

Field-Proven Removal of Dissolved Hydrocarbons from Offshore Produced Water by the Macro Porous Polymer-Extraction Technology

D.Th. Meijer – Akzo Nobel MPP Systems bv

C.A.T. Kuijvenhoven – NAM bv (JV Shell/Exxon; Shell operated)

Copyright 2002

This paper was prepared for presentation at the 2001 Offshore Technology Conference held in Houston, Texas, 30 April-3 May 2001 (Amended for the 2002 Produced Water Seminar)

This paper was prepared for presentation by the OTC Program Committee following review of information contained in an abstract submitted by the author(s). Contents of the paper, as presented, have not been reviewed by the Offshore Technology Conference and are subject to correction by the author(s). The material, as presented, does not necessarily reflect any position of the Society of Petroleum Engineers, its officers or members. Papers presented at SPE meetings are subject to publication review by Editorial Committees of the Society of Petroleum Engineers. Electronic reproduction, distribution, or storage of any part of this paper for commercial purposes without the written consent of the Offshore Technology Conference is prohibited. Permission to reproduce in print is restricted to an abstract of not more than 300 words; illustrations may not be copied. The abstract must contain conspicuous acknowledgment of where and by whom the paper was presented.

Abstract

At the moment there are no field proven technologies available to remove dissolved hydrocarbons (aliphatics and mainly aromatics) from produced water on offshore platforms. Following a joined study of the NOGEP (The Netherlands Oil and Gas Exploration and Production Association) and the Dutch Government, the Macro Porous Polymer Extraction (MPPE) technology was selected from 55 technologies as one of the most promising. The MPPE process is removing the aromatics and aliphatics by an extraction process with the extraction liquid immobilized in the MPPE particles. The MPPE particles can be regenerated in situ with low-pressure steam. The NAM Business unit Offshore and Akzo Nobel MPP Systems performed a successful 4 month full-scale field trial with the MPPE technology on the L2 gas platform (50% unmanned) in the North Sea. The main objective was to prove that the MPPE technology could obtain a separation efficiency of >90% for aromatics and that it was robust and reliable enough to operate under Offshore North Sea winter conditions. The MPPE demo unit size with steam generator was restricted to fit into a standard 15 foot container treating produced water at the platform maximum flowrate of 12 gpm (2.7 m³/h), consisting mainly of equilibrium water and condensed overhead vapors from the glycol regeneration. This small unit realized removal efficiencies of 95 to 99.6% in aromatics with influent concentrations up to 200 mg/l. Aliphatics (2-4 mg/l) and poly aromatics (7 µg/l) were very close to detection limits of analytical equipment that was used, so for these components, only 50 to 75% removal could be observed. (Current commercial units and field tests show that >99% removal efficiencies can be obtained). The effect of an unexpected surfactant spill on the removal performance was negligible. The

availability was 95% due to minor mechanical problems in the steam generator and downtime due to handling and unmanned periods. Potable water consumption for steam generation was 3.5 kg/m³ treated effluent water. Initially preventive prefiltration showed filter lifetimes from 1 to 2 months. A 6 week operational period without prefiltration did not lead to a pressure drop increase over the MPPE bed.

The remote control facility with laptop and mobile telephone was a cost efficient and operationally effective tool, enabling quick response, remote shut down/start up and adaptations of process conditions.

Introduction

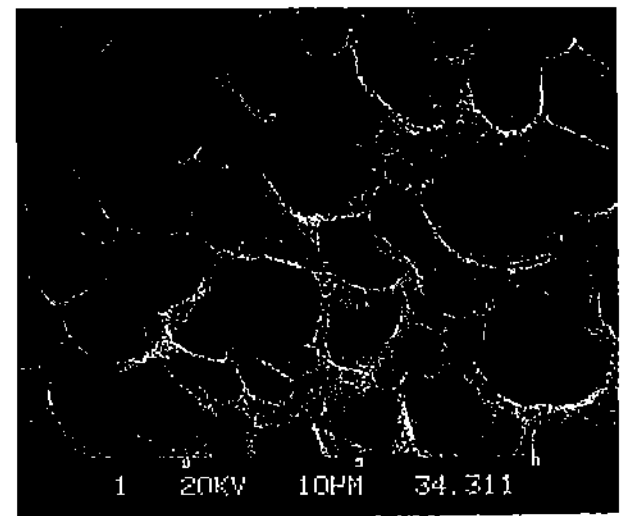


Figure 1: Internal structure of the Macro Porous Polymer

During the production of gas and condensate, water is co-produced in significant amounts. When producing gas offshore, this produced water is normally discharged into the sea. To minimize possible negative impact on the environment, maximum concentration limits have been defined for components, which may be present in the disposed water. In the United States waters, the EPA (Environmental Protection Agency) has established effluent limitation guidelines limiting oil and grease in produced water discharged into the sea as stated in the code of federal regulations: the monthly average should remain below 29 mg/l. Additionally, acute and/or chronic toxicity tests must be performed to determine the impact on aquatic life since toxicity incorporates all other pollutants.

There are four EPA regions that issue offshore general permits. Depending on the location of the

platform and the environment surrounding it, the produced water regulations may vary.

In the North Sea, significant work has been done to reach lower aromatic discharge to the sea. Despite considerable effort, the gas/oil producing companies have not been successful in obtaining the required reduction, mainly due to the lack of suitable and reliable technologies, which can be applied offshore. On request of the NOGEP, Stork Engineering Consultancy B.V. performed a study (ref. 1) into techniques for reducing heavy metals and aromatic hydrocarbons emission on offshore locations. Out of the 55 technologies, one of the most promising was found to be the Macro Porous Polymer Extraction process of Akzo Nobel. This was also recognized by the OSPAR (Oslo-Paris) Convention for the protection of the marine environment of the North East Atlantic who has listed the MPPE technology as Best Available Technology (BAT) for oil and gas produced water.

Based on the above study, the MPPE technique was subsequently tested by NAM Business Unit Offshore on one of their offshore platforms (L2) in the first half of 1999. This paper describes the reasoning behind the selection of the MPPE process for testing on the L2 platform and the subsequent performed field test with the MPPE unit. In addition, other experiences with the MPPE technology, related to offshore application, are discussed.

MPPE technology

The MPPE particles. A scanning electron microscopic (SEM) photograph of Macro Porous Polymer particles is shown in Figure 1. The porous polymer particles have a diameter of 1000 micron, with pore sizes of 0.1-10 micron and a porosity of 70 to 80%.

These polymers were initially developed as controlled release media for the pharmaceutical industry. The application in water treatment started in 1991. Initially, the macroporous polymer was used for absorbing dispersed oil from water, however that was not cost effective. Later, initiated by the oil and gas industry, the idea emerged to remove dissolved hydrocarbons from water. By the mid-nineties, Akzo Nobel developed a (patented) MPPE Technology consisting of an extraction liquid that remained immobilized in the pores of the MPP polymer and had a strong affinity for non-polar substances.

This request by the oil and gas industry was a logical development following their aim of reducing the emission of hydrocarbons in wastewater. Especially for offshore platforms, the removal of dissolved hydrocarbons is the main problem as these cannot be separated by gravity. The dissolved hydrocarbon concentrations in offshore discharged water can be in the hundreds of ppm while at the same

time the dispersed concentrations are meeting levels of 18 to 40 ppm (equal to current standards in the various regions in the world). Current gravity based separation techniques cannot reach lower dispersed oil levels because of small dispersed droplet sizes ($\leq 20 \mu\text{m}$).

The MPPE Process description. In the MPPE process, hydrocarbon contaminated water is passed through a column packed with MPPE particles (Figure 2).

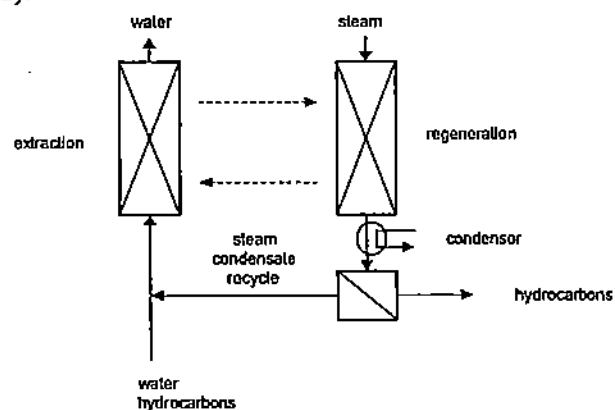


Figure 2: Schematic Overview of Macro Porous Polymer Extraction Process

The particles are porous polymer beads, which contain a specific extraction liquid. The immobilized extraction liquid removes the hydrocarbon components, which have a high affinity for the extraction liquid from the water. The purified water can either be re-used or discharged. Periodical in-situ regeneration of the extraction liquid is accomplished by stripping the hydrocarbons with low pressure steam. The stripped hydrocarbons are condensed and then separated from the water phase by gravity. The practically 100% pure hydrocarbon phase is recovered, removed from the system and ready for recycle or disposal. The condensed aqueous phase is recycled to the system. The application of two columns allows for continuous operation with simultaneous extraction and regeneration. A typical cycle consists of one hour extraction and one hour regeneration.

Applicability. The components that can be removed with this MPPE technique need to have an affinity (i.e. partition coefficient) for the extraction liquid compared to water in order for extraction to occur.

Examples of these hydrophobic components include aliphatic, aromatic (BTEX), polyaromatic and halogenated hydrocarbons such as chlorinated hydrocarbons.

The removal efficiency that can be realized with MPPE is very high, as a result of the high number of mass transfer stages in the packed bed (high specific area for mass transfer) and in-situ separation of

extraction liquid and purified water. Removal efficiencies up to 99.9999% (concentration reduction factor of 10^6) have been achieved in both pilot and full-scale units.

Some examples are presented in table 1.

Table 1: Examples of components removable with an MPPE system

Aromatic and Aliphatic Compounds	Halogenated/ Chlorinated Compounds	Polyaromatic Hydrocarbon
Benzene	Monochloromethane	PCBs
Toluene	Dichloromethane	Naphthalene
Ethyl Benzene	Trichloromethane	Acenaphthylene
Xylene(s)	Tetrachloromethane	Acenaphthene
Cumene	Dichloroethane (1,1 & 1,2)	Fluorene
Limonene	Trichloroethane	Phenanthrene
Nitrobenzene	Tetrachloroethane	Anthracene
Cresol(s)	Chloroethylene	Fluoranthene
Dimethylphenols	Dichloroethylene	Pyrene
Ethylphenols	Trichloroethylene	Benz(a)anthracene
Octanol	Tetrachloroethylene	Chrysene
Nonanol	Trichloropropane	Etc.
Decanol	Chlorobutadiene	
Hexane	Hexachlorobutadiene	
Heptane	Monochlorobenzene	
MIBK	Dichlorobenzene	
TetraHydroTiophene	Chlorobenzenes	
CS ₂	Chlorophthalene	
Tetramethyltetrahydr ofuran	Hexachlorocyclohexane	
Etc.	Monochlorophenol	
	Dichlorophenol	
	Trichlorophenol	
	Dichloro-di-isopropylether	
	Dioxins	
	Etc.	

Offshore produced water

Produced water composition. When producing a gas field, the composition of the produced water will depend on its origin:

- Formation water originating from the produced reservoir below gas/water contact
- Connate water present around the formation in the gas reservoir
- Equilibrium water condensed from the gas phase due to pressure and temperature changes. While producing the gas, the formed water is being mixed with the liquid hydrocarbon phase (being a mixture of different organic components such as longer alkanes, aromatics and polycyclic aromatics). In general, water and the hydrocarbon phase are immiscible, but various components (e.g. aromatics such as Benzene, Toluene, Ethyl benzene and Xylene) are dissolved in the water phase and can reach up to levels of 1500 ppm (or more). Additionally, the separated water phase will contain minor quantities of the immiscible hydrocarbons (mainly aliphatics) in the form of droplets with a size between 1 and 10 micron.

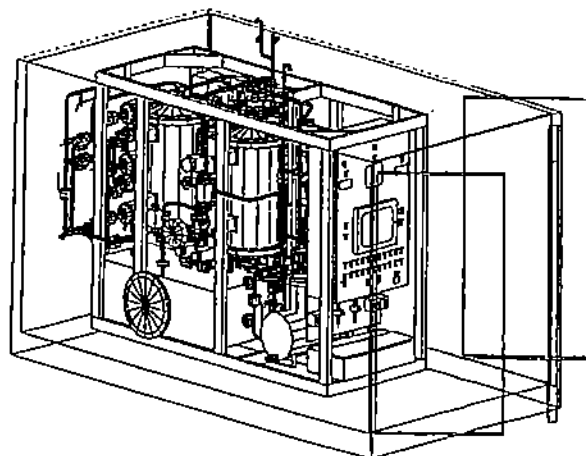
Removal methods. To reduce the volume of aromatics in the discharged water three different approaches can be used:

1. Avoid water production from the well;
The production of formation water and connate water may be controlled, but equilibrium water due to condensation will always form at surface.
2. Water injection back into the well;
After surface separation of the water and the hydrocarbon phase, the water is not discharged into the sea, but feedback to a formation below the surface. This technique is only possible when a well is available for disposing the water.
3. Removal of hydrocarbons from the water;
This can be done at several places, from the well bottom, up to the end of the system where the water is discharged overboard. The removal technologies of the dispersed phase are normally based upon gravitational force and are widely used in the gas and oil producing industry. The removal techniques for aromatics are more complex and are hardly applied in the offshore oil and gas industry.

MPPE unit The unit was delivered to the L2 platform in a 15 foot container (4.60 m long, 2.40 m height and 2.40 m width) with a total weight of 7 tons.

The MPPE process was controlled by a Siemens S5PLC process controller. Using the software package FIX intellution, it was possible to visualize the status of the process and to intervene in the process. In combination with another software package, pcAnywhere, and a telephone line suited for data transport, remote operation of the installation was done from an onshore location in the Netherlands.

For pre-filtration, three 3M 743B elements were used, since these filters have a high dirt holding capacity and high surface area per filter element. The filter elements claim to have a separation efficiency of 99% for particles of 2 micron.



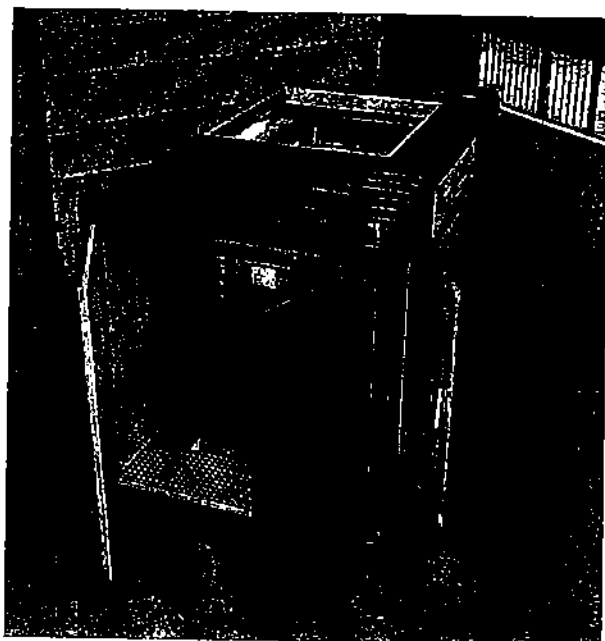


Figure 3: Demo unit

Experimental set up

One of the conclusions of the joined NOGEP A Dutch Government study was that the MPPE technology is one of the most promising technologies, however there was no real offshore experience thus far. Therefore, NAM decided to test this technology offshore for four months on separation performance for aromatics, operational robustness, reliability and attention, and utility requirements.

The L2 platform was selected for the tests because 1) it contains a high concentration of aromatic hydrocarbons in the overboard water 2) absence of suitable injection wells and 3) it creates the ability to fully evaluate the remote operating system of the MPPE unit as the L2 platform is a cyclically manned facility (50% of time unmanned).

The L2 water treatment process. Gas is produced on the L2 platform. When pressure and temperature decrease, equilibrium water and condensate are formed, which are separated in the high-pressure production separator. After drying the wet gas in the glycol system, the dry gas is transported to the Den Helder treating plant. The production water and the

condensed water from the glycol regeneration are degassed in a flash vessel before separation takes place in a skimmer/vessel (figure 4).

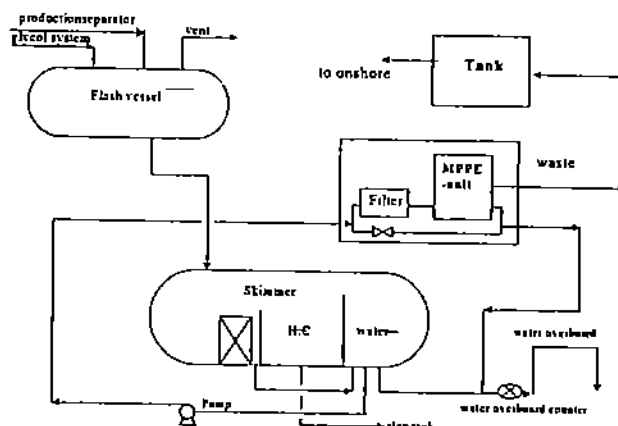


Figure 4: Scheme of liquid production at L2 platform, including MPPE tie-in

The water is discharged overboard and the condensate is stored in the slop tank from where it is shipped to shore. The overboard water, approximately 12 gpm (2.7 m³/hr), is contaminated with aromatics (mainly BTEX) up to a level of 200 ppm and dispersed hydrocarbons (mainly aliphatics) up to a level of 5 ppm. Because only equilibrium water is produced, the salt content is below 1000 mg/l. On the platform, no production chemicals such as corrosion inhibitor or demulsifier are being applied.

Positioning MPPE in the process water treatment. The influent of the MPPE process is taken from the third compartment of the skimmer vessel. This stream is filtered before treatment in the MPPE unit. Depending on the level in the third compartment of the skimmer vessel, effluent is mixed with the influent or discharged as overboard water. The back mixing of the effluent results in a lower concentration of organics in the influent.

Additional testing parameters. The main objective of the test with the MPPE unit was to prove that it could remove aromatics on an offshore location. Once the unit was operating at the expected removal efficiencies (at least above 90 wt%), it was further optimized:
Steam consumption: By reducing the amount of steam used when heating up or regenerating the columns, the amount of potable water was reduced to determine the minimum quantity required while not effecting the performance of the unit.

Solids filters: Because of the solids in the overboard water (maximum 10 mg/l), pre-filters were installed to avoid blockage of the MPPE bed due to accumulation of solids. During the last six weeks of the testing

period, a pre-filter was not used to see whether it was necessary on the L2 platform.

Results

In the period from February 4 to May 27 1999, seven runs were conducted with a total runtime of 2332 hours. The total downtime was 355 hours (15%) of which only 37% was directly contributed to problems with the MPPE unit. The length of the downtime was mainly determined by time concerning travelling/scheduling and not the time it takes for solving the problems. In table 2 the downtime is further specified.

Table 2: Downtimes during MPPE field test

Run	Downtime hours	Description
1 → 2	79	Malfunctioning of the level probe steam generator
2 → 3	4	Preventive maintenance level probe steam generator
3 → 4	38	Power failure platform
4 → 5	160	No overboard water
5 → 6	26	No overboard water
6 → 7	48	Circulation pump thermal overload

Pre-filtration. The pre-filter was installed to remove solids from the influent to prevent the MPPE beds from blocking. Typical solids concentrations during the test period were 1 to 3 mg/l. Only during a one-week period in March, the solids level was as high as 10 mg/l. The pressure drop across the filter elements increased slowly from 0.1 to 0.2 bar at the start, then 0.5 bar after 350 to 500 hours and 0.9 bar after 700 hours runtime. The filter elements can be used up to a pressure drop of 2 bar. Based on the results, the lifetime of three parallel elements is expected to vary between 1 and 2 months.

For a period of six weeks the MPPE unit was operated without pre-filtration. During this period, no significant increase of the pressure drop over the MPPE bed was measured: typically the pressure drop was 0.05 bar at a flow of 12 gpm. Based on these test results, considerations should be given to install coarser filter elements in order to reduce the filter consumption (and the costs!).

Steam consumption Steam is required during heating up (short period with relatively high steam rate) and regeneration (long period with relatively low steam rate) of a "loaded" column. After optimization, the total cycle time was increased from 90 to 140 minutes with a decrease in steam consumption from 16 to 9.5 kg/h (0.4 to 0.25 m³/day). This means 5.9 to 3.5 kg water per cubic meter treated water for steam production. When the steam consumption was further

reduced to 7.5 kg/h (2.8 kg per m³ water), the aromatics removal efficiency deteriorated 50% due to incomplete regeneration.

During the test on the L2 platform, low-pressure steam was produced from potable water. The total hardness of the water was 1.6 mmol/l, which is normal for this type of water. During the testing period the level probe of the steam generator malfunctioned due to scaling. In time the heating elements will also be affected by scaling. Therefore for future operation it is recommended to use demineralized water for the production of steam.

Power consumption. The MPPE process on the L2 platform had an installed power of 50 kW, compared to an average consumption of 15 kW during the course of the trial.

Off gas ventilation system. During the L2 MPPE test, effluent water was used as coolant for the condensed liquids. The effluent temperature was approximately 91°F (33°C). At this temperature, the aromatics have a relatively high vapor pressure resulting in off gases coming from the water/condensate separation system. To minimize emission (< 1l/day) of (vaporized) organic components, a small amount of activated carbon should be installed in the off gas vent line.

MPPE performance

The water samples taken to monitor the performance were analyzed for dispersed hydrocarbons (aliphatics), aromatics and polycyclic aromatics in order to determine the removal efficiencies for hydrocarbons normally present in the overboard water. Additionally heavy metal analyses were performed to establish any removal of these components.

Aromatics removal. Aromatics have been measured using two different analysis techniques:

1. The total amount of aromatics using extraction with freon and analyzing with the triple peak infra-red method (according to NEN-6675).
2. Measurement of the individual aromatics (BTEX) using the gas chromatograph.

The average of the NEN-6675 analysis: influent 150 mg/l with standard deviation of 40 mg/l. Effluent 6 mg/l with standard deviation of 4 mg/l.

The individual analysis results of the BTEX components are shown in figure 5. The 20th of April shows a reduction in the removal efficiency of all BTEX components, which may be explained by the minimum steam flow used. On the 7th of March, an AFFF (surface active component) spill occurred due to the fire alarm on the L2 platform. Via the closed sump, AFFF flowed through the MPPE unit and caused foaming in the unit. The BTEX analysis performed two days later shows only marginal effect.

Average removal efficiency for aromatic (dissolved) hydrocarbons was above 95 wt%.

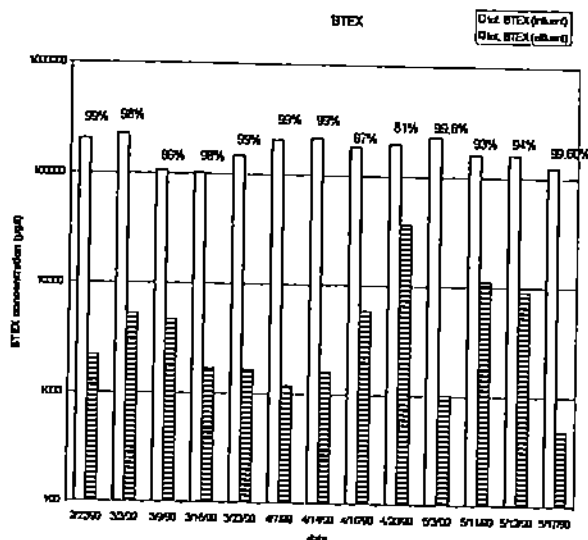


Figure 5: BTEX removal (log scale) during MPPE test on L2 platform

Dispersed (aliphatic) removal. The dispersed hydrocarbon content has been measured using extraction with freon and analyzing with the modified triple peak infra-red method (using only two of the three peaks according to modified NEN-6675).

The average of the NEN-6675 mod analysis: influent 4 mg/l with standard deviation of 2 mg/l. Effluent 2 mg/l with standard deviation of 1 mg/l.

Average removal efficiency for dispersed hydrocarbons was 50 wt%. Note: the measured concentrations for the dispersed hydrocarbons are relatively low and are near to the detection limit of the analysis method. Additional field tests with the MPPE are required to determine the removal efficiency of dispersed hydrocarbons with higher inlet concentrations (commercial and field test applications performed later show that >99% removal of aliphatics can be obtained).

Polycyclic aromatic hydrocarbon (PAH). The total PAH concentration in the water produced from the L2 field was found to be low: total concentration 5 to 7 µg/l consisting of mainly naphthalene (4.5 to 6.5 µg/l). The average removal efficiency was 72% with the lowest values on 7th of March (effect of AFFP spill) and 20th of April (not enough steam used). Note: the MPPE unit was designed to remove aromatics only. In order to obtain higher removal of PAH, the design can be adjusted. (Commercial and field test applications performed later show a >99% removal for PAH's).

Heavy metals. The following heavy metals were analyzed in the influent (Table 3):

Table 3: Heavy metal concentrations

Heavy metal	Concentration range	Heavy metal	Concentration range
Arsenic	Below detection limit 4 µg/l	Lead	Below detection limit 3 µg/l
Cadmium	Below detection limit 0.2 µg/l	Mercury	0.3 to 4 µg/l
Chrome	3 to 30 µg/l	Nickel	5 to 35 µg/l
Copper	2 to 17 µg/l	Zinc	40 to 180 µg/l

A mercury reduction was found in the effluent of the MPPE unit (average 68%). This could mean that mercury:

- evaporates and leaves the unit via the vent line;
- is bonded to the polymer particles of the bed and is not removed by the extraction step;
- is bonded to the material (carbon steel, RVS) of the installation.

This phenomenon needs further attention in future operation.

Other Influent parameters

Salt. Dissolved salt will flow through. The salt content in the NAM test is below 1000 mg/l but also at higher concentrations, salt will not weaken the removal efficiency. Contrary, in lab tests it has been shown that high salt content even improves removal efficiency.

Surfactants. Surfactants were not specifically tested, but an unexpected surfactant spill did not show a negative effect on the performance. Generally corrosion inhibitors and other surfactants in practice will flow through (as proven in DNAPL removals described in the paragraph: other industrial applications). However, they can be partly removed depending on their polarity. Experiences over five years in practice and field tests have shown the robustness of the MPPE technology against surfactants.

Other Technologies for produced water treatment

In 1999, Total Fina Elf E&P Nederland made a comparison between the MPPE technology and steam stripping. This comparison was based on their own steam strippers, installed in two platforms in the North Sea²) and an MPPE unit treating offshore produced water onshore in their Harlingen gas treatment plant³). This MPPE unit is treating produced water from the well and the condensed overhead vapors from the glycol regeneration unit at 18 gpm (4 m³/hr). Benzene concentration levels of approximately 1500 mg/l with spikes of 3000 to 5000 mg/l are reduced to 0.1 mg/l. The column size is 6.6 ft (2 m) high and 2.6 ft (0.8 m) in diameter. The Harlingen unit has been in operation since 1994 and is shown below in Figure 6.

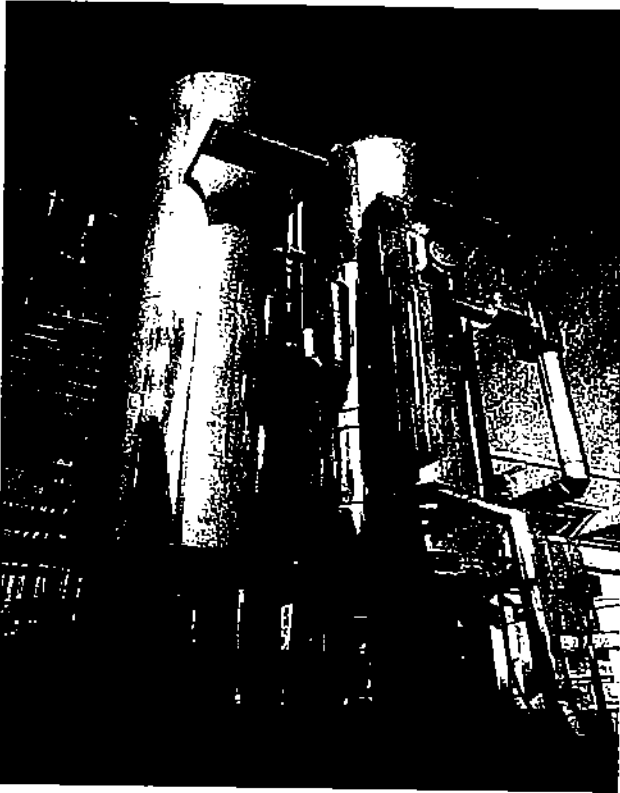


Figure 6: The dual-column MPPE system is sized for the project-specific combination of flow and removal requirements.

This comparison showed that the MPPE technology is 60% lower in Capex and 30% lower in Opex. The latter is a.o. due to the lower energy costs for steam generation. For a steam stripper generally approximately 100 kg steam is consumed per m³ water treated. In the NAM field-test for MPPE, 3.5 to 6 kg steam is needed per m³ water treated.

Apart from the study of the NOGEPa and the Dutch Government, the MPPE technology has also been verified by the Orkney Water Technology Center for treatment of offshore produced water from oil and gas production. These tests, carried out on request of various Oil & Gas companies showed a consistent removal of dissolved and dispersed hydrocarbons from levels of 400 mg/l⁻¹).

Other Industrial applications

The unit at Total Fina Elf E&P Nederland was the first industrial application of the MPPE technology. Ever since 1994, 18 industrial applications have been implemented in the United States, Netherlands, Germany and France, and more than 50 successful onsite field-tests (on and offshore) with mobile MPPE units have been carried out.

Of the current applications, 60% are in process water and/or waste water and 40% are in groundwater.

In the latter application, MPPE has been proven to be very well suited as a separation technique in DNAPL (Dense Non Aqueous Phase Layer) removal ((Alameda California⁵),⁶). DNAPLs consist of heavy chlorinated compounds heavier than water with very low solubility, requiring decades of pump-and-treat to be removed. By adding a surfactant to the groundwater, solubility can be increased from a few mg/l to 50,000 mg/l. MPPE has proven in practice to reduce these influent concentration levels by 95 to 99%. In this way, decades of treatment can be reduced to months or one to two years. This factual experience is very important also for offshore applications where often surface active chemicals such as corrosion inhibitors, oil/water separation chemicals are being used.

The successful test on the L2 platform of NAM has attracted the attention from oil & gas companies worldwide and has resulted in further requests for quotations and field-tests in other oil & gas field areas as well. Many of these initiatives are driven by internal targets of oil & gas companies anticipating more severe environmental regulations especially on dissolved (and dispersed) aliphatics, aromatics and polyaromatics. Publications on the latter components indicate the danger of accumulation in the sea environment (e.g. fish).

Conclusions

- The main objective was to realize a more than 90% removal efficiency for aromatics by the MPPE Technology under real life offshore conditions. The MPPE unit, designed to extract dissolved (aromatic) hydrocarbons from overboard water, was found to perform well (according to expectations) in a 4 month field trial on the L2 offshore location. The reduction of aromatics in the overboard water was found to be more than 95 wt% with variations up to 99.8% removal. The column size was restricted to make the unit fit in a container, so higher removal efficiencies could not be achieved at a water flowrate of 12 gpm. However it is clear that aromatics can be removed with MPPE to any level specified.
- The reduction of dispersed (aliphatic) hydrocarbons was about 50 wt% (influent concentration 2 to 4 mg/l). However real removal efficiencies could not be assessed for these components due to the 50% standard deviation in analytical measurements as the given influent and effluent levels were close to the detection limit. (In practice it has been proven in other cases that aliphatics can be removed > 99%).
- In the 4 months of operation, 7 runs were conducted with a total runtime of 2332 hours and a total downtime of 355 hours (15%). From the total downtime only 37% could be contributed to the MPPE unit, so the availability was >95% including downtime due to travelling and unmanned periods.
- The MPPE process installed on the L2 platform had an average power consumption of 15 kW. The steam consumption under standard operating conditions was 16 kg/h (0.4 m³/day; 5,9 kg/m³ treated water). By optimizing the MPPE process this value could be reduced to 9.5 kg/h (0.25 m³/day; 3.5 kg/m³ treated water).
- Based on the results, the lifetime of the three parallel installed filter elements (99% removal of 2-micron solids) was estimated between 1 and 2 months. Consideration should be given to install coarser filter elements to increase the lifetime of the filter elements.
- The pressure drop over the MPPE bed when applying pre-filtration is typically 0.05 bar at a flow of 12 gpm. Operating the MPPE process without pre-filtration for 6 weeks did not result in an increase of the pressure drop over the MPPE bed. Nevertheless, preventive filter capacity should be installed to be prepared for changes in the solid concentration in the future (MPPE bed lifetimes in commercial units vary from 1.5 to 4 years).

- The remote control facility was a cost efficient and operationally effective tool, enabling quick response, remote shut down/start up and adaptation of process conditions.
- Turndown-ratio in the waterflow is from 20% to more than 100% of installed flow capacity.
- The unit is flexible in operation. If influent concentration increases by 50% of the initial specifications, then the designed effluent concentration can still be reached with only a 10% flow reduction. At lower influent concentrations, higher flows can be applied while maintaining the effluent requirement.
- The MPPE technology proved its robustness against surfactant spills.

Acknowledgement

The authors wish to thank the operational staff of the L2 platform and Messrs. A. Hagens (NAM bv), J.H.M. Jacobs, J.P.C. de Ruiter, E.L. Middelhoek (all Akzo Nobel MPP Systems bv) for their contribution to the experiments and the preparation of this paper.

References

1. NOGEP (Netherlands Oil and Gas Exploration and Production Association) and Dutch Government by C.C.R. van der Kaa & B. Petrusseki; Stork (1998). Inventarisation of removal techniques to reduce the benzene/heavy metal emissions from offshore platforms (in Dutch). Report 61944-00-32-301-2
2. Kloppenburg, M.F.C. and Venema, W.: "De-oiling condensed glycol regenerator overhead vapors by steam stripping", SPE paper nr 37846 presented at the 1997 SPE/UKOOA European Environmental Conference, Aberdeen, 15-16 April 1997.
3. H.M. Pars/Elf Petroland bv & D. Th Meijer/Akzo Nobel nv. Removal of dissolved hydrocarbons from production water by Macro Porous Polymer Extraction (MPPE). SPE 46577. SPE International Conference on Health, Safety and Environment in Oil and Gas Exploration and Production held in Caracas, June 1998.
4. ERT/Orkney Water Technology Center : The removal of dissolved and dispersed organic components from produced water. ERT F92/178, 1997.
5. Hasegawa, M.H. (2000). Surfactant-enhanced subsurface remediation of DNAPLS at the former Naval air station Alameda, California. Proceedings International Conference on Remediation of chlorinated and recalcitrant compounds, May 22-25, 2000 Monterey, USA.
6. J.T.M. Sluys and P.E. Brooks. MPPE in surfactant enhanced DNAPL remediation. Book of abstracts of the International Congress on Implementation of in-situ Remediation Techniques in Utrecht, The Netherlands October 2000.