PANORAMA 2011

a look at ...

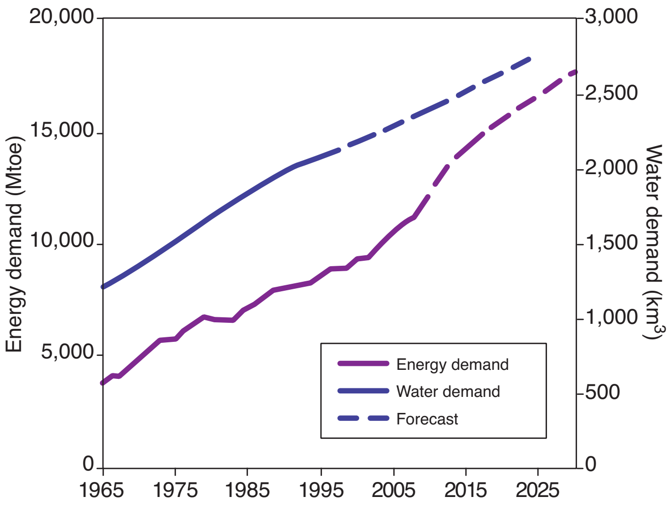
Water in fuel production

Oil production and refining

Water plays a vital role in the production of fuels. Against a background of extremely high pressure to do with the need to protect the environment, better manage energy use and operate in a socially responsible manner – as well as the need to protect water as a resource and reduce greenhouse gas emissions, water management has become a major issue for the oil industry. These issues have all more or less been factored into the integrated water management programmes which have been introduced both in oil production and oil refining. These programmes have been designed to keep waste and emissions to a minimum, and to reduce the quantities of water required.

Water and energy are intimately connected in a complex relationship of production/consumption. The emergence of these concerns to do with the environment and the water stress that has been triggered by climate change have placed the question of this interdependency at the very heart of debate on the international stage. Indeed, increase in energy demand will inevitably go hand-in-hand with an increase in demand for water, as is shown in Figure 1.

Fig. 1 - Global trend in energy/water demand



Source: A. Maheu, McGill Univ., Nov. 2009

It would appear that trying to save these two resources and adopting a sensible approach to using them are vital for sustainable economic, social and ecologically-friendly development. In this interdependency relationship, water looks increasingly to be the resource that is vital to protect. Indeed, there may be alternatives which can be used instead of oil... but there are none for water.

As far as hydrocarbons are concerned, they impact on water availability in two ways. First of all, producing them requires a great deal of water. And then actually using them contributes to the planet's water stress through CO_2 emissions (the final stage of their combustion) and exacerbates global warming. Managing water within the context of the fuel production chain, from extracting hydrocarbons through to refining them, has therefore become a major issue for the petroleum industry.

Water and the production of hydrocarbons

Water plays a vital role in production

But what is it used for?

Very few people associate producing hydrocarbons with using massive quantities of water. Actually, water is already initially present with oil within the reservoirs (formation water). Water is used for drilling, hydraulic

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fracturing, completion and well treatment. It is one of the most commonly used liquids for being injected into the reservoirs through specific wells (injection wells) for oil production support. This is done during so-called "secondary" recovery in order to compensate for the drop in pressure inside the reservoir after it has started production. It is also used to improve the efficiency of oil displacement and extraction (waterflooding, Enhanced Oil Recovery (EOR)).

Growing needs

According to the International Energy Agency[1], global energy demand is set to increase by 0.7 to 1.4%/year between 2008 and 2035 depending on various different scenarios, and hydrocarbons will remain a key feature of energy consumption, even though the percentage of energy requirements for which they are used will fall. Currently, 70% of world production is satisfied by oil fields that started production around 20 years ago (mature fields) and whose recovery factor does not exceed 35% after secondary recovery. Apart from exploration/production in difficult environments (deep offshore, reservoirs at great depths, the Arctic), there are mainly two other possibilities for satisfying the world's energy demand:

- producing so-called "unconventional" reserves: extra-heavy, sand and tar sands, shale gas, gas which is trapped in highly impermeable rock (tight gas), natural gas extracted from coal (CBM) (see the Panorama article "Unconventional gas and water"),
- increasing the recovery factor of mature fields using "tertiary" recovery techniques (EOR). Improving these recovery rates by 1% would produce enough oil to satisfy the needs of two years of global consumption.

Very high quantities of water are required for both these options. In the case of the first, regarding shale gas, for example, 10 to 15,000 m^3 of water/well are needed to fracture the rock – that is 1 to 2 l of water per barrel of oil equivalent (l/boe) (see the Panorama article "Unconventional gas and water"). For EOR methods, be they thermal (involving for example the injection of steam), or chemical (involving additives (alkalines, surfactants or polymers) mixed into the water to increase the efficiency of displacing and sweeping the oil into the reservoirs), requirements can vary between several hundred and several dozen thousand litres of water per barrel of oil equivalent extracted, depending on the maturity of the field and the process (800 l for steam injection, 5,000 for CO_2-EOR and up to 48,000 for micellar processes (micellar-polymer)). In all cases, increasing hydrocarbon production will result in a dramatic increase in water demand. According to the World Energy Council (Water for Energy, September 2010), the share of oil used in meeting the world's energy requirements should fall between now and 2050, but its share in the water consumption for energy production is set to increase (by 10 to 18%).

What sources and what treatment?

Water used to produce energy comes from different sources, depending on location, availability and requirements. These include:

- seawater (for offshore energy production, in particular),
- water from rivers and estuaries,
- water from aquifers,
- wastewater in certain cases (domestic and industrial).

The most striking example is in Saudi Arabia, where approximately 10^6 m^3 of seawater is treated and transported over some 300 to 400 km to be injected into the Ghawar oilfield!

No matter where it comes from, water used for injection is first treated, and then conditioned in order to meet quality requirements. These quality requirements depend on the type of reservoir into which the water is to be injected, the fluids which are already present and the conditions under which the oil is being extracted.

In most cases, the water must be filtered and sterilised, and oxygen and any additives (anti-corrosion, anti-bacteria, anti-scaling, etc.) must be removed from it. In certain circumstances, particularly in order to remedy excessive incompatibility between injection and formation water, specific treatments such as desulphation or even desalination may be required.

The aim is to end up with water of a sufficient quality to meet the main requirement of improving oil recovery, while at the same time maintaining the quality of the wells, the reservoir and the equipment used (preventing corrosion).

The water is produced with the hydrocarbons: production water

Sources

Most of the water that is injected for the purposes of production is normally produced with the hydrocarbons. Indeed, throughout the life of a well, the Water-Oil Ratio (WOR), or the share of water in the fluid that is produced (Water Cut), continues to grow (Figure 2).

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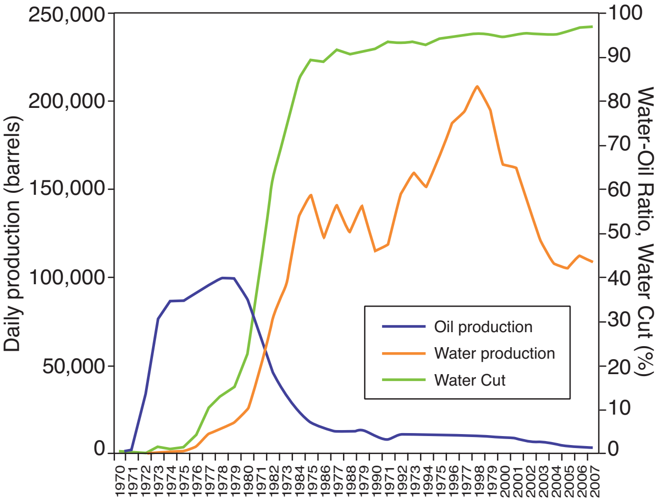
[1] World Energy Outlook 2010

Fig. 2 - Typical changes in production flow rates and in the Water Cut throughout the lifetime of a conventional hydrocarbon producing well



Source: Global Energy Systems oilfield database

Because water is immiscible with oil and naturally more mobile, this phenomenon is inevitable and partly explains the modest recovery factor after secondary recovery indicated above. Water breakthrough and flow rate depend on the recovery process used, the nature of the reservoir and how it is managed. Other sources can be added, such as leaks in the wells, fractures between injectors and producers, or water that comes from underlying water layers through fractures or the formation of water cones.

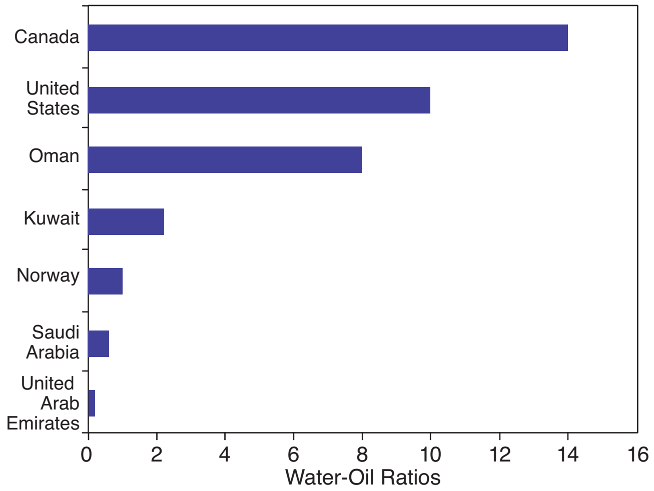
Volumes

Producing hydrocarbons therefore involves producing large quantities of water. On average, at global level, 3 to 5 barrels of water are produced with every barrel of oil. And in certain mature regions, this figure can be as high as 10 to 14! (Figure 3). So in terms of sheer volume, more water is produced than any other fluid by the petroleum industry!

According to a study carried out by IFP Energies nouvelles, an estimated 250 millions of barrels per day (Mb/d) were produced in 2008. This figure is set to exceed 300 Mb/d by 2020, i.e. an increase of 20%. It is thought that this will mainly be due to offshore activities. These fields are currently less mature, and the water production associated with them will increase by more than 50%.

The water produced is of very low quality and requires relatively sophisticated treatment. How extensive, and thus expensive, this treatment depends on the intended use for the water.

Fig. 3 - Water-Oil Ratio by region



Source: Z. Khatib, SPE DL 2009-2010

Quality

Production water has usually spent relatively long periods of time in reservoirs, in which it was in contact with oil, gas and rock. Its quality, like its quantity, depends on its source. It can vary significantly depending on region, the geology of the formation, the types of fluids involved, the recovery process used, the operating conditions and on how the wells and reservoir are managed. Pressures and flow rates can vary considerably in the vicinity of the producer well, disturbing the physicochemical equilibria prevailing within the reservoir. This in turn has a direct impact on the composition of the produced waters. Most often, water is produced in the form of a water emulsion in the oil. This needs to be separated from the hydrocarbons. Various physicochemical processes are used to carry out this separation, which usually involve additives being mixed into the water. Most of these additives remain in the water after separation.

Typically, production water may therefore contain:

- suspended particles (TSS):
    - minerals: clays, silica, various calcium and sulphate mineral precipitates, iron precipitates in particular, bacterial corrosion residue, such as ferrous sulphide, etc.,
    - organic: residual emulsions, bacteria, asphaltene, etc.
- various types of dissolved salts (TDS),
- heavy and radioactive metals,
- dissolved organic products:
    - hydrocarbons, especially: BTEX[2], PAH[3], phenols and naphthalenes,

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[2] BTEX: benzene, toluene, ethylbenzene, xylene

[3] PAH: polycyclic aromatic hydrocarbons

  - additives used to manage wells, for production (drilling, completion, fracturing, well treatment), for conditioning the injection water and for separation,
  - additives used for EOR: alkalines, surfactants, polymers, bacteria (microbial Enhanced Oil Recovery), etc.
- bacteria and waste from bacterial activity (biofilm, ferrous sulphide, etc.),
- dissolved gases (CO_2, O_2, H_2S, etc.).

Production water is therefore corrosive, unstable and oily (it contains emulsions and dissolved oil). It also contains suspended particles ranging from less than 1 micron to 1 mm in size; it is also biologically active and toxic (it contains heavy metals, radioactivity, chemicals), and its salinity can reach saturation.

Production water management: a necessity

Production water was long considered as an inconvenient by-product. On land, once it has been treated using methods that are more or less sophisticated depending on its intended destination, the water is either pumped out into rivers or domestic wastewater networks, or treated by evaporation in settling tanks, or injected into a subsurface formation after basic treatment. On offshore platforms, water is either treated and then pumped back into the sea, or transported back to facilities on land to be treated.

This attitude to production water changed completely around 10 years ago: production water is now seen more as a resource than as a by-product. Managing it has become a major issue for oilfield operators and a key component of overall production costs. There are three main reasons for this:

- concerns associated with climate change and the need to save water,
- the quantities to be treated are growing continuously,
- and environmental regulations are increasingly strict and are being applied to more and more areas. As yet, there is no international standard: each country or group of countries has its own standards. In the OSPAR region[4] for example, the goal is to reach ZHD (Zero Harm Discharge) by 2020. In Brazil, resolution 393 of the *Coselho Nacional do Meio Ambiente* (2007) sets the maximum amount of oil that offshore platforms can discharge into the sea at 42 mg/l per day.

Most oil companies have therefore implemented ambitious production water management programmes.

Management options

The following are the four main types of management options, in order of priority:

- reducing volumes,
- recycling: reinjecting water for production requirements and using it on or off-site,
- reinjecting water into the subsurface to store it, recharging the water tables, disposal, etc.,
- discharging it.

Table 1 shows the possible techniques and uses for these different options.

In most of the production water management programmes implemented by oil companies, reinjecting the water for production requirements (Produced Water Reinjection (PWRI)) is seen as the default option.

On land, most production water (60% of the total volume) is already reinjected (PWRI) and this trend looks set to continue. On offshore platforms, on the other hand, most production water nowadays is treated and then pumped back into the sea (80 to 90% of the total volume), with PWRI only in operation at a few platforms. In the future, however, PWRI should be practised more frequently in order to cater for the strong increase in water being produced that is forecast between now and 2020, whereas the quantities being discharged into the sea should stabilise. If practising PWRI can support production and means that the constraints on the levels of treatment relative to those set by discharge standards can be relaxed, it also has the benefit of having practically no impact on the environment.

Table 1

Possible uses according to management options

Option		Possible techniques/Uses
Reducing quantities		Reduce the amount of water that gets into the wells (PVE), downhole oil/water separation (DOWS, DGWS), subsurface separation
Recycling		Recycling: reinjecting water for production requirements and using it on or off-site: PWRI-WF (waterflooding), PWRI-PS (pressure support) and PWRI-EOR, steam for SAGD
Reusing	On-site	Drilling (WBM), completion, cleaning, cooling, fracturing, domestic
	Off-site	Agriculture, leisure activities, drinking water, etc.
Reinjection into the subsoil		Storage, recharging water tables, disposal
Discharge		Ocean, rivers, evaporation

Source: IFP Energies nouvelles

However, although reinjecting production water is an attractive option from both an economical and an environmental perspective, it involves many difficulties, including:

- fears regarding the severe losses of injectivity to which it can give rise,

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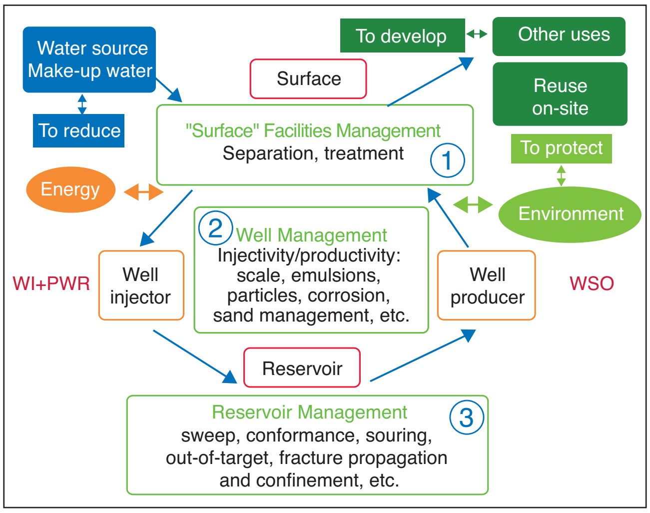
[4] The region covered by the Convention for the Protection of the Marine Environment of the North-East Atlantic or "OSPAR" Convention (OSlo PARis)

- risks of mineral scaling and formation of H_2S (souring) by bacteria,
- management and of fracture initiation, propagation and confinement. Indeed, it is acknowledged that whether or not a PWRI operation is successful is often dependent on whether there are any fractures, the propagation of which must be controlled, especially to avoid the risk of water arriving prematurely in the production well,
- on offshore platforms, the quantity and quality of water constitute bottlenecks, given the limited amount of space available for treatment facilities. In this regard, innovation is required so that more compact and efficient equipment can be designed.

Towards Integrated Water Management (IWM)

In a context in which there is a great deal of pressure to safeguard the environment and be socially responsible, water as a resource has to be protected and CO_2 emissions have to be kept to a minimum. Therefore, managing production water in oilfields is increasingly seen as an integral part of modern IOR (Improved Oil Recovery) approach, which seeks to optimise production by combining the advanced methods used in EOR with better reservoir and well management. Within this framework, production water management is tackled using an integrated approach (Figure 4) which takes the whole cycle into account and is carried out at three levels:

Fig. 4 - Water cycle and Integrated Management (IWM)



Source: IFP Energies nouvelles

1 - Surface aspects: separation and treatment

Up until now, ensuring the high quality of the hydrocarbons has always been the main aim of separation. From now on, and in order to optimise the whole water cycle from a technical-economical standpoint, the quality of the water at the end of the separation process will also have to be factored in. Indeed, the efficiency and cost of the subsequent water treatment phase is greatly dependent on the quality of this feed water. Other considerations involved in the choice and design of the treatment process are flow rate and the targeted water quality. The processes used to treat the water must therefore be increasingly adapted to the identified use or uses for which the water is intended. As far as reinjection is concerned, specifications about the quality of the water are determined by the properties of the well, the reservoir and the fluids already present, and the flow regime under which the injection is operated (matrix or fractured).

2 - Well aspects: injectivity and productivity

One of the major fears associated with PWRI is a loss in injectivity as a result of the production water's clogging capacity and its tendency to lead to souring (the formation of H_2S by bacteria) in the wellbore. Specifications for the water quality required should be indicated so as to keep treatment costs to a minimum while enabling acceptable levels of injectivity over the long-term. In the event of severe losses being forecast, methods for restoring injectivity need to be developed. The corrosive nature of production water should also be taken into account when choosing the well completion type and equipment.

3 - Reservoir aspects: optimising waterflooding

The aim here is to make the most efficient possible use of water in oil recovery, which involves a good displacement and sweep efficiencies. With reinjection, the impact of geomechanical factors is particularly important, especially since the majority of reservoirs which are subjected to conventional waterflooding are likely to be already fractured.

In this integrated management scenario, the quality of the water is seen as the central element. Managing, optimising and monitoring it are all key factors in the success of the operation.

Outlook: challenges and opportunities

If chemical EOR is to be further developed, using production water for these purposes seems imperative. One of the major challenges of the future will involve the impact of EOR additives (surfactants, polymers, etc.) on the aspects discussed above, particularly aspects 1 and 2: separation, treatment and injectivity.

Water in fuel production

Oil production and refining

On the basis of past and current experiments with PWRI, industry professionals are forecasting that this could become the only economically viable water management method insofar as it has no impact on the environment. Currently, recycling rates rarely exceed 85%. Although 100% PWRI is difficult to achieve, oilfield operators are able to get close to it by implementing IOR with IWM.

And it is also worth pointing out that progress being made in oilfield water management strategies that are less harmful to the environment (holistic approach) also generates a number of technical, technological and commercial opportunities: the development of new processes and methodologies, products (which are more efficient at low doses and do not harm the environment), software and facilities (which are less compact and more efficient).

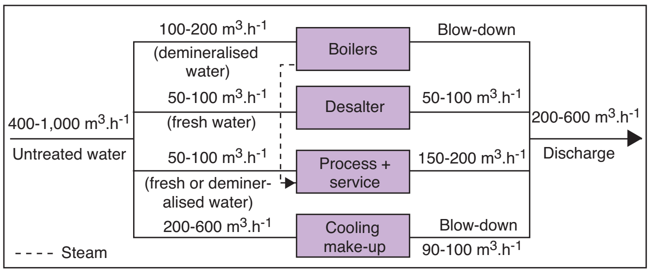
Water used in refining

Oil refining sector is also seeking to make improvements to the way in which water is managed. Real progress has already been made over the last few years – the average water consumption of a refinery has fallen from several m^3 per tonne of crude oil in the 1980s, to 200 to 800 l per tonne.

Refineries still require significant quantities of water. The water need is vital for processing plants to be able to transform oil into fuel. Most often, water is taken from natural environments: underground water, canals, lakes... or even partly from the sea.

As far as a refinery's water networks are concerned, and how water is treated before being discharged, water is divided into the following categories (Figure 5):

Fig. 5 - Example of a refinery being supplied with 8 to 10 Mt untreated water.year^{-1}



Source: Technical memorandum on water, Degrémont-Suez, 2005

- untreated water which is used to meet all of the refinery's water requirements,
- demineralised water which is used to power all the boilers,
- refrigeration water used for cooling and condensing the hydrocarbons in the various refining plants,
- water used in the desalter to reduce the salt content of crude oil before distillation,
- water recovered from steam condensation that has come into contact with hydrocarbons during the refining processes,
- wastewater resulting from the refinery's various aqueous effluents,
- drinking water to which the network is not connected.

Untreated water

Regardless of its origin, water entering the refinery is referred to as "untreated water". It contains minerals and dissolved gases, as well as suspended particles. Untreated water undergoes several treatments before being distributed throughout the rest of the refinery in order to reduce its mineral and organic content, and to filter out its suspended particles.

The first treatment is a rough filtering, a screening operation which is carried out in the pumping well. Coagulation and flocculation processes are then carried out in order to remove the water's very small particles and sediment. The particles obtained once they have coalesced conglomerate to form larger particles known as flocs, which then settle. The water is then continuously filtered and the residue extracted is sent for sludge treatment.

Water for boilers

Steam has a number of applications in a refinery that make it essential. It is used for heat transfer and tracing lines, it is the driving power for various pieces of equipment (pumps, compressors, etc.), it is used to generate electricity, to empty certain pieces of equipment and for stripping in certain processes.

Table 2

Typical pressures and temperatures for different steam types

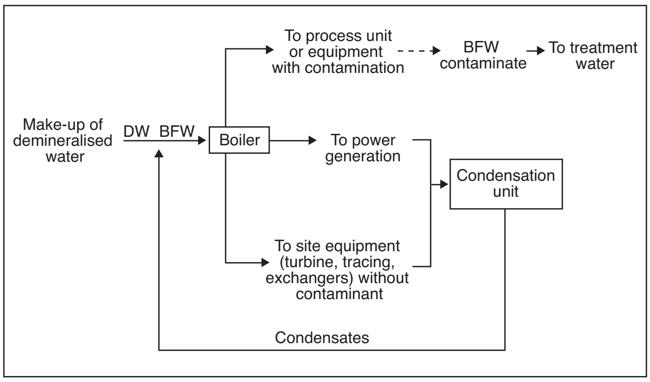
Steam type		Typical pressure (depend on the type of installation)	Typical temperature (depend on the type of installation)	Type of use
HHP	Superheated hight pressure steam	> 45 bar	~ 350 to 400°C	Power generation
HP	Hight pressure steam	45 bar	257°C	Heat exchange Turbine Reboiling
MP	Medium pressure steam	35 bar	242°C	Heat exchange Turbine Steam ventilation Stripping process
LP	Low pressure steam	< 5 bar	152°C	Heat exchange Steam tracing lines Emptying

Source: Saipem

Steam is generated inside the refinery's boilers in a superheated high-pressure form. It is then divided into several types for various applications (Table 2).

The Boiler Feed Water network (BFW) is a semi-closed circuit (Figure 6). The water is made up of condensates (steam recycling), and make-up water which is injected to make up for any wastage in the circuit. This wastage is caused by steam which has been polluted by a process fluid. It cannot be recycled directly and in most cases must be sent to a water treatment system before it can be discharged.

Fig. 6 - Boiler water network



Source: IFP School

Steam has a very high caloric power and thermal capacity, which makes it able to absorb and release heat very effectively. The presence of any impurities can reduce this capacity significantly, negatively affecting the steam network's efficiency. Corrosion, foaming, scaling and furring, etc., are all inconveniences that must be taken into account. In practice, the maximum concentration for these impurities depends on the type of boiler and the conditions in which it is operating (Table 3).

Table 3

Maximum recommended concentrations for boiler water (<100 bar)

	Feed water						
Operating pressure (bar)	Dissolved oxygen	Total Iron	Total Copper	Total Hardness	Non-volatile TOC	Oily matter	pH at 25°C
	(measured before the oxygen reducing agent is added)						
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	
0 - 20.7	0.04	0.1	0.05	0.3	1	1	7.5 - 10.0
20.8 - 31.0	0.04	0.05	0.025	0.3	1	1	7.5 - 10.0
31.1 - 41.4	0.007	0.03	0.02	0.2	0.5	0.5	7.5 - 10.0
41.5 - 51.7	0.007	0.025	0.02	0.2	0.5	0.5	7.5 - 10.0
51.8 - 62.1	0.007	0.02	0.015	0.1	0.5	0.5	7.5 - 10.0
62.2 - 68.9	0.007	0.02	0.015	0.05	0.2	0.2	8.5 - 9.5
69.0 - 103.4	0.007	0.01	0.01	not specified	0.2	0.2	9.0 - 9.6
103.5 - 137.9	0.007	0.01	0.01	not specified	0.2	0.2	9.0 - 9.6

Source: APAVE

In order for a generation plant and steam network to operate properly and efficiently over a long period of time, certain components found in water must be eliminated or have their concentration levels reduced. There are many possible treatment options for eliminating them, but they will not be detailed here.

Cooling water

A plant can be cooled in a number of different ways:

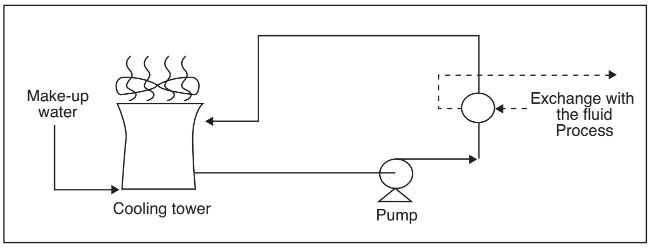
- using an open circuit: the water absorbs surplus heat in a heat exchanger and is released back into the natural environment close to where it was taken from. Its temperature will have been increased by anything ranging from just a few degrees to about ten degrees,
- using a semi-open circuit: the water exits a heat exchanger and is then sent to a cooling tower (generally a wet evaporative cooling tower) where a weak proportion of the flow circulating within the cooling circuit evaporates and evacuates the heat out into the atmosphere. In order to compensate for any wastage, make-up water is required, the volume of which will depend on the type of cooling tower. This type of circuit can absorb between 6 and 10°C,
- using a closed circuit: a predetermined and constant volume of water is used to eliminate the heat of process fluids. The water is cooled by a series of water cooling towers. This type of circuit can absorb between 10 and 16°C.

Open circuit systems are increasingly rare because of environmental and economic factors. In order to comply with regulations, the discharge temperature must be lower than 30°C with a maximum variance of less than 15°C with the natural environment into which it is released. This thermal constraint limits heat exchange and means that high water flow rates are required (up to several dozen m^3 per tonne of crude oil that is refined).

Although by definition a closed circuit uses very little water, initial investment costs are relatively high, and rigorous treatment is required beforehand in order to eliminate any risks of corrosion, clogging or bacteria development.

The semi-open circuit illustrated in Figure 7 is the most commonly used, since it involves relatively low investment costs, runs a lower risk of corrosion and requires less maintenance. But it does require conventional treatments for the make-up water – concentrations of impurities build up within the circuit in proportion to wastage through evaporation.

Fig. 7 - Semi-open cooling circuit



Source: IFP School

Water from desalters and condensed steam from the refinery processes

A desalter can reduce the salt content (less than 1 to 10 mg/l) of crude oil before distillation so as to protect the machinery against corrosion. It involves water washing. Desalters are often fed by recycled water, such as acid condensates from cracking units once the H_2S and ammonia have been stripped out. This way, freshwater can be saved and the discharge flow can be kept to a minimum.

These condensates come from steam condensation which has come into contact with hydrocarbons. They come mainly from the following sources:

- distillation,
- fluid catalytic cracking, hydrocracking and hydrodesulphurisation,
- steam cracking,
- heating products.

Condensation water produced by carrier vapour or the dilution of distilled products (atmospheric and vacuum distillation) account for between 2.5 and 4% of all water and is relatively unpolluted (Table 4).

Table 4

Composition in mg/l of condensed process water

	AD	VD	FCC	HDS GO	Steam cracking
% volume of the total	2.5-3.5	3-4	6-12	3-6	15-35
pH	6-7	6-7	8-9,5	5-6	6-8.5
HS^-, RSH	20-200	10-50	500-3,000	3,000-5,000	10-20
Cl^-	5-100	5-50	10-50	10-30	10-30
CN^-	-	-	5-200	5-10	-
NH_4^+	10-60	5-30	300-3,000	1,500-3,000	Traces
Phenols	10-30	5-10	80-300	10-20	20-30
HC	30-60	5-20	5-60	5-20	30-50
CH_3CO_2H/CH_3CHO	-	-	-	-	50-100

Source: P. Leprince, "Le raffinage du pétrole" (refining petroleum), Ed. Technip, 2006

The most polluted condensates are produced by refining operations. During cracking or fluid catalytic cracking, injection, carrier and aeration steams are used. Heavy and viscous products that are processed are often rich in sulphur which is hydrogenated and carried by steam as H_2S. A second source of polluted water is water used to wash the column heads in order to reduce scaling from ammonium sulphate salts. In hydrodesulphurisation processes, sulphur is converted into H_2S and mercaptans, and nitrogen compounds into ammonia. The water also contains phenols as a result of various chemical reactions. These condensates account for between 6 and 12% of the hydrocarbons.

The water that is produced by steam cracking is more of a "petrochemical" water than a refinery water, even though several refineries are fitted with steam cracking plants. The water is used to lower the hydrocarbons' partial pressure and thermodynamically favours cracking. It also avoids the formation of coke. This water accounts for between 15 and 35% of the hydrocarbons.

The heating condensates from products are polluted when they accidentally come into contact with the hydrocarbons. Even if only very small quantities of organic products are present, the water has to be subjected to an initial treatment before being recycled in the boiler.

The "process water" treatment section is fed by steam condensates which have come into direct contact with hydrocarbons, as well as water that has been recovered from the flare drum, worn soda and water used to wash the heat exchangers and cooling towers. This water is usually steam-stripped in order to remove the H_2S and — in certain cases — the NH_3. It is then sent as washing water to the atmospheric distillation units' desalters (Figure 8); this lowers the water's phenol content. The water is then sent to the actual treatment station.

When it leaves the settling tank, the water is air-stripped. Sulphur is removed in the form of H_2S and is sent to an incinerator after separation.

The water is then sent to a settling tank/flocculator where lime is injected for flocculation. The mineral sludge produced is then extracted and sent to a sludge treatment plant. The final stage is biological treatment: bacteria use the dissolved oxygen to convert the carbon from the organic matter (COD and BOD5[5]) into CO_2.

In the specific case of synthetic motor-fuel production from natural gas, coal and — in the future — biomass, water is both used and produced. It can account for as much as 1,000 l per tonne of the total amount processed (use), as well as per tonne of hydrocarbons produced

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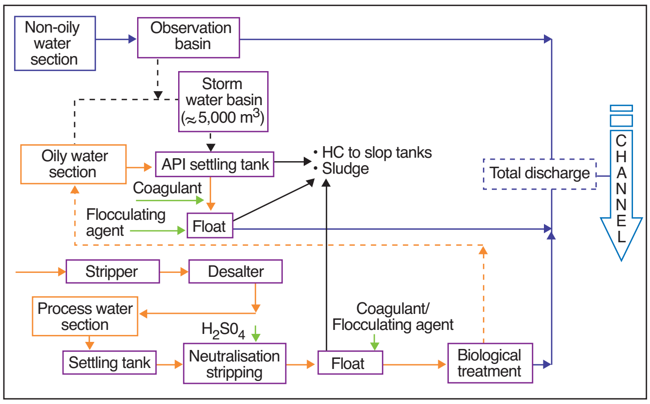
[5] DCO : demande chimique en oxygène
DBO5 : demande biochimique en oxygène après 5 jours

(production). Water is needed in gasification to obtain the synthetic gas (CO and H_2), and for the water gas shift reaction which produces hydrogen from CO. Water is also produced by the Fischer-Tropsch reaction which converts synthetic gas into hydrocarbons.

Fig. 8 - Treatment operations for process water and wastewater



Sources: Total, IFP School

In these processes, water is both used and produced – making it all the more necessary for its recycling to be optimised so as to reduce waste. This water is subjected to treatments that are similar to those used in a refinery. The chemical and biological treatments depend on the way in which it is recycled and on how the discharge of waste is regulated (Table 5).

General discharge or wastewater

Wastewater is subdivided into oily water and non-oily water. Non-oily water includes water that has been drained from boiler and refrigeration circuits, neutralised effluent from demineralisation chains, domestic water (from showers, toilets, etc.), water from laboratories and all other so-called "clean" water. This water is sent to a monitoring basin where any hydrocarbons can be trapped before it is pumped out into the natural environment. If any accidental pollution occurs, an analyser which continuously looks out for any traces of hydrocarbons can reroute this water towards the oily water section (Figure 8).

Oily water is water from the paving in the facilities, rainwater, water that has been used to wash the floors and containers, and water that has leaked from the exchangers. This water can account for a significant proportion of the total amount discharged (> 50 l per tonne of untreated water). Oily water is collected and sent to a settling tank. The bottom of the tank is scraped in order to recover any sludge which has thickened and become dehydrated. It is then dumped or incinerated. The surface of the water is also scraped in order to collect any hydrocarbons. These are then sent to slop tanks. Once the water has been clarified and rid of most of its hydrocarbons and suspended matter, it is sent to the float (Figure 9).

Fig. 9 - Example of a refinery float

Sources: Total, IFP School

In order to eliminate dissolved hydrocarbons and any fine suspended particles, coagulation (aluminium or ferrous salts, etc.) and flocculation agents (polymers) are used in order to get them to coalesce into corpuscules that are large enough to settle (flocs). The float is fitted with a scraper for any sludge floating on the surface or that has settled at the bottom. This sludge is regularly removed and sent to the sludge treatment plant.

Waste standards

Standards relating to refinery waste vary from country to country. In France, refineries are subject to legislation with regard to water within the framework of the law of 2 February 1998, which has been amended several times. Since 2005, this law has required that all new refineries pump out no more than a maximum flow rate of water into the natural environment. This depends on the complexity of the installations. The flow rate varies between 100 l to 800 l per tonne of water treated. Pollutant flows quoted by tonne of refined water are also subject to regulations (Table 5).

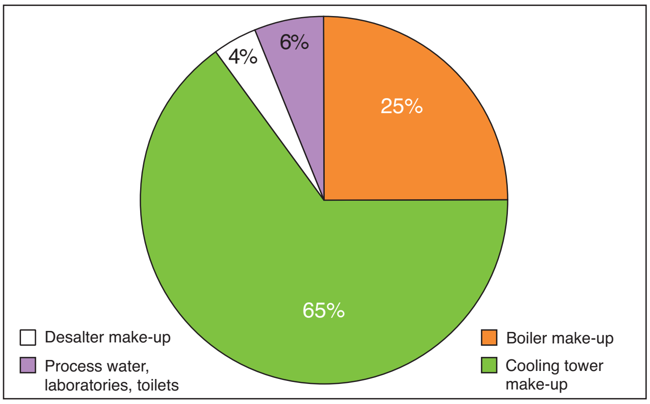
Table 5

Pollutant flow regulations for new refineries (monthly averages)

Refinery category Maximum authorised specific flow	1	2	3	4
Water flow rate (in m^3/t)	0.1	0.2	0.4	0.8
MSOM (in g/t)	2	5	10	15
COD (in g/t)	10	15	30	60
BOD5 (in g/t)	5	5	10	15
Total nitrogen (in g/t)	5	5	10	15
Hydrocarbons (in g/t)	0.1	0.25	0.5	2
Phenols (in g/t)	0.01	0.05	0.05	0.1

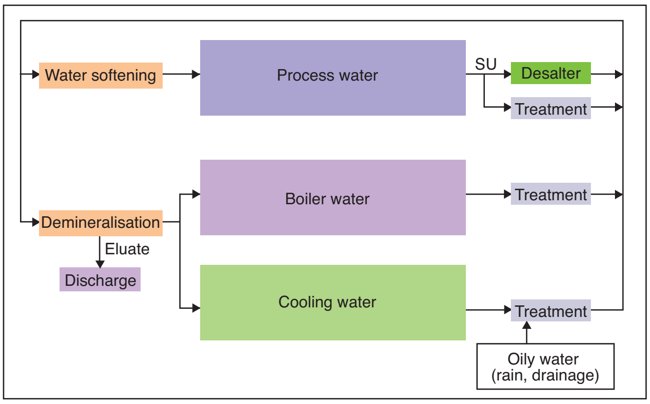
Sources: INERIS and JORF 12 February 2005

Fig. 10 - Average distribution of water consumption in a refinery



Source: Techniques and engineering, G1150-9, 2009

Fig. 11 - Optimising refinery water circuits, towards zero discharge levels



Source: IFP school

Outlook for improvement

The quantities of water used in refineries are variable and are made up of, in decreasing order of volume, make-up water for refrigeration, heating, processes and desalination (Figure 10). In order to reduce water consumption, the efficiency of equipment and of each circuit has to be improved, and the overall layout of the refinery's water networks has to be optimised, together with how water is treated and recycled.

As far as the steam network is concerned, investing in high-energy efficiency equipment will result in a lower energy contribution and so less steam. Removing as many impurities as possible also makes it possible to optimise the water's heat transmission power. By definition, a closed loop recycle circuit uses less water. The treatment quality of the make-up water is of crucial importance. Recycling wastewater once it has been treated is a solution that can theoretically result in nearly no water having to be discharged (Figure 11).

Conclusion

During the energy transition phase, hydrocarbons will continue to account for a significant share of energy supply, particularly for the transport sector's requirements. Against a backdrop of climate change, a number of other major environmental concerns and the increasing scarcity of water, water use throughout the fuel production chain needs to be managed.

In oilfields, production water is now seen more as a resource than as a by-product of oil production. Production water management has become an aspect of IOR in its own right, a vital practice in order to bring about sustainable development and secure greater profitability for the oilfields. These programmes seek to increase the percentage of water that is recycled and encourage its reuse, all in order to protect the environment and save water.

In the refining sector, water use is already being reduced and the quality of the water that is discharged is being improved so as to limit the impact that the industry has on the environment. Even almost zero discharge is a realistic target – the technology is already available. It is dependent to a great extent on the various standards imposed by lawmakers and on the investment and operations costs involved.

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