pilot system. Our pilot units, capable of treating 20 gallons per minute (685 barrels per day), are deployed to your site to demonstrate the process for your water characteristics before the full-scale system is designed, enabling us to optimize performance and minimize cost. Long-term operation and maintenance contracts are also available to ensure continued optimization of your system and extend the performance guarantee for the life of the contract.

Flexible Project Delivery Options

Our project delivery can be tailored to your purchasing preferences:

- Engineer / Procure
- Design / Build
- Design / Build / Operate / Maintain
- Design / Build / Operate / Guarantee*

Typical Performance Data

Constituent	Feed Water	CeraMem® Ultrafilter Filtrate	Double Pass RO Permeate	Removal Efficiency
Free Oil (>20µ), ppm	100	<0.2	Non-Detect	>99.9%
Total Suspended Solids, ppm	100	<0.2	Non-Detect	>99.9%
Total Hardness, ppm as $CaCO_3$	236	<10	Non-Detect	>99.9%
Calcium, ppm	65	<3.2	Non-Detect	>99.9%
Magnesium, ppm	18	<0.5	Non-Detect	>99.9%
TDS, ppm	2,200	2,500	<15	>99.3%
Boron, ppm	8.6	8.6	<0.03	>99.7%
Silica, ppm	220	<50	<0.03	>99.9%
Organics, ppm	210	210	<0.99	>99.5%

* Veolia is the only water treatment company that offers DBOG project delivery. Long-term operation contracts include facility maintenance, treatment chemicals and guaranteed system performance for the life of the contract. DBOG contracts eliminate risks associated with rising costs, performance and availability.

VEOLIA

The CoLD® Process

Treatment of Flowback/Produced Water

Benefits of the CoLD Process

- Achieves complete desalination of high TDS produced waters
- Lowest CAPEX and OPEX as compared to conventional methods
- No chemical softening or sludge production
- Produces clean water and stable solids for disposal or reuse
- Simple, robust process with high reliability and availability

Innovative Process Solutions

Veolia Water Technologies is the global leader for innovative process solutions that use HPD® Evaporation and Crystallization as core technologies. With more than 800 installations in more than 30 countries, Veolia has decades of process design experience in the oil & gas, power, chemical, mining, salt, and fertilizer industries, providing wastewater treatment, volume reduction, and Zero Liquid Discharge (ZLD) systems.

The **CoLD® Process** is a proprietary crystallization process developed by Veolia as a simpler and more economical approach to desalination of produced water than conventional thermal processes. The CoLD Process eliminates the need for expensive pretreatment of the produced water, thereby reducing capital and operating costs. The CoLD Process is an ideal solution to address stricter water reuse standards, ZLD, and increasing regulation of discharge limits of total dissolved solids (TDS) facing the shale oil & gas industry.

Process Background

In the North American onshore oil & gas industry, on average nearly eight barrels of water are brought to the surface for every barrel of oil. This produced water is often highly saline and contaminated by hydrocarbons and even radioactive elements: it is a hazardous waste that requires treatment, disposal, and increasingly, recycling.

Increased reuse of produced water is driving the implementation of physical, chemical, biological, and thermal treatment methods. Physical, chemical, and biological treatment methods can reduce the concentrations of certain pollutants, but the volume and salinity of the produced water is unchanged. Thermal desalination of produced water is a proven method to completely separate the salts from the water, so both can potentially be beneficially reused.

Veolia has applied proven process designs based on HPD® Evaporation and Crystallization technologies used in the salt, fertilizer, and chemical industries to develop a simple and robust process to separate the flowback and produced water from hydraulic fracturing into clean water and a stable, non-hazardous solid for disposal and/or reuse.

WATER TECHNOLOGIES

The CoLD® Process

Produced Water Chemistry

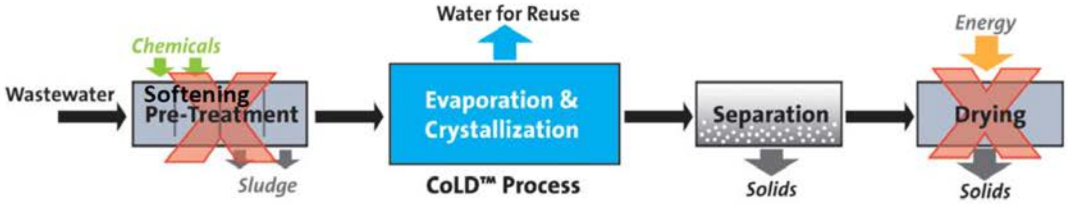
Some portion of the frac fluid injected into a well will return to the surface during the first few days to weeks. This is referred to as flowback water. Over a much longer period of time, additional water that is naturally present in the shale formation (produced water) continues to flow from the well. Both flowback and produced water can contain very high levels of TDS, composed mainly of dissolved chloride salts of sodium, calcium and magnesium. Significant quantities of barium and strontium salts may also be present as well as some heavy metals and naturally occurring radioactive material (NORM). The produced water is also contaminated with a range of hydrocarbons.

Limitations of Conventional Methods

Conventional thermal processes for desalination of produced water require complete softening of the produced water using lime, soda ash, caustic, and other chemicals to replace the calcium and magnesium ions in the produced water with sodium ions in order to produce a crystalline solid.

In some cases, a final drying step is necessary to produce a stable solid suitable for disposal. Softening pretreatment equipment includes chemical feed/storage facilities, solids settling or filtration equipment, and sludge dewatering equipment. Drying equipment is capital and energy intensive. These additional facilities increase the footprint of the ZLD system as well as the capital costs and overall maintenance. The logistics of unloading, storing, and preparing chemicals, and dewatering and transporting sludge for disposal substantially increase the OPEX.

The **CoLD® Process** operates under vacuum at low temperature. The chemistry of many produced waters favor the formation of hydrates and double salts which precipitate at low concentrations as the temperature of the solution is lowered. When concentrating the waste stream at low temperature, dissolved solids will crystallize at relatively low concentration, without the need for chemical softening pretreatment and the resulting sludge production.



Advantages of CoLD Crystallization

The CoLD Process will completely desalinate high TDS produced water containing significant quantities of chloride salts. Substantial savings in CAPEX and OPEX are achieved by eliminating the chemical softening step and discharging the final solid product as a wet cake, which does not require any further drying in order to transport it to a disposal site. This results in a simpler flow scheme, less equipment to operate, and a smaller footprint. It also eliminates the cost of buying, shipping, storing, and handling of bulk chemical softening reagents and the dewatering, storage, transport, and disposal of softener sludge. The CoLD Process recovers all the water contained in the feed at a quality suitable for discharge under an NPDES permit or reuse.

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