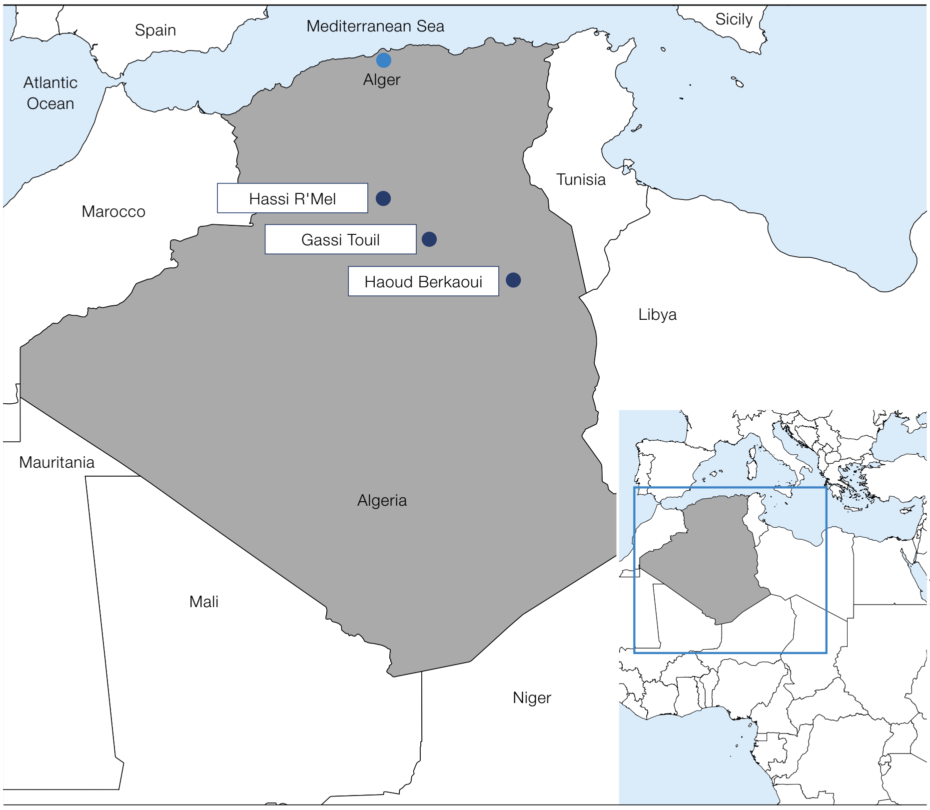
Untroubled waters

A flexible, compact and efficient solution for oil and water separation technology

MARCO APICELLA, NUNZIO BONAVITA, PAOLO CAPELLI, RAIMONDO CIANFRUGLIA – Produced water is oily wastewater that is co-produced during oil and gas production and whose management constitutes a major challenge in environmental terms due to its highly saline nature. Produced water is essentially water trapped in underground formations that is brought to the surface along with oil or gas. It is by far the largest volume byproduct or waste stream associated with oil and gas production. Management of this produced water presents considerable challenges and costs to operators [1] and disposal of produced water can be problematic in environmental terms due to its highly saline nature.

1 Locations of the water de-oiling plants



Oily wastewaters constitute a major environmental problem in many industries [2]. Metal, textile, automotive, petrochemical and aeronautical industries are affected by this problem. Conventional treatment of process effluents typically involves a combination of physical, chemical and biological processes. In addition to formation water, produced water from gas operations also includes condensed water and has a higher content of low molecular-weight aromatic hydrocarbons such as benzene, toluene, ethylbenzene and xylene (BTEX) than those from oil operations; hence they are relatively more toxic than produced waters from oil production. Studies indicate that the produced waters discharged from gas/condensate platforms are about 10 times more toxic than the produced waters discharged from oil platforms [3].

Standard oily wastewater remediation relied for decades on API 650 for oily wastewater separation (OWS) treatment. OWS uses gravimetric lagoon separation, then reprocesses the recovered floatable oil portion and uses holding-pond clarification of the wastewater portion before "land-farming" discharge, which led to substantial groundwater and air pollution. OWS certainly can't be expected to meet the more stringent requirements of modern environmental regulations, or be deployed for remote sites as a package treatment plant option.

Various new configurations of separation technology have expanded oily wastewater treatment options; everything from hydro cyclones to coalescing plate filters, and even the use of ultra filtration to separate and concentrate the individual waste streams. Oily wastewaters can be generally separated into oil and aqueous phases by gravity separation, using either the API separator, or a parallel-plate separator. The surface oil can then be skimmed off by various devices. Air flotation can also be used for the more difficult separations, or where better performance, or more rapid recovery is required. Chemical additives may be used in air flotation to improve separation. Ultrafiltration is an important technology employed to clean up the wastewater to make it suitable for discharge into municipal sewers and provide an oily concentrate rich enough to support combustion.

While these methods offer a good process response through a wide range of flows, and can meet typical 100 mg/l total hydrocarbon cleanup regulations, they are incapable of meeting proposed European environmental protection legislation, and also risk non-compliance with the ATEX Directive for processes operating in explosive environments [4].

Moreover, none of these filtration methods are capable of treating the produced wastewater for removal of heavy metals, COD, nitrogen and phosphorus without more advanced treatment processes, such as chemical precipitation, air strip-

The management of oily wastewater constitutes a major challenge in environmental terms due to its highly saline nature and the often demanding environments where it is produced and processed.

ping, chemical oxidation, or activated carbon adsorption. Again, these advanced processes generally cannot be deployed for remote sites as a package treatment plant option and all produce a toxic concentrate or sludge requiring further treatment or disposal as special waste.

Water de-oiling plants

From 2000 to 2006 ABB has built and studied in North Africa water de-oiling plants in three different locations → 1:

- Three plants in the Hassi R'Mel region (total of 3,400 m^3/day).
- Three plants in the Haoud Berkaoui region (total of 4,800 m^3/day).
- One plant in the Gassi Touil region (total of 2,400 m^3/day).

Construction of these seven plants has been performed by ABB in partnership with SARPI (joint-venture ABB/Sonatrach).

After handover, the plants were operated and maintained locally until 2007 when, because of a change in policy, it was decided to outsource the related services.

ABB and SARPI were selected to perform both operation and full service activities for a period of five years on the following four water de-oiling plants:

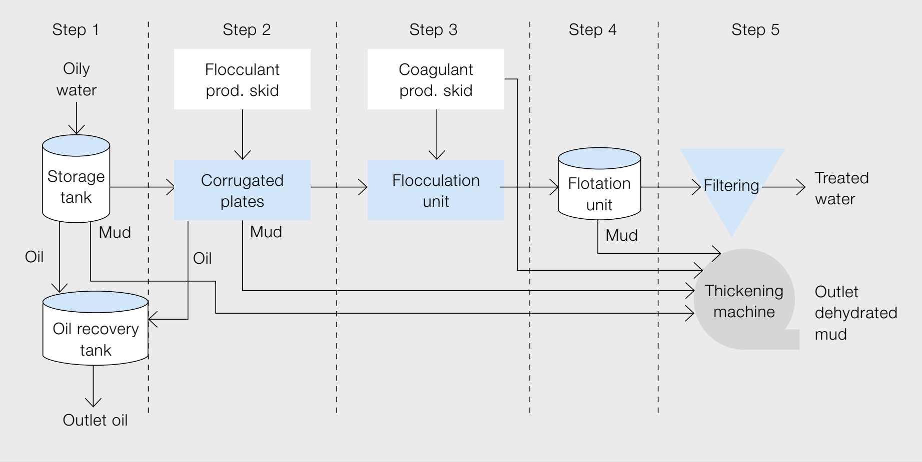
- Three plants in the Hassi R'Mel region since March 2009.
- One plant in the Gassi Touil region since February 2009.

The three water de-oiling plants located in the Hassi R'Mel region are named "North," "Central" and "South" based on their relative geographical location.

The largest is the Central plant with a daily treatment capacity of 2,400 m^3/day, while the other two are significantly smaller with a treatment capacity of just 500 m^3/day.

The plant in Gassi Touil has the same capability as the Central plant in Hassi R'Mel and was built in the same period (start-up in 2001) while the two smaller units, North and South, had their start-up in 2006. Both the Gassi Touil and the Hassi R'Mel Central plant underwent a major revamp in 2008 as part of the present project, in order to improve both their effectiveness and efficiency.

2 Oily water treatment schematic



Process technology

Schematically it is possible to distinguish three separate treatment cycles:

- Water: Water coming from existing oil & gas production plant, which contains hydrocarbons and solid particles in suspension, is collected in a storage tank. The water is passed through a corrugated plate interceptor (CPI) and then to a flocculation unit, where specific chemicals (flocculant and coagulant) are added. Water is transferred to a flotation unit and the cleaned water is passed through a filter unit before underground injection.
- Oil: Floating hydrocarbons on the surface inside the storage tank and the CPI are recovered by oil skimmers (disc-oil) and collected in a recovered oil tank before being sent to the client's oil production unit.
- Mud: Flocculant masses (flocs) developed inside the CPI and the flocculation unit are sent to the flotation unit. Flocs grow until they become mud, which is recovered by the scraper inside the flotation unit and sent to the thickening machine. Mud collected at the bottom of storage tank, flotation unit and flocculation unit are also sent to the thickening machine.

The water treatment process is similar for Hassi R'Mel, Gassi Touil and Haoud Berkaoui plants and it consists of five main phases shown in figure → 2:

During the storage phase, lighter hydrocarbons collect on the surface of the water in tank S-101 and are recovered by oil skimmer (disk-oil) before being sent to recovering oil tank S-108. The

Traditional mechanical filtration is enhanced by chemical filtration where sand grains become coated with the chemical additives.

3 Hangar H-101 (Hassi R'Mel)

The solution utilizes easily available cheap base ingredients, a feature which is highly advantageous in desert areas.

water is transferred to the CPI S-102 in order to perform the physical separation of water and hydrocarbons. Specific flocculant is added to water inside the CPI in order to produce flocs that grow until they become mud, so facilitating the recovery of hydrocarbons and solid particles. The third phase happens in the flocculation unit S-103 where a specific coagulant is added to water inside S-103, in order to remove colloidal material.

From flocculation unit S-103 water is transferred to flotation unit S-104, where compressed air is injected, causing very fine air bubbles to collect on the flocs and raise them to the surface of the water. The floating solids are recovered by scraper and sent to thickening machine S-105. The treated water then follows different paths depending on the plant:

– At the Gassi Touil and Haoud Berkaoui plants, treated water is transferred to an external basin where it evaporates.
– At the Hassi R'Mel plant, treated water passes through a filtering unit before being injected underground.

The fifth and last phase is solid thickening and drying where collected solids from flotation unit S-104, mud from storage tank S-101, and solids from the CPI and from flocculation unit S-103, are agglomerated and centrifuged. The resulting centrifuged mud is stored in an external area.

Challenges

Tackling water treatment in these specific cases has been particularly challenging. The authors went through extensive research and testing activities, with trials of a large number of commercial products commonly used for oily and industrial waters, but without reaching fully acceptable results.

However a novel stoicheiometric formulation of traditional products achieved surprisingly good results and gave indications about the best directions to be followed. Additional experiments resulted in the design and realization of a skid-mounted device, which is able to automatically process and prepare the additive in the optimal doses, starting from raw materials that are also available in these developing regions.

The filtration phase has also been improved because water entering the filters is mixed with the same additive. This way the traditional mechanical filtration is enhanced by chemical filtration where sand grains become coated with the chemical additives.

Finally the process is flexible enough to allow further tailoring to the specific plant features and/or needs. In our experi-

4 Operational activities at the plants

- Periodical process parameters checks (on site and in control room).
- Recording and analysis of process parameter values and trends.
- Plant management according to process parameter trends, ie, opening/closing control valves adding/reducing chemical additives, etc.
- Visual checks of equipment and instruments.
- Preliminary diagnosis of incorrect running, ie, abnormal noise, abnormal vibration, abnormal temperature, etc.
- Recoding consumption and refilling of chemical additives.
- Putting equipment into a safe condition before starting maintenance activity.
- Planned equipment shutdowns and startups.
- Coordination with maintenance personnel and laboratory technician.

5 Water quality results for Hassi R'Mel Center de-oiling plant

	Units	Inlet water	Outlet water	Acceptable values after treatment
Hydrocarbon concentration	mg/kg	278.90	0.70	5
Suspended solids concentration	mg/kg	11.05	0.34	20 (SiO_2)
Filtration degree	µm	>> 5	< 5	5

ence, the capability to understand and adapt to water and environment specific challenges is no less important than the underlying technology.

Advantages

The innovative approach and equipment are currently patent-pending and present the additional advantage of being relatively cheap and potentially able to significantly remove heavy metals through an ionic exchange-like procedure.

The water treatment process has been selected because of some striking advantages inherent in its implementation.

In fact the proposed approach:
- Can be adapted to treat oily water with high salinity.
- Is not dependent on the pH of the wastewater.
- Is not dependent on the temperature of the wastewater.
- Has full flexibility of flow (0 to 100 percent of maximum inlet water flow).
- Improves energy efficiency by minimizing the number of pumps through the use of gravity flow.

The approach is also characterized by a reduced footprint, it is housed in an indoor area just 35 meters wide and 80 meters long ➔ 3. The solution allows easy management by local operators and utilizes chemicals which can be produced on site starting from easily available cheap base ingredients, a feature which is highly advantageous in desert areas like the locations discussed here. Lastly, it should be noted that because of the design, the de-oiling plants can be built on skids (in factories or workshops) and then hauled to site for final installation and commissioning.

Operation and results

Gassi Touil and Hassi R'Mel Central plants were commissioned after revamping in the first quarter of 2009.

For each water de-oiling plant, three groups have been set-up in order to assure continuous and efficient operation:
- Plant operation team, composed of one site manager and four operators (two on day shift and two on night shift).
- Plant maintenance team. Composed of one mechanical technician, one electrical technician, one instrument technician, and one helper.
- One laboratory technician.

Maintenance activities are based on a detailed maintenance plan which has been prepared, starting with equipment maintenance manuals and an analysis of equipment criticality. The plan was developed in order to ensure plant availability and reliability and to guarantee full compliance with health, safety and environmental requirements. Planning has reduced corrective maintenance and has maximized planned and preventive maintenance activities including:
- Major overhauls.
- Mechanical and static equipment inspections.
- Instrumentation and electrical component checks.
- Spare parts replacement.
- Lubrication refilling.
- General cleaning.

In order to ensure the correct operation of the water de-oiling plants, laboratory analyses are regularly performed by a laboratory technician who is in charge of water analysis for all the water de-oiling plants in the same region. Correct operation requires the following quality analyses to be carried out daily on water samples:
- Hydrocarbon concentration (HC).
- Suspended solids concentration (TSS) or turbidity.
- Filtration degree (only for Hassi R'Mel Region).
- pH (only for flocculant preparation).

After the plant's startups and first operational experiences, laboratory analysis provided consistently excellent results ➔ 5. Note that hydrocarbon content and suspended solid concentration values in the outlet water are respectively seven and 55 times smaller than the client's contract specifications ➔ 6.

> The process is flexible enough to allow further tailoring to the specific plant's features and needs and the innovative approach and equipment have a significantly reduced physical footprint.

The plant uses standard equipment (pumps, motors, air compressors, etc.) and instruments (indicators, transmitters, etc) for which the operators don't need specific know-how or experience. Operation of the water de-oiling plants is relatively simple and the whole process

6 Visual evaluation of the water purification process results

is controlled and regulated by a DCS located in the control room. The plant layout and hydraulic profile are designed to maximize the use of gravity flow and to reduce the number of pumps. Electrical and instrument components are ATEX Directive compliant and the plant is protected by a fire fighting system which uses water, foam and CO_2 as appropriate. The plant construction and setup took approximately two years, including six weeks for pre-commissioning and commissioning.

> Hydrocarbon content and suspended solid concentration values in the outlet water are respectively seven and 55 times smaller than the client's contract specifications.

Options for the future

The oily-water treatment strategy and implementation described above is proving a remarkable success in a number of respects. First it has reached and exceeded performance targets in terms of the quality of the treated and released waters. Secondly this performance has been obtained in a reasonably short period of time and with a clever and careful procedure which has proved to be sustainable over time. Last but not least, this design is energy efficient, and enables the operator to minimize operating costs.

Because of its inherent features, the described approach (presently patent-pending) is suitable for the treatment of highly saline wastewaters, making it an excellent fit for the treatment of wastewater from oil and gas production plants.

The methodology promises to be easily and successfully extended to water treatment units in such diverse environments as oil refineries and pulp and paper plants, not to mention the potentially large market of oil production from oil sands in regions like Alberta, Canada, where the extraction process demands huge volumes of water.

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Further reading
The technical part of this article is based on results that have been published in polutionsolutions-online.com, May / June 2010 and in Processing and Control News Europe, June 2010.

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