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Produced Water Treatment Using Wetlands - Reducing The Environmental Impact Of Oilfield Operations

Dr. Roman Breuer, BAUER Nimr LLC; Ernst Grissemann, BAUER Nimr LLC

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Abstract

In order to reduce the environmental impact of produced water management a wetland system is being installed in the Sultanate of Oman. The facility will reduce the disposal of hydrocarbon polluted produced water into deep aquifers, recover hydrocarbons by means of an additional oil/water separation step and decrease the overall power consumption of the oil field operation by using a gravity flow system. During construction measures have been taken to reduce the impact by using only local materials for the installation of a sealing layer.

The project is currently in the commissioning phase and first result have shown that up to 60 bbl/d of crude oil were recovered, an overall a reduction of the power consumption between 1.2 and 1.8 Mio MWh can possibly achieved in the 20 years of operation and due to the installation of a mineral sealing layer the impact during construction could be reduced by 80 % for this element compared to the installation of an artificial sealing.

Introduction

In November 2008 Petroleum Development Oman (PDO) has awarded a Build-Own and Operate contract to implement a new and sustainable strategy of managing produced water in the Nimr Oil Field in the South of the Sultanate of Oman, the setup of the Nimr Water Treatment Plant (NWTP).

The Nimr Water Treatment Plant, which is based on a constructed wetland technology, is under construction since May 2009 and bound to be finally commissioned in January 2011 [5].

Currently the produced water from the oilfield is still managed through deep disposal wells [1]. In the year 2003 PDO committed phasing out shallow water disposal, leaving the oil producer with deep disposal options only [7]. Growing produced water quantities, new environmental regulations, the high power consumption for the operation of the existing deep disposal wells as well as maintenance requirements have initiated a search for new produced water disposal options in the Sultanate of Oman. Due to the influence of the environmental regulators the desire to replace the deep disposal wells has grown and PDO initiated pilot trails with wetlands [1, 2] proving the suitability for treatment and for commercial application.

Although the scope of the installation of the NWTP is still to manage a quantity of 45,000 m³/d produced water the tender process was influenced by environmental authorities requesting proposals to reduce the environmental impact of the oilfield operations. Therefore Petroleum Development Oman had integrated this request into the tender documents and the contractors had to provide technical concepts focusing on sustainable aspects.

The proposed and approved design, besides managing the produced water, was focusing on four major aspects to reduced the impact of the overall project: a, recovery of excess crude delivered to the facility instead of disposing it in deep wells; b, reduction of the overall energy requirements of the oil field operation by generating a gravity flow system; c, carbon fixture due to biomass growth in the wetland system and d, replacing high impact construction materials with locally available materials.

The facility is currently being commissioned, therefore theoretical calculations and first results shall be presented in this paper.

Technical Outline of the Project

A three stage process combining an Oil/Water Separator, a Constructed Wetland and a Water Evaporation and Salt Crystallization Facility has been designed to receive initially 45,000 m³ produced water per day [5].

The heart of the system is an advanced constructed wetland. Figure 1 shows an overall layout of the system starting with the incoming water pipeline, continuing with the three treatment units of the facility mentioned above. Main focus was to build a gravity flow system allowing the facility to operate with minimum external power requirement, see attached cross section (Figure 2) [5].

The Wetland or Reed Bed system will initially use common Reed (Phragmites australis) as the only plant species. In the future operation it is planned to evaluate additional local plant species to potentially enhance biomass production or better usability of the produced biomass. Currently the wWetland system consists of 24 wetland cells, divided in 6 tracks and 4 terraces (Figure 1) [5]. Starting with the initial inflow water level in the buffer pond each wetland terrace is divided by a level difference of minimum 50 cm up 95 cm maximum, depending on the local topography to ensure gravity flow of the water into a collecting channel. Thereafter the water is transferred into evaporation terraces for concentration and salt crystallisation.

Reduction of Environmental Footprint and Carbon Emission

The contract scope for the NWTP is to manage a quantity of 45,000 m³/d of produced water. However, the tender process was influenced by the local environmental authorities and Petroleum Development Oman in order to integrate sustainable concepts into the technical tender.

The proposed and approved design was therefore focusing on four major aspects to reduce the impact of the overall project: a, recovery of excess crude delivered; b, reduction of the overall energy requirements; c, carbon fixture due to biomass growth and d, replacing high impact construction materials with locally available materials.

Oil Recovery

The use of disposal wells implements that remaining hydrocarbons will be disposed off together with the produced water. This practice leads not only to the loss of product for the oil producer, but also to the pollution of aquifers with hydrocarbons.

With oil-in-water concentrations of 150 ppm in average and up to 1,000 ppm in peak times the inflow of crude oil into the NWTP will vary between 16,000 bbl per year and 107,000 bbl respectively at a crude density of 925 kg/m³.

Provided a recovery rate of the installed Oil/Water Separator of 90 % the amount of crude oil returned form the facility to the operator will be between 14,500 bbl and 96,000 bbl per year.

All recovered crude oil will be returned at a specified quality to the client PDO allowing the oil producer to recover approximately 0.04 US $/m³ of the paid water treatment fee if the estimated minimum quantity is achieved.

The Oil/Water Separator is currently under commissioning and therefore only initial results are available. In the first days of operation a recovery of up to 60 bbl within 24 hour was achieved. As no analytical data of inflow and outflow concentrations is available up to now the performance of the separator can currently not be determined. Online oil-in-water measurement for the inflow is under installation as well as mobile oil-in-water measuring devices for the outflow of the separator.

Gravity Flow System

Energy consumption has been identified as one of the most important factors during the design phase. The currently in use disposal wells are consuming between 3.6 and 5.5 kWh/m³ of disposed water [4]. Therefore the main focus was to reduce the energy consumption of the treatment facility down to almost zero. A gravity flow system was chosen to achieve a maximum reduction of energy used. Subsequently the selection of a suitable location allowing the installing of such a system without leading to a high level of earth movements was very important. This was achieved in coordination with the client who provided two possible locations.

In this paper the data for energy consumption within the facility will include the power consumed during operation for the instrumentation (flow metering), office and accommodation facilities (including water supply, air conditioning, kitchen, etc.) as well as the Oil/Water Separator and the complete Wetland, see Table 1. The salt facilities will not be included at this stage as the design parameters are not completed at this stage. All data presented represents calculated figures as operation is bound to start in January 2011 and no measured data is available as of today.

Table 1: Power Consumption NWTP during operation

Unit	kWh/d	kWh/m³
Instrumentation	1,000	0.02
Camp & Offices	3,000	0.07
Oil/Water Separator	0	0
Wetland (with gravity flow)	0	0
Wetland (with intermediate pumping)	(2,100)	(0.05)
Buffer	600	0.01
Total	4,600	0.10

Due to the level difference from the point of entry into the facility to the collecting channel, see Figure 1 and 2, of 3.6 m and level differences between the individual treatment steps of 50 cm to 95 cm gravity flow was achieved reducing the power requirements in the wetland down to zero. Main power consumers of the facility are therefore the infrastructure facilities such as the office and the instrumentation.

In a theoretical calculation it was additionally determined that a variation of the Wetland design considering intermediate pumping of the water from one treatment level to the other will increase the power consumption of the plant by approximately 50 %, Table 1. Therefore the assumption was made that the Wetland will be installed on an even ground level.

Comparing the power requirements of the deep disposal wells, a common waste water treatment plant and the Wetland system for the total operational period, see Table 2, the balance for power consumption and carbon emissions is clearly in favour of the Wetland system. Both are more than 50 times higher for the disposal wells. Therefore a reduction of carbon emission of almost 1 Mio tons can be achieved during the operation period of 20 years using the Wetland system.

Table 2: Compared Power Consumption for Disposal Options [4]

Disposal Options	Power required (Operation)	Total Power used in 20 years	CO_2 Emissions in 20 years
	kWh/m³	MWh	Tons*
Deep Well Disposal	3.6 - 5.5	1,180,000 - 1,800,000	Up to 975,000
Waste Water Treatment Plant	0.8	~ 260,000	~ 140,000
Wetland (with intermediate pumping)	0.15	~49,000	~ 26,600
Wetland (with gravity flow)	0.1	~ 32,850	~ 17,700

*calculated with 0.54 kg/kWh, common energy mix [8]

Carbon Fixture - Biomass Production

Reed Beds can achieve a yield of 4 to 44 t/ha of dry biomass per year [3]. For the location at Nimr a productivity above 40 t/ha was estimated, which potentially produces 9,360 t/a of dry biomass per year.

Second, the Reed Bed as a biological system is a sink for CO_2 by fixing carbon in the plant structures through photosynthesis, translating to a yearly fixture of 15,000 t CO_2 [4]. Test fields simulating the full scale implementation have been installed in February 2010 and first result for biomass productivity are expected for the same time in 2011.

Construction Measures

Due to the size of the project and the large quantities to be used it was necessary to develop a strategy to reduce the impact of the used construction materials. The project location is about 700 km away from the Sultanate of Oman's capital Muscat and immense logistic measures would have been required to install an artificial underground sealing such as a commonly used HDPE lining. Furthermore, the production of HDPE materials requires high input of resources. A special mineral sealing layer has been developed to replace HDPE liner systems and to use local available materials to reduce the environmental impact. Therefore laboratory studies have been conducted prior to the commencement of the project as the proposal had to be approved by the local authorities. Table 3 indicates the size of the project with 234 ha subject to the installation of an underground sealing.

For the buffer pond and collecting channel HDPE lining was chosen which still adds 155,000 m² installation with a higher impact. More than 2.6 Mio m³ of soil had to be moved for the project out of which almost 630,000 m³ were used for the sealing layer installation.

The laboratory studies indicated that the chosen sealing layer would provide sufficient permeability values for a 20 cm sealing layer or a 30 cm with a k_f-value of 1.0 x 10^{-7} m/s or 2.5 x 10^{-8} m/s respectively. Finally 20 cm have been approved by the client and the authorities. On site data in test fields and the already completed wetland cells have established a k_f-value of 1.3 x 10^{-7} m/s to 1.7 x 10^{-7} m/s on average.

Table 3: Summary of facility implementation

Facility	Total Area / Quantity
Wetland	2,340,000 m²
HDPE Lining	155,000 m²
Sealing Material	630,000 m³
Earth Movements (Cutting, Filling, Rock Breaking)	2,600,000 m³

Following the idea of reducing carbon footprint by reducing energy consumption and construction measures a carbon balance has been calculated comparing the installation of the used sealing layer with a HDPE lining system to prove the proposed and executed measures. Table 4 presents the relevant data for the installation of the mineral sealing layer, considering the total production chain starting with equipment mobilisation, production of material, transport on site up to the final installation of the sealing.

Table 4: Carbon Footprint - Mineral Sealing Layer Installation

Actions	Action Elements	Equipment	Records	kWh/m²	kg CO_2/m²
Mobilisation	Transport Muscat to Nimr (~ 700 km)	Low Bed Trailers	2 trips per equipment	0.30	0.09
Production of Sealing Material	Resourcing, Screening, Watering, Handling	Screening Plant Dozer, Loader Excavator, Grader Roller, Water Tanker	Diesel consumption per day Daily production ∅ 2,250 m³	4.52	1.29
Transport on site	Site Transport	Trucks	Total distance per truck/day	0.86	0.25
Water Supply	Water Wells Operation	Pumps & Generators	Diesel consumption per day	0.24	0.07
Installation	Spreading, Watering, Compaction	Grader, Water Tanker, Roller	Installation of ∅ 5,000 m²/d	0.78	0.22
Maintenance	30 % over all activities			2.01	0.57
TOTAL				**8.71**	**2.49**

*calculated with 1 Liter Diesel = 9.8 kWh = 2.8 kg CO_2 [8]

All values have been calculated using the actual on site average consumption of diesel and productivity by the used equipment adding a 30 % to the total figure for wear and tear as well as maintenance.

Furthermore the average figures for material production and layer installation with 2,250 m³/d and 5,000 m²/d respectively have been used for this calculation. With more than 50 % the resourcing of the material and secondlythe equipment maintenance contribute the most to a total of 8.71 kWh/m² installed sealing layer. Installation itself contributes with only 9 %.

Once the presented figures are compared with literature data [6] for the installation of an HDPE liner, Table 5, it is obvious that although the transport and installation of the HDPE liner on site has a lower impact than the sealing layer installation, the overall balance is in favour of the chosen technology. The sealing installation using local material totals to only 21 % of the impact caused by the use of the HDPE lining due to the high environmental footprint of the raw materials and the production of the material. Therefore this taken measure contributes significantly to the reduction of the environmental footprint of the project. Practically the installation of the mineral sealing layer totals to a carbon footprint of 1 Mio tons while the installation of a HDPE sealing layer would have resulted in a footprint of 5 Mio tons.

Table 5: Impact Comparison Mineral Sealing Layer – HDPE Lining [6]

kWh/m²	**HDPE Liner [6]**	**Mineral Sealing Layer**
Feedstock (raw material)	35.54	
Production	4.29	
Transport	0.42	
Installation	0.70	
TOTAL	**40.95**	**8.71**

Conclusions and Forecast

The presented project has the aim of reducing the environmental impact by clearly defined elements. The recovery of excess crude oil delivered to the facility is achieved by means of an Oil/Water Separator and initial data indicates a recovery rate of 60 bbl within 24 hours. Extrapolating this data an annual recovery of 14,500 to a maximum of 96,000 bbl could be achieved and the client PDO could recover approximately 0.04 US $/m³ of the paid water treatment fee.

Additionally a decrease in the overall power requirements for the produced water disposal is realised by a level difference of 3.6 m. From the point of entry into the facility to the collecting channel where treated effluent is transferred into an evaporation area gravity flow is achieved throughout the whole facility. Comparing the energy requirements of the facility with the currently operated deep disposal wells the Wetland system uses only 2 to 3 % of the power required. Thus a reduction of carbon emissions of almost 1 Mio tons is realised during the operation period of 20 years.

Finally replacing high impact construction materials such as HDPE lining with locally available soil materials gains an impact reduction by almost 80 % of carbon emission.

As the project is currently in the transition from the construction phase to the operational phase the presented data will have to be verified within the next couple of month with additional data.

Literature

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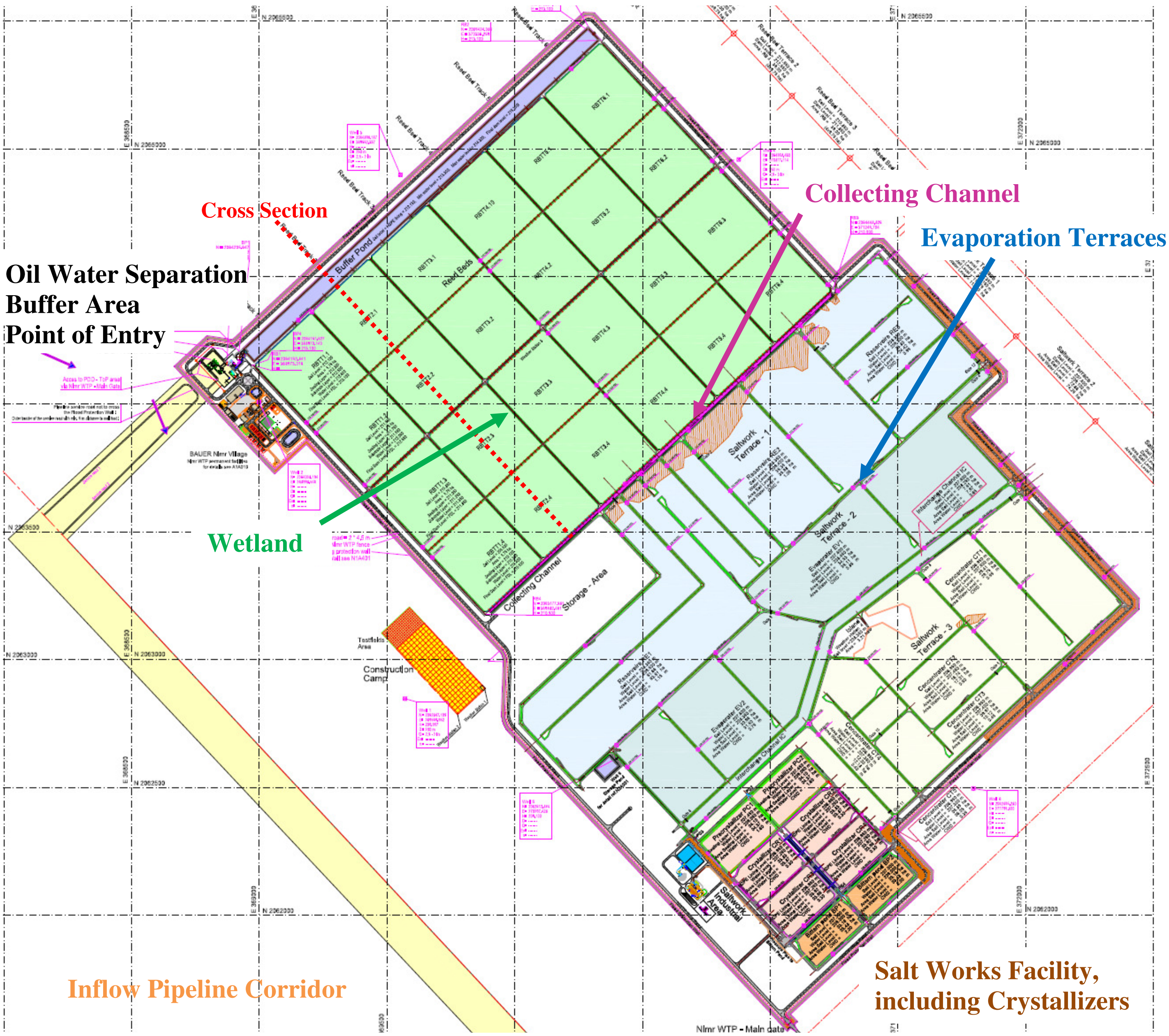

Figure 1: Nimr Water Treatment Plant – Design Overview

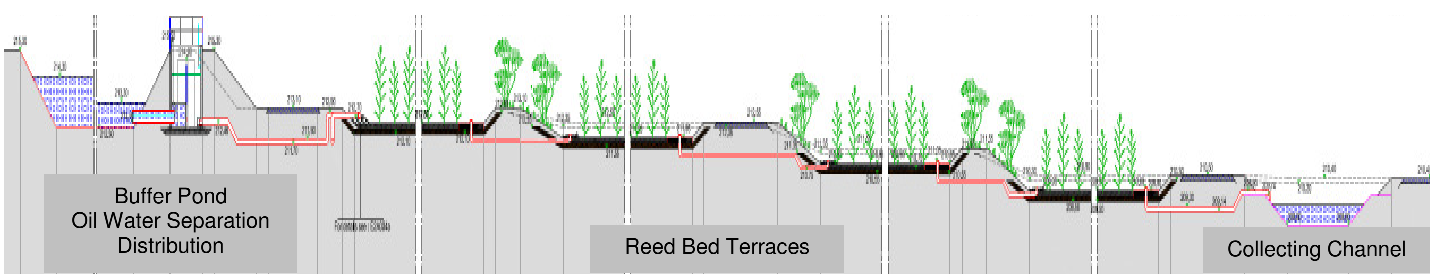

Figure 2: Nimr Water Treatment Plant – Reed Bed Cross Section