Emilio Gabbrielli

THE 7000-YEAR STORY OF SEA WATER DESALINATION

RECENT ARCHAEOLOGICAL DISCOVERIES
MAKE THE USE OF DISTILLATION 5000 YEARS
OLDER THAN PREVIOUSLY BELIEVED

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FIRENZE

Author's note

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Front Cover
Drawing by Leonardo da Vinci,
Fornacello da-sstillare acqua forte [Stove for distilling strong water]
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Back Cover
Boquete Nitrate Company's solar desalination plant at the Oficina Domeyko mine, Antofagasta, Chile, 1907. Source: "The Illustrated London News", No. 243, 15 August 1908.

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crossing. This shows that much has yet to be discovered and confirmed about the spread of our species to all parts of the planet.

When I set out to write this book I was already familiar with the history of desalination from ancient Greece, which I had absorbed during years of professional activity in the field and which interested me greatly. I began researching documentation on ancient desalination in various parts of the world to fill in the gaps and properly validate the facts I was aware of. In doing so, I never expected to be confronted with a third upheaval in history, this time in the field of distillation, and therefore *de facto* also of desalination, of which I was completely unaware. It has been a progressive, but rapid and limited discovery. Ongoing research has led me to establish just enough to be able to talk about desalination starting from prehistory, but also to realise that I have merely scratched the surface of an enormous mass of archaeological discoveries and information, often still being processed. This is also because the oldest pottery finds are often found fragmented, so that it is only many years after their discovery that they can be properly catalogued, reconstructed and their function understood.

How did I make this discovery? As a good Florentine, I wanted to take a particularly close look at the Etruscans, who had been settled in Tuscany for almost a thousand years BCE and were famous for the production of perfumes and essences. I was keen to explore whether they had had anything to do with the beginnings of desalination, or at least distillation. Angelo Pontecorboli had suggested that I consult a book he had published (Martinelli M., Florence 2016, pp. 9-14), written by an expert on the Etruscans, which discusses perfumes in the ancient world, but which focuses on Etruscan civilisation. So I did, and having reached page 9, I began to read about an interesting find at Pyrgos, on the island of Cyprus. This was a diversified and complex industrial site, the centre of which was a 4,000m^2 building, destroyed by a terrible earthquake around 1850 BCE, which produced olive oil, wine, perfumes, dyes for textiles, copper and ceramics. Turning to page 12, I was astonished when I read:

> Among the many vessels found around such as amphorae, funnels (the oldest so far ever found), jars, pyxes, incense burners, braziers, mixers and mortars, now in the Limassol Archaeological Museum, two groups of four polished earthenware vessels ("Red Polished IV, metallic ware") each forming a distilling apparatus, are of unique interest, the first example in history of an alembic found *in situ* whose functionality has been verified by means of a replica. The set, of enormous historical importance, and of which a replica is exhibited at the Archaeological Museum of Camaiore, sets back by more than 2,600 years the knowledge of distilling practices, believed to be an Arab invention of the 7th century. The system, consisting of two jars, an alembic and a basin, could be completed by a fifth element, namely the horseshoe shaped holder that supported the jar over the fire [...]

I then saw the image of the original in the Limassol Archeological Museum (Fig. 1) followed by that of a replica in the Museo Civico Archeologico di Camaiore on the Tuscan coast. It immediately became clear to me that this find, even if it does not prove that the inhabitants of Cyprus used desalination of seawater 4,000 years ago, shows that they had the knowledge and the equipment to do so more than 1,500 years before Aristotle first spoke of the possibility of desalinating seawater by condensing the steam produced through boiling.

A few days after reading about this, on a visit to the Archaeological Museum in Camaiore, standing in front of the reproduction on display, I was struck by the realisation that with that alembic, well designed and based on a clear understanding of the process of distillation 4,000 years ago, it would have been possible to go to the beach a few kilometres from the museum, light a fire and desalinate seawater. This meant that I was looking at an alembic of considerable size, more than 2,000 years older than the first attempts to develop the alembic in Alexandria in the early centuries of our era and its definitive development by the Arabs, whom I had always believed to have been the first.

1. Alembic from almost 4,000 years ago found *in situ* at Pyrgos, Cyprus, on display in the Limassol Archaeological Museum (from: Pyrgos Mavroraki, Advanced technology in early middle bronze age Cyprus, www.pyrgos-mavroraki.eu).

After this discovery I tried to investigate the reality of ancient distillation, which quickly revealed that ancient alembics had been found practically all over the world since the fifth millennium BCE, which was totally unexpected (Belgiorno M.R., 2008, pp. 52-55). In the words of the archaeologist Belgiorno, who discovered the Pyrgos alembics and identified their function:

> Experiments conducted with replicas of Neolithic pottery found in Iraq shed new light on ancient knowledge of distillation and technology for the production of perfumed and alcoholic compounds. The evidence provides links in the Mediterranean and Central Europe with a chronology ranging from the fifth millennium to the end of the second millennium regarding the invention of various apparatuses characterised by a rounded body and additional elements such as spouts, filters and the presence of an internal or external collection channel.

The distillation apparatuses in Iraq mentioned above come mainly from Tepe Gawra and date back to the fourth millennium BCE (Belgiorno M.R., 2018). The photograph shows evidence of operation with a replica (Fig. 2). But even earlier apparatuses are coming to light, such as one in south-western Slovakia, where the remains of an ancient alembic dating back to 4,000 BCE have been found at the archaeological site of Abrahám, which consists of three movable parts for distillation in one section: boiling, condensing and collecting (Fig. 3).

Two examples of Tepe Gawra's links with the Mediterranean and Central Europe are similar alembics from the middle of the second millennium BCE, found one more time in Slovakia and in Sardinia (Belgiorno M.R., 2022). All this makes it likely that alembics were used extensively in the Mediterranean basin from even earlier times than the Pyrgos alembic.

From the still fragmentary data available, it emerges that even in the case of distillation and the appearance of apparatus that can be identified as ancient alembics, these seem to have spread originally from what is known as the Fertile Crescent, Mesopotamia, the region between the Tigris and the Euphrates, which, thanks to extremely favourable conditions for human settlement and agriculture, saw the rise of the first great organised civilisations. However, distillation practices have also been associated with forest-dwelling or nomadic peoples such as, for instance, in Mongolia (Belgiorno M.R., 2018, pp. 51-59) and even in pre-Hispanic Latin America. It is therefore clear that distillation is a very ancient art, which existed for many centuries before its parameters and functions were formalised and recorded in writing.

2. Functional tests carried out with a replica of an alembic from Tepe Gawra, Iraq, dating back to the 4th millennium BCE (from: Belgiorno M.R., 2018, cover, photo by A. De Strobe).

Desalination using solar energy

Speaking of 18th century innovations, one cannot fail to mention that two scientists recommended the use of solar energy for desalination by distillation, a method already suggested by Della Porta in the previous century.

Among the various authors who wrote a treatise on desalination in the 18th century was the Jesuit Niccolò Ghezzi (d. 1742). One of his most notable proposals is to use the heat of the sun for desalination, where his suggestion to "soil the water with earth" indicates that he had understood that the dark colour absorbs more heat and thus favours evaporation. These are his words:

> A vase in the form of a retort could be used, on which the sun would shine (which, even in temperate climates and days, has no small activity in raising vapours), so that the top of the vase would be protected from the action of the sun; which would result in a more abundant and prolonged release of fresh water. Moreover, as I already told you, to facilitate, and increase the evaporation of water, whether sweet or sour, it is very useful to soil it with earth; which would lead to withdraw more of it, as I have experienced (Ghezzi N., 1742, pp. 210-211).

The above-mentioned Scottish physician James Lind went further and carried out experiments in desalinating sea water using solar energy, which he concentrated with parabolic mirrors (Nebbia G., Menozzi G.M., 1966b, p. 164). Lind's interest in desalination and the possible use of solar energy, which overcomes fuel shortages, was motivated not only by his concern for the health of seafarers, but also by his desire to give practical survival advice to Europeans, who were increasingly travelling in very hot and dry regions (Lind J., 1768, pp. 323-342). Hence also his interest in comparing water produced by distillation with rainwater and confirming that they are of the same excellent quality.

The title page of Lind's book on this particular subject is detailed and informative. In it we read the main title *An Essay on Diseases incidental to Europeans in hot Climates with the Method of preventing their fatal Consequences*, followed by further details, and ending with "To the whole is annexed, A simple and easy Way to render salt Water fresh, and to preserve and to prevent a Scarcity of Provisions in long Voyages at Sea".

Despite the marginal beginnings of attempts at solar desalination, in the following century, as will be seen in the next chapter, the most notable application of desalination on land was to be a large brackish water distillation plant, which used not only solar energy for desalination but also wind to drive the pumps needed to extract the water from the wells.

Desalination by filtration through porous materials: reality or imagination?

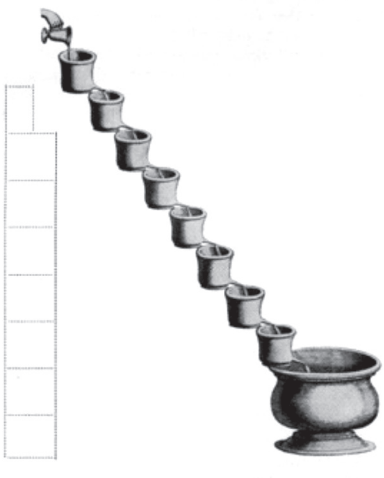
One thing is certain: the commitment and meticulousness with which some researchers experimented with filtration as a means of desalination must be acknowledged. Suffice it to mention the Bolognese Luigi Ferdinando Marsili (1658-1730), founder of the Institute of Sciences in Bologna and considered the father of oceanography, as his contemporary Stephen Hales was of botany. His scientific contribution was recognised by, among others, King Louis XIV of France, who had him appointed a member of the Royal Academy, and by Isaac Newton, who introduced him as a member to the Royal Society of London.

Marsili's various contributions include the method of completely evaporating a given volume of water to calculate the amount of dissolved salts, which is called TDS (see p. 183) and the measurement of the salinity of seawater at different depths, which showed that the salinity is greater at the bottom than at the surface (Nebbia G., Menozzi G.M., 1966b, p. 158).

In order to test the possibility of desalinating water by filtering it through different materials, as had been suggested since ancient times, Marsili thought it was necessary to do this in several successive stages, so he created a series of 15 vessels, each placed higher than the previous one, so that the water could flow through them one after the other (Fig. 32) (Nebbia G., Menozzi G.M., 1966b, pp. 159-160). He experimented with garden soil and sand after washing them thoroughly to remove all traces of salt. The total thickness through which the water had to pass was almost two metres. He achieved better results with sand, but even after 15 passes, this method failed to produce fresh water.

No scientist in the 17th century managed to do any better than Marsili, but at the 2011 IDA World Congress in Perth, James Birkett surprised the delegates with something astonishing, which he called the "final mystery" of the paper he had presented on desalination on the eve of the Industrial Revolution (Birkett J.D., 2011a). He quoted an extract from an adventure book written by Daniel Defoe, author of the famous novel *Robinson Crusoe*, titled *The Life, Adventures and Piracies of the Famous Captain Singleton*. Captain Singleton and his men are wandering thirsty in the desert when they find a spring of brackish water. As Defoe relates:

> […] here our Surgeon stepped in to encourage us and told us he would shew us a Way to make the salt Water fresh, which indeed made us all more cheerful, tho' we wondered what he meant.
> He took two of our large Matts and sow'd them together and they made a kind of Bag four Foot broad, three Foot and a Half high, and about a Foot and a Half thick when it was full.
> He caused us to fill this Bag with dry Sand, and tread it down as close as we could, not to burst the Matts. When the Bag was full within a Foot, he brought some other



32. Attempt at desalination by passing water through a series of vessels containing sand or other porous materials, from an experiment by Luigi Ferdinando Marsili (from: Nebbia G. et al, 1966b, p. 160).

> Earth and filled up the rest with it, and still trod all in as hard as he could. When he had done he made a Hole in the upper Earth about as broad as the Crown of a large Hat and bid a Negroe fill it with Water, and as it shrunk away to fill it again and keep it full. The Bag he had placed at first cross two Pieces of Wood, about a Foot from the Ground, and under it he ordered some of our Skins to be spread that would hold Water. In about an Hour, and not sooner, the Water began to come dripping thro' the bottom of the Bag, and to our great Surprize was perfect fresh and sweet; and this continued for several Hours; But in the End the Water began to be a little brackish. When we told him that, Well then said he, turn the Sand out and fill it again; whether he did this by way of Experiment from his own Fancy or whether he had seen it done before, I do not remember.

This is an accurate description of a rudimentary desalination system by filtration using two types of material, what we now call ion exchange (see p. 205), including the need to compact the material and replace it when it is exhausted.

Today artificial resins are used, and it is only since the end of the 19th century that we have known about the ion exchange properties of certain natural soils, sands, clays and zeolites. How did Defoe come up with this in the early 18th century? Is it possible that he came up with this method out of pure imagination? Or did Defoe actually see someone using this process and the only trace left of it is in his novel?

James Birkett reported that he had researched the subject at length, but had not been able to shed any light on the mystery, so he challenged others in the desalination community to come up with hypotheses or new findings. More than ten years have passed and, to my knowledge, no one has made any progress. My opinion is that such a precise description cannot just be the figment of a novelist's imagination and that, however unlikely it may seem, ion exchange had indeed been discovered already by someone and that by pure chance Defoe, no doubt of a curious nature, had happened to witness its application and was so impressed by it that he wanted to include it in his novel.

... And if you start going down this road, won't my assertion that the ancients could not yet have identified sands and other desalinating materials be shown to be rash?

The end of the century

Returning to the method of desalination by distillation, in his writings the aforementioned Stephen Hales also wrote extensively about the now widespread practice of ship captains building stills from what was already available and in use on board, which he also recommends, providing a number of practical tips for implementing it. Indeed, many of the captains described their experiences in order to promote and share them with other sailors.

One example is Captain William Chapman, who on a voyage to northern Russia suddenly found himself without water, so he made do with what was on board and built a distiller that enabled the crew to overcome this difficult situation. It was an extremely crude piece of craftsmanship, but he was so surprised and pleased by its operation and the ease with which it could be operated that he reported it to the Royal Society in London (Chapman W., 1759, pp. 635-639).

His apparatus was primitive, but it certainly worked. It consisted of making a circular hole in the wooden lid of an ordinary large cooking pot and inserting a short piece of wooden tube about 4cm in diameter at right angles. At the top of this tube, another one was inserted at an acute angle, which descended to attach itself to a third pewter tube obtained by rolling up a plate. This pewter tube passed through a barrel of cold water, where the steam condensed and was collected in a receptacle. Chapman was amazed at how little fuel he needed to use, as the cooking pot was placed on the kitchen hearth, which had to work all the time.[9]

As the century progressed, more and more captains took the initiative, as Chapman had done and as Hales had reported and advised, to distil seawater when necessary with what they had at hand. Following this line of thought, in 1790 a certain Jacob Isaaks in New York State submitted to the US government what he called a "petition for a seawater distiller" (Nebbia G, Menozzi G.M., 1966b, pp. 170-171). Isaaks's request was original in that he did not claim to have discovered a new type of still, but proposed to use what was already on board a ship, with minor modifications, to create one and desalinate water. The applicant claimed that his proposal was based on several practical tests which had cost him a lot of work and money.

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[9] This consideration by Chapman also seems to be at the basis of the system illustrated by Leonardo in his drawing (see Fig. 23, p. 50).

observations, in which he claimed to have obtained fresh water from underwater springs off the coast of Bahrain in the Persian Gulf,[5] were published in 1595.

One cannot mention John Huyghen Van Linschoten without adding that he was also one of the first to record a concrete application of collecting vapour condensate from the air, which, as we shall see, was also attempted in the Atacama Desert, but without success. The case reported by Van Linschoten concerns the collection of natural dew that would form on the leaves of a particular tree in the Canary Islands. This is how he describes this phenomenon and the practice of exploiting it to produce fresh water:

> But God in hïs mercie hath provided for the want of water both for men and beastes, in this manner: for there is a great tree, which no man knoweth, (for the like is not found in any other place) the leaves whereof are small and long, and greene without changing: this tree is covered and compassed about with a small cloud, which continueth in one forme, and never altereth nor diminish: and this cloud casteth dew upon the leaves of the tree, which hang down, and drop continually (without ceasing) a most cleare, thinne, and fine water, which falleth into Cesternes, that by the inhabitants of the Island are made round about and under the tree, therein to keepe and preserve the water.

To return to the fresh water that in Cobija could be drawn from the sea: unfortunately, this unusual but providential source of supply proved to be short-lived because, following the earthquake and Great Tsunami of 1871, the geology of the area was disturbed and the pool of fresh water in the sea disappeared, never to be found again despite the many searches done by the inhabitants. However, the rapid development of the city had already made it necessary to supplement the water collected in the sea with desalination plants on land, which were already in operation. They were called *condensadoras* and in 1858 there was already one that could produce 14,000 litres per day.

A few years later, the port of Taltal, further south along the Atacama Desert, which had already belonged to Chile before the war, also did not need to resort to developing a desalination system, as it could rely on numerous natural fresh water springs, the *aguadas*, which were the land equivalent of Cobija's pool in the sea.

But these cases, however curious and interesting to learn about, were far from providing the solution to the water needs of the entire coast, which was bustling and in full development to ensure the export of minerals. Fortunately, a solution was available. Desalination by distillation had become so well established on ships that by this time there were several companies in Europe and the

[5] This part of the Arabian Sea is also called the Arabian Gulf, especially in Arab countries. In this text we will use the more internationally accepted form, Persian Gulf, or simply Gulf.

United States that manufactured desalination equipment also for use on land (see p. 103), making it possible to build new port cities that developed thanks to the supply of fresh water from the desalination of seawater. Even towns on the slopes of the Andes that supported mining activities were able to desalinate brackish water from local wells.

This was not an easy and inexpensive operation. Most of the distillers, with their ever-increasing capacity, had to be imported, mainly from Great Britain. Since they operated thermally and were still extremely inefficient, they needed large quantities of fuel. This was usually coal, also imported mainly from Great Britain. Obviously, the extremely high cost of supply could only be offset by the increasing demand for, and therefore value of, the minerals extracted and exported.

Not that the transport of fresh water by land or sea did not also exist, but it was extremely difficult due to the lack of infrastructure. In fact, most of the water was initially transported from the South and distributed by mule, but soon alternative ways of supplying the new ports with fresh water had to be found. Various solutions were tried, such as producing fresh water locally by experimenting with techniques to condense water vapour from the atmosphere on different surfaces and under different conditions. In 1861, for example, the Universidad del Norte commissioned studies to obtain fresh water by condensing fog.

All these initiatives were unsuccessful in practice, and desalination by evaporation and condensation of the steam produced quickly proved to be the only viable option. Within a quarter of a century, from 1850 to 1875, we went from having no desalination apparatus on land to having dozens and dozens of sites and also several companies that began to produce and sell water.

Thanks to this, Cobija survived the loss of its underground river and other towns developed, such as Tocopilla, Mejillones, which became the main port for the export of guano, and above all Antofagasta. It was along the 200 kilometres between the ports of Tocopilla and Antofagasta, which is a significant part of the Atacama Desert, that the world's largest concentration of desalination plants for human consumption was installed.

Antofagasta's rapid rise began in 1866, with the discovery of saltpetre. The population grew rapidly, reaching 400 in 1868 and 3,000 by 1872. The first large distiller was commissioned in 1868 and with its capacity of 270,000 litres per day was able to supply fresh water to the entire population.

By 1872, there were already 10 major stills operating in Antofagasta (Fig. 37a), under different owners and with different capacities. The stills were called by the names of their owners, such as Juán de Dios Vara or Teofilo Reska, or by more imaginative names, such as *La Estrella* (The Star), *El Sol* (The Sun) or *Los 4 Amigos* (The 4 Friends). By 1868, most mining companies, such as the *Compañia del Salitre* (Saltpetre Company), also had their own still, and sold water to the local population as well. In those early years, Antofagasta was 100% dependent on desalinated water from the sea (Maino V., Recabarren F., 2011).[6]

Desalination ensured the availability of fresh water that allowed the city to exist and develop, but its distribution was far from the convenience of running water that we are used to in more developed countries today. To obtain fresh water, consumers had to travel to the desalination plants located on the coast. The service was not immediate and long queues formed waiting for water to be delivered. For those who could afford it, home delivery was possible via small tanks transported by hand-drawn carts or by mules.[7]

The rapid development of the railways in the Atacama Desert was a powerful facilitator of the mining boom and the movement of people, but even with trains, the need to supply fresh water for the locomotives' steam engines posed great logistical challenges. In several cases, the solution to ensuring the water supply was the installation of distillers of brackish water extracted from wells located at strategic points along the railway.

In the case of Caldera, built in 1851 as a port to serve the mining town of Copiapó 75 km inland, a seawater distiller was installed to produce 34 m^3/day of fresh water (Fig. 37b). The reason for this is clearly stated in a report for the US House of Representatives:

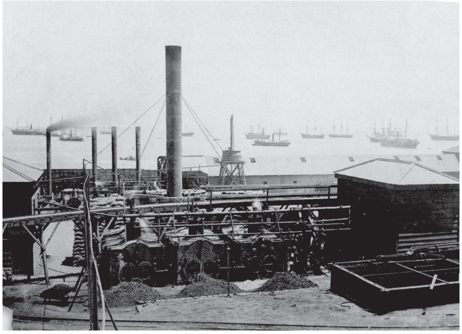
> Before the completion [of the railway] it was ascertained that none of the water could be used without rapid destruction of the engines, and it became necessary to erect a distilling apparatus to obtain suitable supplies. But even these has (sic) been a gain, the profits on the distilled water sold more than paying for the entire quantity prepared (Gilliss J.M., 1855, p. 248).

Sadly, the same page also contains this paragraph, which confirms the inhuman exploitation of the indigenous population for the construction of the railway:

> In a country producing nothing, not even a drop of water, where every article of consumption, as well as for the advance of the work, had to be conveyed from the starting point, it is most fortunate that a race could be found who are content to live so poorly provided. Otherwise, the cost for the maintenance of laborers alone must have much longer deterred any one from undertaking such a road. But the engineers have already brought near the day when the natives laying this track

[6] Most of the information on desalination in the Atacama Desert not specifically referenced is taken from this beautiful book.

[7] It is a reality we will find again in similar situations such as in Gibraltar (see p. 100) and also in our time in the Programa Água Doce in Brazil (see p. 157).



37a. One of the desalinators that operated in Antofagasta from the 1870-1880 decade, photograph from 1918 (from: Maino V. et al, 2011, p. 41).

37b. Desalination device with a capacity of 34 m^3/day built in 1851 in the port city of Caldera, mainly to power locomotive boilers (from: Gilliss J.M., 1855, p. 248).

must be startled from their lethargy by the scream of the engines upon its rails, or the doom of certain starvation awaits them.

The strategic value of desalination was also quickly discovered in military applications. During the aforementioned War of the Pacific (1879-1883), the Chilean army made important use of it in both the productive and destructive aspects.

On the productive side, the Chilean army found it difficult to supply water to its troops advancing along the coast of the Atacama Desert, so it developed small desalination units on wheels that followed the army as it advanced. They were called *resecadoras*.[8] On the destructive side, the desalination plants installed in ports along the coast, such as Antofagasta and Tocopilla, which at the time belonged to Bolivia, i.e. the enemy, were excellent strategic targets for the Chilean warships, which were easily able to target and bomb them thanks to their light colour and their location right on the seashore.

There is no clear evidence of locally built desalination apparatuses, but surely there must have been some - just as there had been in Djerba three centuries earlier - among which there probably were the Chilean army's *resecadoras*. There is, however, one exception, so important and significant that it constitutes an almost mythical landmark, not only in the history of desalination but also in the field of renewable energy. This is the Las Salinas wind- and solar-powered desalination plant, designed and built by the Swedish engineer Charles Wilson.

8 It would have been interesting to include a photograph of a military *resecadora* in this book. It seems confirmed that at least one exists because more than one Chilean assured me that he had seen one in a book or article, but without remembering where. It has not been possible to trace it, not even through the Military Museum in Santiago.

64b. The Persian Gulf oil spill during the first Gulf War in 1991: oil burns against a barrier (from: https://sociogatherers.wordpress.com).

Before 2000, water desalination was still a very expensive process because the MSF system, although the most widely used desalination method, consumes a lot of energy. For this reason it could only be used on a large scale for drinking water production purposes in oil-producing countries, which have extensive economic resources and can use the fuel extracted directly on their territory. Oil was used to produce desalinated water and electrical energy in so-called "dual purpose" plants (Gabbrielli E., 1981). In these cases, the energy for distillation is generally provided by the residual steam from the energy production process, which is of lower thermal content.

The dependence of countries such as those in the Persian Gulf on desalination clearly represents a potential risk in a conflict situation, when the facilities could become an easy target for wartime destruction in an attempt to bring a whole society to its knees. Although morally water resources should be preserved by the warring parties, this has never been the case in practice. We have already seen in this story how the Egyptians tried to use thirst to overcome Caesar's Romans besieged in Alexandria and the Turks the Spaniards barricaded on the island of Djerba, and how the Chileans bombed desalination plants on the Bolivian coast from their ships. A serious attempt to disable Saudi Arabia's desalination plants also took place during the Gulf War of 1990-1991.

Kuwait was invaded by Iraq in August 1990. On 16 January 1991, a US-led coalition launched what became known as the Gulf War to liberate Kuwait. A few days later Iraqi forces responded to the attack by dumping huge amounts of oil into the Persian Gulf. One of the Iraqis' main objectives was to contaminate the seawater intakes of the desalination plants of Saudi Arabia, which was part of the coalition. This would have been an incalculable social disaster as 70% of Saudi Arabia's population and part of its agriculture already depended on the water produced by the desalination plants. Disaster was averted by the creation of floating barriers (Fig. 64b) that kept the oil at a safe distance from the seawater intakes, but during the first few days, concern was high (Linden O., Jerneloev A., Egerup J., 2004).

As a result, the desalination plants in the Persian Gulf were front page news in newspapers around the world for days. This meant that a large part of the world's population heard about desalination for the first time; many became aware that seawater desalination was already a reality and that there were countries, such as Kuwait and Saudi Arabia, that relied on it as their primary source of fresh water. And not just countries with small populations like Kuwait, but also much larger ones like Saudi Arabia, with a population of more than 30 million people. Tony Walker, for example, headlined his article in The Sydney Morning Herald on 27 January 1991 as follows: *The US has accused Iraq of "environmental terrorism" after millions of barrels of Kuwaiti crude oil flooded into the Persian Gulf, threatening water-desalination plants and marine life*.

On 26 January 1991, Thomas W. Lippman and William Booth wrote in the Washington Post under the headline *Oil spreading off Kuwait poses ecological disaster*:

> Desalination plants in the Saudi cities of Jubail and al-Khobar both appear to be in the path of the spill because Persian Gulf currents run counterclockwise. The plants operate by a process known as "reverse osmosis", in which filters screen out molecules of salt from the incoming seawater. If oil reaches these filters, they will become overwhelmed and useless. […] Oil booms and skimmers have been provided to protect water desalination plants and power stations from the 35-mile-long oil slick moving south along the Saudi Arabian coast.

This quote is characteristic of the inaccuracies published, even in major newspapers, in the rush to write an article, especially when discussing a phenomenon as little-known at the time as desalination. In fact, even if the two chroniclers correctly describe the operation of RO, almost all the plants in Jubail and Al-Khobar they refer to were not RO plants but MSF distillation plants. In any case, if oil had entered the plants, the catastrophic result would have been the same, although surely the plants would have been stopped in time to ensure the integrity of the equipment before the oil entered.[5]

The Kuwaiti facilities continued to operate during the Iraqi occupation, but were later severely damaged during the war, although they returned to operation soon after the liberation of Kuwait. The Gulf War was certainly a wake-up call for all countries that depend on desalination, but this is no different from the criticality, and therefore vulnerability, of other infrastructures that provide water resources that must be protected, be they dams or treatment and distribution infrastructure. In any case, the Gulf War had no impact on the acceleration of the construction of new desalination plants, both in the region and around the rest of the world.

While MSF technology had come to dominate the seawater desalination market, RO plants continued to establish themselves in the field of brackish water desalination at the same time, steadily relegating ED to an increasingly secondary role. RO plants, along with other similar forms of filtration such as UF, were also increasingly being used by water utilities in the treatment of surface water that had a higher than normal salinity or, more importantly, contained worrying levels of contamination. These applications became widespread in the United States after the Milwaukee disaster in the spring of 1993, when some 400,000 people fell victim to a cryptosporidium epidemic caused by the presence of this bacterium in the city's water supply. Traditional treatment had failed to remove it and as a result, at least 69 people died.

RO desalination applications also grew rapidly. Eight RO plants with a capacity of more than 100,000m3/day appear in the plant register for the period 1970-2000. Two of these, in Saudi Arabia, were already built to treat seawater, while the other six were built to treat brackish water, one in Saudi Arabia, one in Taiwan to reclaim river water, and four plants in the USA. These four deserve special attention.

The first three, two in California, in San Diego and El Segundo, and the other in Florida, in Orange County, near Orlando, are important because they are the first three large-scale reuse projects, i.e. dedicated to using desalination techniques to treat wastewater, thus helping to set an important course in the fight against water scarcity. In this case, although RO membranes reduce the salt content of the treated water, the main objective is different, namely to remove impurities and pathogens so the water can be safely reused (see Fig. 106, p. 203). It is interesting to highlight

[5] Even the political world had to take note of desalination. On 28 January, for example, the British Government's Secretary of State for the Environment, Michael Heseltine, addressed the House of Representatives as follows: "Mr. President, with your permission I will make a statement on the UK's response to the environmental damage that is occurring in the Gulf. The oil spill in the Gulf appears to be the largest ever. It is 35 miles long and 10 miles wide. It appears to contain about 8 million barrels of oil and is moving along the Gulf at 15-20 miles a day. [...] The threat affects desalination plants and fresh water supplies, birds and other wildlife, fish, marine mammals and crustaceans, and local communities that depend on the sea for their livelihoods [...]."