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A SHORT HISTORY OF WATER DESALINATION

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A SHORT HISTORY OF WATER DESALINATION

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One of the ways in which humanity may face the shortage of fresh water in the future is undoubtedly the transformation of brackish waters and sea water into fresh water with one or more of the many processes already developed or under development (1).

The problem of water desalination is not new and even from ancient times man, crossing the deserts in caravans or during long navigations on the oceans, has speculated on the possibility of obtaining at least a small amount of fresh water from so large a quantity of salt water surrounding him, and possibly has tried to obtain it.

Recently some papers have given an account of the history of water desalination (2) (3) (4) (5) (6) (7).

In the present paper a review will be made of current knowledge in this field, extending the information already presented in a previous paper (8).

For further information on the authors quoted, reference is made to the classical work of Sarton (9).

Desalination in antiquity

The oldest reference to what seems water desalination is presented in *Exodus, 15,* 22-25: "So Moses brought Israel from the Red Sea, and they went out into the wilderness of Shur; and they went three days in the wilderness, and found no water. And when they came to Marah, they could not drink of the waters of Marah for they

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(1) A review of the literature in this field is contained, among others, in the book: G. Nebbia, "Il problema dell'acqua e la trasformazione delle acque salmastre in acqua dolce", Cacucci Editore, Bari, 1965.

(2) Huber, "Über die Mittel zur Herstellung genussfähigen Wassers aus Meerwasser", *Marine-Rundschau, 9,* 1045, 1129, 1369, 1551 and 1686 (1898).

(3) E.C. Smith, "A Short History of Naval and Marine Engineering", Cambridge University Press, London, 1938.

(4) C.A. Hampel, "Fresh Water from the Sea", *Chemical and Engineering News, 26,* (27), 1982-1985 (1948).

(5) T.G. Thompson, "Fresh Water from the Sea", *Technion Yearbook,* 1957.

(6) P.H. Schadewaldt, "La distillazione dell'acqua di mare a bordo dei velieri", *Atti del XVIII Congresso Nazionale di Storia della Medicina,* Sanremo, Ottobre 1962.

(7) P.H. Schadewaldt, "Die Wasserversorgung an Bord. Eine medizinhistorische Studie", *Gesnerus, 20,* 47-89 (1963).

(8) G. Nebbia and G. Nebbia Menozzi, "Aspetti storici della dissalazione delle acque salmastre", *Acqua Industriale, 8,* (41), 13-18 and (42), 23-24 (1966).

(9) G. Sarton, "Introduction to the History of Science", Williams & Wilkins Co., Bal-

were bitter: therefore the name of it was called Marah. And the people murmured against Moses, saying, What shall we drink? And he cried unto the Lord; and the Lord shewed him a tree, which when he had cast into the waters, the waters were made sweet".

Nobody can say what type of tree this was.

The different nature of fresh water and saline water was already known to the philosophers of ancient times.

THALES OF MILETO (c. 624-548 B.C.) (9; Vol. I, page 72) considered water as the first and main element and the origin of all things and suggested that fresh water is really sea water filtered through the earth.

The same theory was presented by DEMOCRITUS (460?-350? B.C.) (9; Vol. I, pages 88-89); his works have reached us only as titles and fragments, but his views influenced Aristotle, and, later, Theophrastus and Plutarch.

PLATO (c. 427-347 B.C.) (9; Vol. I, pages 113-116), the true founder of the occidental philosophy, considered the problem of water in a few passages of his works.

In *Timeo* he referred to the vegetable juices (*kumoi*) suggesting that they originated from the ground water filtered through small pores of plants (*Timeo,* 59 E) (10).

In *Laws* he stated that clay is impermeable to water (*Laws,* VIII 844 B) (10), the first statement of the true qualities of this substance.

ARISTOTLE (384-322 B.C.) (9; Vol. I, pages 127-136) dealt extensively with the problem of water in his works (11), and he discussed the nature and the properties of saline water and the possibility of water desalination.

One of his first speculations was about the nature of the sea: "Some again believe that the sea is, as it were, the sweat of the earth which it sweats out when the sun heats it: which is the reason why it is salt because sweat is salt. Others suppose that the earth is the cause of its saltness: just as water strained through ashes becomes salt, so the sea is salt because earth with this property is mixed with it" (*Meteorologica,* Book II, Chapter I, 353 b 10) (12; page 125).

Discussing the fact that the rivers are less salty than the sea, Aristotle reported: "So some say that rivers not only flow into the sea, but out of it, and that the salt water becomes drinkable by being filtered" (*Meteorologica,* Book, II, Chapter II, 354 b 15) (12; page 133).

In pseudo-Aristotle's *Problems* can be found also that if one digs near the sea, one would find first fresh water and then salt water (this is a phenomenon which has been confirmed by experience): "Is it because the water consists of the sea itself which percolates beneath the earth? Naturally, therefore, the water on top is sweet; for sweet water is lighter than salt water, and the sea contains some elements of sweetness, which when mixed with earth comes more to the surface" (*Problems,* Book XXIII, 37) (13; Vol. II, page 37).

In the same *Problems* the question of change of salinity after heating is treated: "Why is salt water drinkable when it is cold, but more drinkable when it is heated,

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timore, Md., Vol. I, 1927; Vol. II-I and II-2, 1931; Vol. III-1, 1947; Vol. III-2, 1948.

(10) "Platonis opera recognovit brevique adnotatione critica instruxit Ioannes Burnet", Scriptorum Classicorum Bibliotheca Oxoniensis, Oxford, 1945, Vol. IV.

(11) "Aristotelis opera omnia graece et latine cum indice nominum et rerum absolutissimo", Firmin-Didot, Paris, Vol. III, 1854; Vol. IV, 1878; Vol. V, 1874.

(12) Aristotle, "Meteorologica", with an English translation by H.D.P. Lee, Harvard University Press, Cambridge, Massachusetts, 1962.

(13) Aristotle, "Problems", with an English translation by W.S. Hett, Harvard University Press, Cambridge, Massachusetts, 1957.

when it is hot and when it is cooling?... Now the drinkable is the opposite of the briny and the brine is boiled out when it is heated, but is precipitated when it grows cold" (*Problems*, Book XXIII, 18) (13; Vol. II, pages 25-27).

The same statement is also found elsewhere: "Salt water evaporated forms fresh and the vapour does not when it condenses condense into sea water again". (*Meteorologica,* Book II, Chapter III, 358 b 15) (12; page 157).

In the above passages there is evidently a great deal of confusion and misunderstanding although it appears that the author felt the need to explain the change that took place during heat treatment of the sea and salt water.

The extraordinary idea that sea water can be made sweet by boiling it is found in *Geoponica,* II, 47.3, in Cassius (14) and also in Hippocrates (15) who generalized stating that not only water, but anything else is sweetened by boiling.

Perhaps the idea arose from a misunderstainding of some account of distillation (16).

The statements become a little clearer in another passage where, after having mentioned other liquids, paying particular attention to wine (that gives water when it evaporates and condenses), Aristotle concluded: "For the present let us confine ourselves to saying that a certain amount of the existing sea water is always being drawn up and becoming fresh" (*Meteorologica,* Book II, chapter III, 358 b 20) (12; page 157), what might be interpreted as a reference to the natural water cycle (16a).

The most interesting statement is the one referring to the possibility of sea water desalination: "Make a jar of wax and put it into the sea, having fastened its mouth in such a way as to prevent the sea getting in. It will be found that the water which gets through the wax walls is fresh, for the earthy substance whose admixture caused the saltiness is separated off a though by a filter" (*Meteorologica,* Book II, Chapter III, 358 b 34, 359 a) (12; page 159).

The same idea is expounded in the *History of Animals*, after a consideration on the water filtration from sea in living organisms. "Of testaceans, some, that are incapable of motion, subsist on fresh water, for, as the sea water dissolves into its constituents, the fresh water from its greater thinness percolates through the grosser parts; in fact they live on fresh water just as they were originally engendered from the same. Now that fresh water is contained in the sea and can be strained off from it can be proved in a thoroughly practical way. Take a thin vessel of moulded wax, attach a cord to it, and let it down quite empty into the sea; in twenty-four hours it will be found to contain a quantity of water, and the water will be fresh and drinkable" (*History of animals*, Book VIII, Chapter II, 590 a 20-24) (17; Vol. II, page 116).

Aristotle's statement that sea water becomes fresh after filtration through a « wax » vessel has been the object of many discussions among philologists and historians of science (18) (19) (20) (21) (22) (23).

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(14) J.L. Ideler, "Physici et Medici Graeci Minores", I, page 163.
(15) Hippocrates, "Airs, Waters, Places", 8.
(16) M. Glycas, *Annales*, I, page 10 (19 Bekker).
(16a) A.B. Biswas, "The Hydrological Cycle", *Civil Engineering*, 70-74, April 1965.
(17) "The Works of Aristotle - Volume II", William Benton Publisher, Encyclopaedia Britannica Inc., 1952.
(18) H. Diels, "Aristotelica", *Hermes, 40,* 310-316 (1905).
(19) E.O. Von Lippmann, "Chemisches und Alchemisches aus Aristoteles", *Archiv Geschichte Naturwissenschaften und Technik* (Leipzig), *2*, 233-300 (1910).
(20) E.O. Von Lippmann, "Die 'Entsalzung des Meerwassers' bei Aristoteles", *Chemiker-Zeitung, 35*, (70), 629-630 (1911).

In 1905 Diels (18), discussing the tradition of the idea of wax vessel, indicated that these stories were rst originated by Democritus.

One possible interpretation is that the Greek sentence *angeion kérinon* (wax vessel) ought to be read *angeion keràminon* (i.e. earthen vessel) and that desalination might be obtained by filtration through a sort of earthen vessel.

Von Lippmann reported (20) that a chemist, Dr. Erdmann, had attempted to desalt sea water by filtering it through an earthen vessel but with no success. Equally unsuccessful have been any trials to obtain fresh water by filtration or osmosis through wax (24).

So far no scientific explanation may be given to this intriguing and widely quoted passage.

In THEOPHRASTUS' (24a) study of vegetal physiology, he discussed the problem of salt water and stated that what is saline is heavy, remains in the ground and is not absorbed by roots and does not penetrate the plant (*On the origin of plants,* VI, 10), and that the salt parts are not round; instead, what is sweet is round, and this justifies the different absorption by the plants (*De sensu et sensibilibus,* 66).

In the following centuries an interesting account of water problems and their solution is found in the narrative of the war in 48 B.C. between Caesar (9; Vol. I, pages 216-217) and Ptolemy XII.

In that year CAESAR was besieged in Alexandria with his army: General Ganimedes, who was the chief of the operations against Caesar, decided to interrupt the town's fresh water supply and consequently Caesar's army were left without water and began to panic. "By encouragement and reasoning Caesar allayed his men's alarm, declaring that sweet water could be found in wells and trenches, inasmuch as all sea-shores naturally possessed veins of sweet water..." (26; page 19).

"Having harangued his men to this effect and put fresh heart into them all, he briefed his centurions as follows: they were to interrupt their other tasks and turn their attention to digging wells, continuing without any cessation all through the night.

Where-upon, the business being once undertaken with unanimous enthousiasm for the task, in the course of that one night a great quantity of sweet water was discovered" (26; pages 21-23).

This passage is important, first because it sometimes has been misinterpreted in the sense that they believed Caesar used some form of distillation to distribute fresh water to his soldiers, and second because it gives a correct interpretation of the presence of fresh water near the sea shore.

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(21) E.O. Von Lippmann, "Die 'Entsalzung des Meerwassers' bei Aristoteles: ein Nachtrag", *Chemiker-Zeitung, 35,* 1189-1190 (1911).

(22) E.O. Von Lippmann, "Abhandlungen und Vorträge zur Geschichte der Naturwissenschaften", Vol. I, 1906; Vol. II, 1913; see Vol. II, pages 157-162.

(23) W. Brieger, "Zur 'Entsalzung des Meerwassers' bei Aristoteles", *Chemiker-Zeitung, 74/75,* 302 (1918).

(24) See: M.K. Stephanides, *Athena, 13,* 3 (1901), and D'Arcy W. Thompson in the Oxford translation of Aristotle's *Historia Animalium.*

(24a) Theophrastus (376-286 B.C.), pupil of Plato and Aristotle, was the author of works of botany (*Enquiry into plants, On the origin of plants*) and of natural science, among which a collection of *Physical questions,* in 18 books, has reached us simply as fragments (25).

(25) "Theophrasti Eresii opera, quae supersunt, omnia, graece recensuit, latine interpretatus est... F. Wimmer", Firmin-Didot, Paris, 1866.

(26) Caesar "Alexandrian, African and Spanish Wars", with an English translation by A.G. Way, Heinemann, London, 1955. Aulus Hirtius, one of the Generals of Caesar, is probably the author of the book on the Alexandrian War.

PLINY (23-79 A.D.) (9; Vol. I, pages 249-251), the author of the great and encyclopedic *Natural History* (27), dealt in various passages with the problem of desalination.

At one point he states: "But the nitrous and salty-acid streams that in the desert flow to the Red Sea are made sweet within two hours if pearl barley is added, and the barley itself they eat" (Book XXXI, 36) (28).

At another point is written: "Because those at sea often suffer from the failure of fresh water, I shall describe ways of meeting this difficulty. If spread around a ship, fleeces become moist by absorption of evaporated sea water, and from them can be squeezed water which is fresh. Again, hollow wax balls, let down into the sea in nets, or empty vessels with their mouth sealed, collect fresh water inside. But on land sea water is made fresh by filtering through clay" (Book XXXI, 70) (29).

PLUTARCH (c. 50 - 125 A.D.) (9; Vol. I, pages 251-252), a writer of historical and philosophical works, flourished in Greece a short time after Pliny.

One of his *Moralia* is entitled: "Causes of Natural Phenomena" (*Quaestiones Naturales*) (30), and contains several references to scientific problems and also to desalination.

"Or is the salty flavouring exstinguished in fruits by the action of heat, just as men remove the saltiness and tang of sea-water by boiling it?

Or is a flavouring, as Plato said, water that has been strained through a plant, whereas even the sea loses its saltiness when filtered? For this saltiness is earthy and in large particles (31); hence by digging on the seashore men come on drinkable moisture; frequently, too, they draw up sweet filtered water from the sea in vessels made of wax, the salty earthy constituents being thus separated from it; previous passage through white clay also renders the sea, so filtered, quite drinkable, because the clay retains the earthy constituents and does not let it through" (*Moralia,* 913 C D) (30; pages 164-165).

ALEXANDER OF APHRODISIAS, one of the greatest commentators of Aristotle, flourished at the time of Septimius Severus and Caracalla (193-217 A.D.), reported the same concepts as Aristotle had. In his *Natural Problems* he wrote: "Some say that the origin of the saltness of the sea is the earth itself. The water, in fact, running through the ground, takes its same properties" (Book II, Chapter X) (32; page 173).

In his commentary on Aristotle's *Meteorologica*, Alexander presented the first description of distillation as a means of obtaining fresh water from the sea: "Some obtain fresh water from the sea in the following way: they place large vessels,

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(27) Pliny, "Natural History", Harvard University Press, Cambridge, Massachusetts, 1963, Vol. VIII.

(28) "Nam nitrosas atque salmacidas in desertis Rubrum mare petentes addita polenta utiles intra duas horas faciunt ipsaque vescuntur polenta" (27; pages 398-399).

(29) "Quia saepe navigantes defectu aquae dulcis laborant, haec quoque subsidia demonstrabimus. Expansa circa navem vellera madescunt accepto alitu maris, quibus dulcis humor exprimitur; item demissis reticulis in mare concavæ ex cera pilæ vel vasa inania opturata dulcem intra se colligunt humorem. Nam in terra marina aqua argilla percolata dulcescit" (27; pages 420-423).

(30) "Plutarch's Moralia", with an English translation by Lionel Pearson and F.H. Sandbach, Harvard University Press, Cambridge, Massachusetts, Vol. XI, 1965.

(31) See also, Plutarch, *Quæstiones Conviviales*, 627 B and C (from Aristotle).

(32) "Quæstiones Alexandri Aphrodisiæi naturales, de anima, morales: sive difficilium dubitationum atque solutionum libri IV, nunc primum in lucem editi, Gentiano Herveto Aureliano interprete", Basileæ, 1548.

containing sea water, on the fire and collect the vapor in appropriate covers, placed on the vessels; by condensation of the vapor they obtain fresh water" (33).

A contemporary of Alexander is AELIAN (c. 170-235 A.D.) (9; Vol. I, page 326) who was born at Praeneste and lived in Rome under Septimius Severus and Elagabalus.

He was essentially a compiler and his main works, written in Greek, are a collection of historical anecdotes and a treaty on the peculiarities or the nature of animals.

In the latter work (35) he referred to the possibility of water desalination using wax vessels and indicated the transmission of this idea from Democritus, to Aristotle and finally to Theophrastus.

"Aristotle, and Democritus before him and third in order Theophrastus, assert that fish are not nourished by salt water but by the fresh water that is mingled with the sea. And since this seems almost incredible, the son of Nichomachus (Aristotle), wishing to confirm the statement by actual practice, says that in every sea there is some drinkable water and that it can be proved in this way. If one makes a thin, hollow vessel of wax and lets it down empty into the sea, having attached it so that it can be hauled up, after a night and a day it is, when drawn up, full of fresh and drinkable water. And Empedocles of Agrigentum asserts that there is some fresh water in the sea, not indeed perceptable to all, through it does nourish fishes. And this sweetening of the water in the brine he says is due to natural causes, which you may learn from his writings" (Book IX, 64) (35; Vol. II, page 283).

ST. BASIL (329 - 379 A.D.) (9; Vol. I, pages 361-362), Archbishop of Cesarea, who, to spread the faith, travelled widely and particularly in the East, reported in his *Homilies* (36) the method followed by the seamen of his time to obtain fresh water from the sea; they boiled sea water in a vessel on the fire and suspended over it sponges in which the vapor condensed; by squeezing the sponges fresh water was obtained (37). Shortly before he made the usual erroneous statement that sea water becomes fresh by filtration through sand (38).

OLYMPIODOROS, the great commentator of Aristotle, who lived in Alexandria in the sixth century, after having given an account of water desalination through wax vessels, tried to prevent any forthcoming objections to this procedure: "Someone might observe that the water has become sweet because of wax in which a part of

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(33) "Per hunc quidem modum maris aquam potabilem nonnulli reddunt: lebetes enim ejusmondi aqua plenos multo igni imponentes et vaporem in operculis superimpositis colligentes et recipientes in aquam permutato untutur potu", from: "Johannis (Philoponi) Grammatici in libris de generatione et inter. et Alexandri Aphrodisiæi in Meteorologica Commentarii", Venezia, 1527, page 97; this passage lacks in the translation of the Commentary made by Alexander Piccolomini in 1548, different however from the translation by Camotius (1556) (34; page 311).

(34) A. de Humboldt, "Histoire de la Géographie du Nouveau Continent", Librairie des Sciences Naturelles, Paris, n.d., Vol. II.

(35) Aelian, "On the Characteristics of Animals". With an English translation by A.F. Scholfield, in 3 vols., Harvard University Press, Cambridge, Massachusetts, 1955.

(36) "Sancti Basilii Cæsareæ Cappadociæ archiepiscopi, opera omnia quae extant", Paris, 1721 (Greek and Latin texts).

(37) "Quin etiam ipsam maris aquam a navigantibus concoqui videre licet: qui vapores spongiis excipientes, in necessitatibus utcumque penuriam elevant" (IV Homily: De aquarum congregatione) (36; page 39).

(38) "(Mare) ubi in obliquis non autem recta tendentibus diverticulis inclusum est... tum superficie disrupta foras erumpit; atque emendante amaritudinem percolatione, potui aptum evadit" (36; pages 38-39).

honey has remained, but should this reason be valid, sea water would also become sweet if the water was poured into the wax vessel through its mouth", which does not happen, Olympiodoros says, since desalination occurs only if the filtration takes place through the vessel walls (39; page 43).

Olympiodoros also reported the desalination procedure previously indicated by St. Basil (36): "Seamen, when they lack fresh water at sea, obtain it as follows: they boil the sea water, then place large sponges over the boiling water to collect the rising vapor. When they squeeze the sponges, the water obtained is fresh" (39; page 43) (34; page 311).

A contemporary and a friend of Olympiodoros, JOHN PHILOPONUS (9; Vol. I, pages 421-422), commented on almost all of Aristotle's works and his writings were widely diffused among the Syrians and Arabs.

In his work on the nature of animals he described the statement of Aristotle that water desalination may take place by filtration through the walls of appropriate vessels, although he clearly indicated the use of earthen vessel (*kerameoun angeion*) instead of wax vessel (18; page 311, note 1).

Water desalination in the Middle Ages

The scientific knowledge of the Greek and Latin world passed to the Arabic and Eastern world where such knowledge was elaborated and enlarged.

The Persian physician ABU MANSUR MUWAFFAQ IBN 'ALI AL-HARANI (9; Vol. I, page 678) in his *Book of the Foundations of the True Properties of Remedies* written about 975 A.D. indicated distillation as a system for water desalination (40) (40a).

The great Arabian naturalist AL-BIRUNI (973-1048) (9; Vol. I, pages 707-709) in his *Chronology of Ancient Nations* (41) (42) dealt with water desalination as follows: "People say that on the 6th (January) there is an hour during which all salt water of the earth is getting sweet. All the qualities occurring in the water depend exclusively upon the nature of that soil by which the water is enclosed, if it be standing, or over which the water flows, if it be running. Those qualities are of a stable nature, not to be altered except by a process of transformation from degree to degree by means of certain *media*. Therefore this statement of the waters getting sweet in this one hour is entirely unfounded. Continual and leisurely experimentation will show to any one the futility of this assertion. For if the water were sweet it would remain sweet for some space of time. Nay if you would place — in this hour or any other —

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(39) "Olympiodori philosophi Alexandrini in Meteora Aristotelis Commentarii", Venezia, 1551.

(40) F.R. Seligmann, "Codex vindobonensis sive medici abu Mansur Muwaffak ibn Ali Heratensis Liber fundamentorum farmacologiae", Vienna, 1838, Persian text and Latin translation. German translation: "Die pharmakologischen Grundsätze des Abu Mansur übersetzt und mit Erklärungen versehen von Abdul-Chalig Achundow", Koberts Historische Studien aus dem pharmak. Institut der Universität Dorpat, Halle, Vol. III, 113-414 and 450-481 (1893).

(40a) A. Bittel, "Zur Geschichte multiplikativer Trennverfahren", *Chemie-Ingenieur-Technik*, *31*, 365-378 (1959).

(41) Al-Biruni, "The Chronology of Ancient Nations", edit. C.E. Sachau; text, Leipzig, 1878, page 250; translation, London, 1879, page 240.

(42) E. Wiedemann, "Entsalzung des Meerwassers bei Bîrûnî", *Chemiker-Zeitung*, *46*, 230 (1922).

in a well of salt water some ratls (43) of pure dry wax, possibly the saltishness of the water would diminish. This has been mentioned by experimenters, who go so far as to mantain that if you make a thin vase of wax and place it in sea water, so that the mouth of the vase emerges above the water, those drops of water which splash over into the vase become sweet. If all salt water were mixed with so much sweet water as would overpower its nature, in that case their theory would be realized (i.e. all salt waters would become sweet)".

The Bizantine philosopher and naturalist NICEPHOROS BLEMMIDAS (c. 1197 - 1272) in his *Physical Epithome* repeated the statement of desalination by filtration through wax vessels (44).

GILBERTUS ANGELICUS (about 1245) (9; Vol. II/2, page 658) used an alembic as a relief from thirst during his voyage in the Holy Land in 1227 (45).

The problem of water desalination is dealt with also in the medical work *Rosa medicine* (46) by JOHN GADDESDEN (c. 1280 - 1361) (9; Vol. III/1, pages 880-882) in which the author indicates four desalination methods: the filtration of sea water through the earth, the boiling and condensation of water vapor on linen, the distillation with alembics, and the filtration through the walls of a wax vessel, this latter following Aristotle's tradition (47).

A long chapter on water desalination and purification is contained in the celebrated work *De re aedificatoria* (48) by LEON BATTISTA ALBERTI (1404-1472), the great scientist and architect of the XV century.

The 8th chapter of Book X begins with Joseph who is said to have stated that Moses, arriving in an arid place where only a well containing salty water was available, had ordered his soldiers to stir it and the water became potable. Alberti then quoted the use of a paste of rye which would desalt saline waters. He added that Solinus is reported to have said that sea water, after filtration, becomes fresh (49); Alberti

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(43) The *ratl* is a weight unit, about 500 grams. See: W. Hinz, "Islamische Masse und Gewichte", Brill, Leiden, 1955.

(44) N. Blemmidas, "Physical Epithome", c. 17; see: Migne, "Patrologia Græca", CXLII, coll 527-1634.

(45) Gilbertus Angelicus, "Compendium medicinæ", Lyon, 1510, fol. 363 (de regimine transfretatium).

(46) Johannes Gaddesden, "Rosa anglica practica medicine a capite ad pedes", editio princeps: Pavia, 1492 (one copy may be found in the Putti Library, Istituto Rizzoli, Bologna).

(47) "Dulcis aqua de marina fit quadruplice: 1º sic aqua marina transeat multis vicibus per harena et efficiet dulcis; 2º bulliat aqua salsa in cacabo et linteamen mundum ponatur super fumum: postea exprimatur et transeat: erit illa aqua dulcis; 3º sic distillet aqua salsa per alembicum suaviter et erit aqua dulcis; 4º modo fiat de cera unum vas concavum subtile et ponatur in alio vase pleno aqua salsa ita ut non intret per orificium superiorem et tunc intrabit per poros cere illud quod subtile erit: et hoc est dulce et stabit in vase cereo et istum modum tangit Aristoteles et expositores in 2º Metaurorum et sic pisces per brancas separant peropte salsam terrestrem adustam ab aquosa insipida et nutriunt dulci aqua aliqualiter. Similiter carnes salse bis cocte in aqua dulci amittunt salsedinem si cum hoc laventur bene et frequenter". (46; fol. 173br).

(48) L.B. Alberti, "De re ædificatoria", 1452: first printed in 1485. An English translation has been published in London in 1955.

(49) This is a very intriguing point. Alberti and, later, Della Porta — the latter probably deriving his ideas from the former — refer to Solinus (fl. in the 2nd half of the 3rd century A.D.) the author of a collection of naturalistic and geographical information, *Collectanea rerum memorabilium*, or *Polyhistor* (many editions and translations; critical edition by T. Mommsen, Berlin, 1895). We have not been able to locate this statement in the consulted edition of Solinus' work.

also said that placing an earthen vessel tightly closed in the sea, the vessel will fill with fresh water.

Here again the tradition of the wax vessels changes to the more reasonable, but equally not yet confirmed, idea of desalination by filtration through earthen vessels.

Water desalination in the Renaissance and in modern times

Geographical discoveries, expansion of commerce and long voyages across the oceans gave a new importance to the problem of fresh water, especially on ships, and scientific observations and reports of practical applications multiplied rapidly.

We have attempted to follow this increasing interest in order to see the development of past ideas in the light of the new experimental method.

For further information about the various authors we refer the reader to the bibliographical works of Thorndike (50) and Partington (51).

In chronological order we first meet ANDRÉS LAGUNA (1499 - 1560), personal physician of the King of Spain Charles V, who prepared and edited a translation with comments on Dioscorides' *Materia Medica* (52).

In the comment in the 12th chapter of Book V he wrote: "It is possible to obtain fresh, or at least potable water from sea water by filtering through sand, or distilling by alembics, or exposing fleeces over the side of a ship, during the night; vapor condenses on the fleeces and water may be recovered in the morning by squeezing them. If one places a sphere of wax, tightly closed, in the sea, fresh and good water may be collected in it" (52a).

Similar observations are reported in his medical treaty (53).

A Spanish author (54) has seen in Andrés de Laguna an inventor of the distillation processes, but it appears that he reported what was already available through tradition and experience.

The traveller JEAN DE LERY during his voyage to Brasil in 1556 distilled sea water to obtain fresh water (55).

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(50) L. Thorndike, "A History of Magic and Experimental Science", Columbia University Press, New York, Vol. I, 1923; Vol. II, 1923; Vol. III, 1934; Vol. IV, 1934; Vol. V, 1941; Vol. VI, 1941; Vol. VII, 1958; Vol. VIII, 1958.

(51) J.B. Partington, "A History of Chemistry", Mc Millan, London, Vol. II, 1961; Vol. III, 1962.

(52) C.E. Dubler, "La 'Materia Medica' de Dioscorides: trasmision medieval y renacentista", 5 vols., Barcelona, 1955.

(52a) "Hazese de la marina dulce, o alomenos salobre, y potable colandola por arena, destilandola en alambiques, y estendendo al derredor de las naos, a la noche, algunos vellones de lana, para que reciban en si el vapor, y a la mañana esprimiendolos. Echanse también en la mar dentro de alguna red, unas pelotas de cera, buecas y muy liulanas, las quales cogen en si una agua dulce y suavissima" (52; Vol. III, page 514).

(53) A. Laguna, "Compendium curationis precautionibusque morbi passim populariterque grassatis", Strassburg, 1542, last fol.

(54) A.H. Morejon, "Historia bibliografica de la Medicina española", Madrid, 1843; see: 52; Vol. IV, 31-32.

(55) "Il ne seroit pas possible en ceste extremité de boire... je responds que quelque recepte qu'on ne peust alleguer de la faire passer par dedans de la cire, ou autrement d'allambiquer". J. de Lery, "Histoire d'un voyage faict en la Terre du Brésil, autrement dite Amerique", Genf, 1580, chapter 4, page 32.

In 1560 — two years before the Lepanto battle, marking the defeat of the Turks in the Mediterranean — Philip II, King of Spain, had sent a fleet against the Turks in Tunisia. The fleet, at the command of the Duke of Medinaceli, viceroy of Sicily, reached the small island of Gelves (Djerba), near the Tunisian coast, in February 1560. A Turkish fleet, at the command of the admiral Piali, arrived here on the 11th of May; the Spanish fleet abandoned the island leaving a small garrison that was besieged by more than 12,000 Turks and resisted until the 29th of July, when the remainder surrendered.

During the siege the garrison suffered thirst because the water in the reservoirs was soon exhausted. One Sicilian captain, SEBASTIAN DE LA POLLERE, discovered that fresh water could be obtained distilling sea water with a sort of alembic; he is reported (55a) (55b) to have been able to obtain as much as 40 large barrels of fresh water daily (55c).

JEAN TAISNIER of Hainault in his *Introduction to Astrology* of 1559 lists various practical inventions as a triumph of astronomy; he foresees, for example, that ships will be guided to distant ports and that sea water will be rendered potable (50; Vol. V, page 584) (55d).

In 1567 JACQUES GOHORY (died in 1576) under the pen name, Leo Suavius, wrote a *Compendium* of the philosophy and medicine of Paracelsus in which the *Static Experiments* of Nicholas of Cusa are quoted as sources for a method of extracting fresh from salt water by immersing a waxen sphere in the sea (50; Vol. V, page 637) (51; Vol. 2, page 162) (55e; page 375).

Undoubtedly one of the most significative and striking figures of this period of experimental science is GIOVAN BATTISTA DELLA PORTA (1535 - 1615) (50; Vol. VI, pages 418-423); one can not be surprised, therefore, that his interests have also covered the field of water desalination.

The whole problem will be dealt with in another paper (56); only a short summary of his contribution will be given here.

The problem of water desalination has been treated in both editions of his book *Magiae naturalis*. The first edition was in four books and appeared in 1558 (57): here three desalination systems were reported: (a) by filtration through wax vessels;

(55a) L. Cabrera De Cordoba, "Felipe II, rey de España", Madrid, 1876.

(55b) F. Duro, "Estudios historicos del reinado de Felipe II. El desastro de los Gelves (1560-1561)", Madrid, 1890.

(55c) "Un siciliano que llamaban el Capitán Sebastián se ofreció á sacar agua dulce para beber de la de la mar. D. Alvaro le prometió 500 ducados en dinero y 200 de renta. Hiciéronse muchos alambiques y henchíanlos de agua de la mar y les deban fuego, y destilaba agua dulce y muy buena, sana, sin ningún sabor de sal. Hacía 40 barriles della, que bastaban á dar ración á 700 hombres. Cada Oficial, sin esto, hizo su alambico para su casa, y muchos vivanderos hicieron los suyos, con que sacaban agua para vender. Vendíanla al principio á un real el cuartucho; después fué faltando leña, y vino á valer á dos reales el cuartucho, que media azumbre de la medida de España. Esta agua fué muy gran parte á que no muriese mucho mas gente de la que murió" (55b; page 122-123).

(55d) J. Taisnier, "Astrologiæ indiciariæ ysagogica et totius divinatricis artis encomia cum nonnullis Habrahami Iudei et Luce Gaurici dictis... In Epistola dedicatoria quatuor mathematicæ quantitates cum earum laudibus et utilitate notantur", Coloniæ, 1559.

(55e) Teophrasti Paracelsi philosophiæ et medicinæ utriusque universae compendium ex optimis quibuscumque eius libris cum scholiis in libros IIII eiusdem De Vita Longa... auctore Leone Suavio", Paris, (n.d. but 1567). Other editions in Frankfurt, 1568, and Basel, 1568.

(56) G. Nebbia and G. Nebbia Menozzi, "Il contributo di Giovan Battista Della Porta alla dissalazione delle acque salmastre", to be published in *Acqua Industriale*.

(b) by filtration through the walls of an earthen vessel; (c) by contact in a vessel with sands of rivers (58) (59).

The second edition of the *Magiae Naturalis,* in 20 books, appeared in 1589 (60) and water desalination is treated in the first chapter of Book 20, which contains a list of curious statements and quotations, together with some new genuine information and observations.

The following desalination methods were reported: (a) distillation with stills having one or more condensation tubes: (b) condensation on fleeces of the vapors formed on a water surface; (c) filtration through a series of many vases filled with earth, placed one above the other, so that the filtrate of one vase entered the vase underneath (Della Porta noted that he had not observed any desalination with ten vases, that he had been told that a "friend" had succeeded with 20 vases, and argued that perhaps the different earths have different desalination properties) (61); (d) filtration through clay giving fresh water, according to Solinus (62); (e) desalination with wax and earthen vessels, already recorded by Aristotle, Pliny and Alberti (Della Porta noted that the wax vessel method should be of limited practical use and that the method of desalination through earthen vessels had been tried by himself, but with no success) (63); (f) heating of sea water, suggested in the pseudo-Aristotle's

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(57) "Magiæ naturalis sive de miraculis rerum naturalium libri IIII", Napoli, 1558. Other editions: 1560 (Antwerp); 1561 (Antwerp and Lyon); 1562, 1564 (Antwerp); 1564 (Lyon); 1567 (Antwerp); 1569 (Lyon); 1585 (Antwerp); 1591 (Lyon). French translations published in Paris, 1570; Rouen, 1631. Italian translations with the title: "De i miracoli et meravigliosi effetti dalla natura prodotti libri IIII", Venezia, 1560, 1562, 1572, 1611, 1638, 1665. German translation with the title: "Natürliche Magie", Madgeburg, 1612.

(58) "Nunc docetur aqua salsa quomodo reddatur potabilis. Quod docet Aristoteles. Si vas cereum efformabimus vacuum, et in maris aquas immergimus, quæ per ceræ poros intro delabitur, fiet potabilis. Sic crudo fictili vase obstructo ore (quod enim intro permeat, percolatum est quod salsedinem facit per commixtionem) secernitur. Fit aliter uberius et celerius: sabulonem fluminum in salsam aquam immittas, et paulisper immoraberis, et lineo panno subiecti vasis ori obtento colatur, donec salsamentum amiserit omne et dulcescet: multa uti vilia sileant". (Book II) (57; Antwerp edition, 1567, page 136).

(59) Strangely enough the above passage lacks in the Italian translation appeared in Venezia in 1560.

(60) G.B. Della Porta, "Magiæ naturalis libri XX, ab ipso authore expurgati", Napoli, 1589. Other editions 1591, 1597, 1607 (Frankfurt); 1619, 1644 (Hannover); 1650 (Rouen); 1651 (Leyden). English translations: "Natural Magick by John Baptista Porta A Neapolitane, in Twenty Books", T. Young and F. Speed, London, 658 (a facsimile reproduction, New York, 1957, 1958); and J. Wright, London, 1669. German translation: "Magia naturalis, oder Hauss-Kunst- und Wunder-Buch... von allen Fehlern... gereinigt", Nürnburg, 1713. Italian translation with the title: "Della Magia Naturale del Sig. Gio. Battista Della Porta Napoletano Libri XX", Napoli, 1677.

(61) "Magna ergo vasa terra replebimus, atque super gradus accommodabimus, ut alterum intra alterum excolet, et sic per multa vasa dilabens aqua salsa, fortasse salsedinem in vase relinquet. Ego per decem vasta expertus sum, et salsa etiam erat. Amicus autem per viginti excolatam dulcem dixit" (60; Napoli edition, 1589, page 293).

(62) "Inquit Solinus marina aqua argilla si percoletur, dulcescit, et salem adimi compertum est" (60; Napoli edition, 1589, page 293). About this statement see note (49).

(63) "Sed Aristoteles experimentum affert ex cereo vase: nam si quis ceream pilam confecerit vacuam, continentis soliditatis, et ipsam in mari immerserint, intus dulcis aquæ plenam reperiri, quum per ceræ poros salsedo corpulenta magis neget introitum. Et Plinius demissis reticulis in mari concavæ e cera pilæ, vel vasa inania obturata, dulcem intra se colligere humorem: nam in tenui marina aqua argilla percolata dulcescit. ...Leo Baptista Albertus vas fictile bene clausum, in aquis salsis immersum, repleri dicit potabili. Sed ego omnibus vasis argillaceis sum expertus, et semper salsam inveni". (60; Napoli edition, 1589, page 294).

Problems (Della Porta tried it and observed that after boiling the water is more saline than before, and this, he correctly explained, because pure water has been lost by evaporation and the remaining solution is more concentrated); (g) desalination with pearl barley, according to Pliny.

All his comments contained both his faith in previous authors and a noticeable dose of criticism, so that he gave more credit to the results of his own experience than to the statement of the authors. This causes Della Porta to be such a singular author.

Della Porta presented the first correct explanation of the presence of fresh water near the sea shore, indicating it as caused by fresh water coming from the interior of the country and reaching as a water table the coast, where it superseeds the sea water; this explanation is presented in polemics with those who believe fresh water is due to filtration and desalination of sea water by the sand.

Della Porta mentioned also some methods for purifying impure water by addition of inorganic compounds (like salt, lime, special woods, etc.). In the 2nd chapter of

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hæc in latas fidelias aquæ plenas immiſtus, vt citiùs vapores in aquam craſſeſcant. Optimè omnia iam parata, obuertè ad intenſiſſimũ ſolarium radiorum æſtum: nam extemplo in vapores ſoluuntur, & gut tatim in ſubiecta vaſa ſtillabunt. Veſperi poſt Solis occaſum remoue, ac nouis herbis reple. Herba po ligonus, ſiue *linguæ paſſarinæ* vulgò vocata, conciſa, extillataq;, maximè oculorum inflammationibus præſtat, alijsq; morbis. Ex hiperico elicitur aqua omne ſpaſmum profligatura, ſi dolens membra ea abluerit: & alia, quæ longum eſſet recenſere. Modus diſtillandi pictura proſtat.

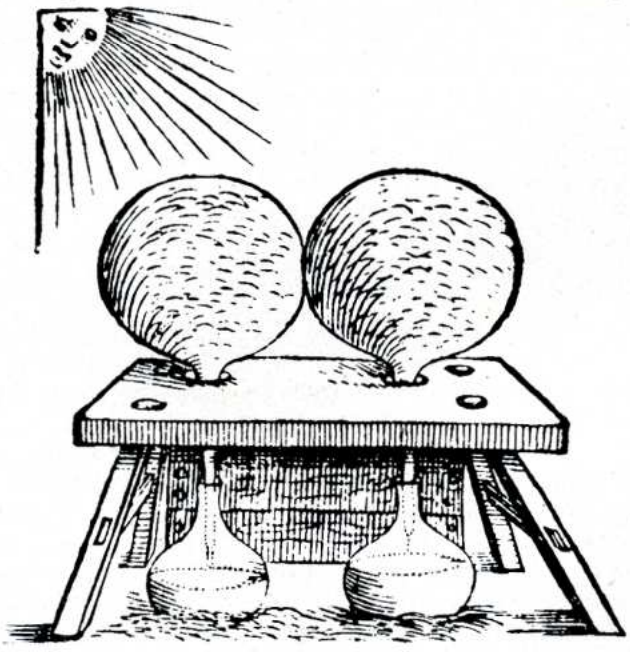

Figure 1. The use of solar energy for distillation, according to Della Porta (66).

(64) "Sunt qui ad id (use as a filtering material for desalination) sabulonem probent: et ratio quæ illos movebat fuit, quod semper dulces aquæ in littoribus reperiuntur, dicuntque id evenire per harenas colatæ dulcescant ex mari, quod falsum est: nam aqua dulcis, quæ iuxta mare reperitur, non ex mari est" (60; Napoli edition, 1589, page 293).

Book XX of *Magiae naturalis* Della Porta described a method for obtaining water from the air (60; Napoli edition, 1589, page 295).

He suggested filling a glass vessel with saltpetre and ice: this causes a decrease of temperature that determines the condensation of the air humidity on the external walls of the vessel. The water so condensed is collected below the vessel.

This suggestion is an interesting anticipation of a very important problem also in modern times, that of obtaining fresh water by condensation of air humidity (65).

In another book, although not in relation to water desalination, Della Porta suggested the use of the solar energy as a source of heat for distillation (figure 1) (66).

A contemporary of Della Porta, JOHN JACOB WECKER of Basel (1528-1586) (50; Vol. VI, pages 215-216) (51; Vol. 2, page 29) in his work *De secretis* (67) reported literally the statement of Della Porta on water desalination as contained in the first edition of his *Magiae naturalis* (58) (67; Basel edition, 1582, page 93). The authorship of the statement is correctly attributed to "Ioan. Bapt. Porta".

A picturesque figure was the inventor of secrets LEONARDO FIORAVANTI of Bologna (1517-1588) (68), the author of a treaty of "physics" in four books (69). In chapter 95 of Book I he stated that distilled water has very good curative properties and that the addition of distilled water to fresh water causes the second not to putrify (70).

At this point it may be interesting to recall that also Ferdinand II (1610-1670), Grand Duke of Tuscany, is said to have never drunk anything but distilled water to maintain his health. This statement is contained in pamphlet 93.

Almost at the same time Sir RICHARD HAWKINS (1560-1622), one of the British admirals who, with Sir Francis Drake and Sir Martin Frobisher, defeated the Spanish Armada in 1588, performed a voyage in the South Seas.

In June 1593 he left Plymouth with his ship "Daintie" and in June 1594 was imprisoned by the Spaniards who had captured him. He remained prisoner in Peru and Spain until 1602. After various adventures he died in London on the 18th of April, 1622.

In the same year his travel journal, composed about 1603, was printed with the title: "Observations in his Voyage into the South Sea" (71).

In this book it is reported that fresh water was obtained by distillation.

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(65) See, for instance: G. Nebbia, "Il problema dell'acqua nelle zone aride. La estrazione dell'acqua dall'atmosfera", *Annali Facoltà Economia e Commercio Università Bari, 17*, 105-122 (1961-62); "The Problem of obtaining Water from the Air", in: "Solar and Aeolian Energy", Plenum Press, New York, *1964*, 19-24; "Methods for obtaining Water from the Atmosphere in Arid Lands", in: "Science et technique pour les régions peu développées", Roma, *1963*, 135-138.

(66) J.B. Della Porta, "De distillatione libri IX", Roma, 1608.

(67) I.I. Wecker, "De secretis libri XVII plurimis authoribus collecti, methodiceque digesti", Basel, 1560, 1582, 1588, 1603, 1629, 1642, 1662, 1701, 1740. French translation, Lyon, 1584; Geneve, 1616; Rouen, 1699.

(68) D. Furfaro, "La vita e l'opera di Leonardo Fioravanti", Cattedra di Storia della Medicina, Università di Bologna, 1963.

(69) "Della Fisica dell'eccellente dottore e cavaliere M. Leonardo Fioravanti Bolognese, divisa in libri quattro", Venezia, 1582.

(70) "L'acqua del mare distillata è miracolosa; conviene molto negli idropici, et in quelli che patiscono humidità interiore. Imperoche ella è essiccante e risolve le male qualità. Il segreto che ho detto è, che mettendo un mezzo barile di detta acqua distillata, dentro una grandissima botte di nave, conserva l'acqua dolce, che mai non si corrompe" (69; page 134).

(71) Richard Hawkins, "Observations in his Voyage into the South Sea", ed. by C.R.D. Bethune, Hakluyt Society, 1847; ed. by C.R. Markham, Hakluyt Society, 1878.

"Although our fresh water had fayled us many dayes (before we saw the shore) by reason of our long navigation, without touching any land, and the excessive drinking of the sicke and diseased (which could not be excused) yet with an invention I had in my shippe, I easely drew out of the water of the sea sufficient quantitie of fresh wateh to sustaine my people, with little expence of fewell; for with foure billet (of wood) I stilled a hogshead of water, and therewith dressed the meate for the sicke and whole. The water so distilled we found to be wholesome and nourishing" (72).

Hawkins also discovered that orange or lemon juice in the sailor's diet decreased attacks of scurvy.

During the voyage made by Pedro Fernandez de Quiros (1565-1615) in the South Seas in 1606, when he discovered the New Hebrides and named them as Australia (from "terra australis" and "Austria"), a copper still was used; it worked reasonably well but it was possible to obtain only small quantities of fresh water (73): "6th February (1606): On this day the hearth was arranged and the apparatus for retaining fresh water from salt. 7th: The fire was lighted over the machine and it began to give fresh water with much ease. This day they got three Peruvian jarsfull. The object was to try the machine, and the water found to be clear, soft, and good for drinking".

Gerònimo Cortés of Valencia (c. 1550-1615) among other things in his fourth treatise of *Phisonomia* revealed the secret of making sea water drinkable (50; Vol. VI, page 428) (51; Vol. 2, page 30) (74) (74a).

Francis Bacon (1561-1626), Baron of Verulam, one of the most outstanding figures in the field of philosophy and natural science, dealt, among many other subjects, also with the problem of desalination.

In his natural history *Sylva Silvarum* (75) which was published posthumously in 1627, he reported various methods of desalination, after reviewing information available in literature.

The first chapter of the 1st century of *Sylva Silvarum* has the title: "Experiments in consort touching the straining and passing of bodies one through another; which they call percolation".

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(72) See also Dr. Shaw's Abridgment of Mr. Boyle's Works, Vol. III, page 220.

(73) G. Leza, "True Account of the Events of the Voyage that the Captain Pedro Fernandez de Quiros made to the Unknown Southern Lands", in: "The Voyages of Pedro Fernandez de Quiros 1595-1606", English translation and edition by Sir C. Markham, London, 1904, Vol. I, page 196; Vol. II, page 333.

(74) Geronimo Cortés, "Phisonomia y varios secretos de naturaleza". This work enjoyed much popularity; was first published in Cordova in 1601, then in 1603 (Zaragoza), 1607 (Alcalà), an enlarged edition in 1609 (Tarragona), 1610 (Barcelona), 1612 (Alcalà) 1614, 1675 (Madrid), 1681 (Barcelona), 1689 (Valencia), etc., 1958 (Paris). The fourth treatise occupies fols. 29ar-61bv in the edition of Tarragona, 1609.

(74a) "*Secretos para hazer el agua del mar dulze que se pueda beuer.* Aristoteles escriue, que para boluen el agua del mar dulze que se pueda beuer hagas un vaso de cera bien atapado, y lo metas en el mar y el agua que entrare en el vaso perdera la sal, y quedara dulze. Co (*sic* instead of Lo) mismo sucedera si metieres en vaso de tierra nuevo, con tal que tenga la boca bien cerrada". J. Cortes, "Libro de phisonomia natural, y varios efetos de naturaleza", Alcalá edition, 1607, fol. 46ar. We acknowledge the help of Dr. J.J. Morales of the Servicio Nacional de Informacion, Biblioteca Nacional, Madrid.

(75) F. Bacon, "Sylva Silvarum, or a Natural History, in Ten Centuries, published after the Author's Death by William Rawley, London, 1627", in: "The Works of Francis Bacon, collected and edited by James Spedding, Robert Leslie Ellis and Douglas Denon Heath", London, 1859, Vol. II.

"Dig a pit upon the sea-shore, somewhat above the high-water mark, and sink it as deep as the low-water mark; and as the tide cometh in, it will fill with water, fresh and potable. This is commonly practiced upon the coast of Barbary, where other fresh water is wanting. And Caesar knew this well when he was besieged in Alexandria: for by digging of pits in the sea-shore, he did frustrate the laborious works of the enemies, which had turned the sea-water upon the wells of Alexandria; and so saved his army, being then in desperation. But Caesar mistook the cause, for he thought that all sea-sands had natural springs of fresh water. But it is plain that it is the sea-water; because the pit filleth according to the measure of the tide; and the sea-water passing or straining through the sands leaveth the saltness (76).

I remember to have read that trial hath been made of salt water passed through earth, through ten vessels one within another, and yet it hath not lost his saltness, as to become potable: but te same man saith, that (by the relation of another) salt water drained through twenty vessels hath become fresh (77). This experiment seemeth to cross that other of pits made by the sea-side; and yet but in part, if it be true that twenty repetitions do the effect" (75; pages 339-340).

Later, in the same 1st century Bacon stated: "It is reported by some of the ancients, that sailors have used, every night, to hang fleeces of wool on the sides of their ships, the wool towards the water; and that they have crushed fresh water out of them in the morning, for their use (78). And thus much we have tried, that a quantity of woll tied loose together, being let down into a deep well, and hanging in the middle some three fathom from the water for a night in the winter time, increased in weight (as I now remember) to a fifth part" (75; page 372).

And in the 9th century: "Experiment solitary touching the dulcoration of salt water. It hath been observed by the ancients that salt water boiled, or boiled and cooled again, is more potable than of itself raw: and yet the taste of salt in distillations by fire riseth not ; for the distilled water will be fresh. The cause may be, for that the salt part of the water doth partly rise into a kind of scum on the top, and partly goeth into a sediment in the bottom; and so is rather a separation than an evaporation. But it is too gross to rise into a vapour; and so is a bitter taste likewise; for simple distilled waters, of wormwood and the like, are not bitter.

Experiment solitary touching the return of saltness in pits upon the sea-shore. It hath been set down before, that pits upon the sea-shore turn into fresh water, by percolation of the salt through the sand: but it is further noted by some of the ancients that in some places of Africk, after a time, the water in such pits will become brackish again. The cause is, for that after a time the very sands through which the salt water passeth become salt; and so the strainer itself is tincted with salt. The remedy therefore is, to dig still new pits, when the old wax brackish; as if you would change your strainer" (75; pages 632-633).

Again the interpretation of the phenomena is inaccurate since the water in the pits near the sea-shore becomes brackish with time because of the mixing of the fresh water with the sea water underneath as a result of pumping. This does not seem to be explainable as an ion exchange (79).

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(76) This passage refers to the story of Caesar but, strangely enough for such a great naturalist, Bacon seems to have misunderstood the real nature of the fact. Indeed one finds that fresh water table generally extends up to the sea and stays above the sea water, being lighter than this. Della Porta had correctly interpreted the fact; see note 64.

(77) This statement is taken by Della Porta (60; Book XX, chapter 1).

(78) See: Pliny, *Natural History*, Book XXXI, 70 (29).

Water desalination is considered also in Bacon's moral and fiction novel *The New Atlantis*, written about 1624 and published in 1627 (80). The inhabitants of the Atlantis state: « We have also pools, of which some do strain fresh water out of salt; and others by art do turn fresh water into salt" (80; page 157).

Almost contemporary to Bacon, the great British explorer Sir WALTER RALEIGH (c. 1552-1618) made experiments on the distillation of sea water during his imprisonment in the Tower of London, prior to his execution there in 1618 (81).

The possibility of obtaining fresh water by distillation on board ships is reported by JAN HUYGEN VAN LINSCHOTEN (1563-1611), the great traveller to the Indies; he remained in the East Indies from 1583 to 1588 (51; Vol. 2, page 109) (82) (83).

In 1624 Dr. AEGIDIUS SNOEK of Amsterdam was charged by the Dutch East India Company to develop a distillation method to be used on board ships of the same Company. In the following decades the Company experienced a greater mortality on ships without sea water stills than on those furnished with such devices (7) (83a).

RENÉ DESCARTES (1596-1650), the great mathematician and philosopher, in his *Traité des Météores* stated that salt water becomes fresh on filtration through sand (84).

In 1646 the Jesuit NICOLAUS CABEO wrote a commentary on the *Meteorologica* of Aristotle (50; Vol. VII, pages 422-423) (85).

As for the origin of rivers Cabeo followed Aristotle in maintaining that some come from the sea by way of subterranean vapors, but that more come from precipitation. Evaporation, however, is greatest from the sea, so that in that sense rivers may be said to come from the sea (85; Vol. I, pages 368-371).

In the *Philosophical Transactions* for the years 1665 and 1666 there is the following anonymous statement: "An observing gentleman... adds that, to separate

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(79) Information on the historical aspects of ion exchange as a desalting process may be found in the following papers: (a) J.T. Way, *Journal Royal Agricultural Society England*, *11*, 313 (1850) and *13*, 123 (1852); (b) O.M. Elliott, "Compression distillation", Proceedings, 12th Annual Water Conference of the Engineers' Society of Western Pennsylvania, *1951*, 25-31; (c) R. Kunin, "Ion exchange resins", Wiley, New York, 1958; (d) J.W. Minken in: "Acqua dolce dal mare", Tamburini, Milano, 1965, 3-12.

(80) F. Bacon, "The New Atlantis", in: "The Works of Francis Bacon, collected and edited by James Spedding, Robert Leslie Ellis and Douglas Denon Heath", London, 1859, Vol. III.

(81) An edition of the *Works* of Walter Raleigh in eight volumes has been published in London in 1829.

(82) The travel report has been published with the title: "Itinerario... van J.H. van Linschoten naer Oost ofte Portugaels Indien 1579-1592", in three parts, Amsterdam, 1595-1596; such report enjoyed a great popularity. An Italian translation appeared in Amsterdam in 1596 with the title: "Viaggio alle Indie Orientali"; a Latin translation appeared in Frankfurt and Amsterdam in 1599; an English translation appeared in 1598 and has been reproduced (only Vol. I) more recently: "The Voyage of John Huyghen van Linschoten to the East Indies", Hakluyt Society, London, 1885. Other works: J.H. Linschot, "Histoire de la navigation aux Indes Orientales, contenant diverses descriptions de lieux jusqu'à présent découverts par les Portugais, avec des annotations de B. Paladanus", Amsterdam, 1619; J.H. Linschot, "Le grand routier de mer, traduit de flamand en françois", Amsterdam, 1619; J.H. Linschot, "Description de l'Amerique", Amsterdam, 1619.

(83) This information was known to writers on desalination as Lorgna; up to now we have not been able to locate the exact reference.

(83a) D. Shonte, "De geneeskunde in den dienst der Oost-Indische Compagnie in Nederlandsch-Indie", Amsterdam, 1929.

(84) R. Descartes, "Traité des Météores", published with the "Discours de la Méthode", in 1637. The quoted statement is in Book III, 3, 7.

(85) Nicolaus Cabeus, "Commentarius in Meteorologica Aristotelis", Roma, 1646, 4 vols. in folio.

salt from salt-water, without fire, if you take a vessel of wax, hollow within, and every were tight; and plunge it into the sea, or into other salt-water, there will be made such a separation, that the vessel shall be full of sweet water, the salt staying behind: but though this water have no saltish taste, yet, he saith, there will be found a salt in the essay, which is the spirit of salt, subtile enough with the water to penetrate the wax" (85 a).

In 1668 the narrative of the travels in Europe, Egypt, Syria and the Near East of Mr. De Monconys appeared in Lyon (86); the work is rich of naturalistic observations since this gentleman got into contact with all the learned people of the various countries he visited.

Mr. De Monconys reported that he obtained information, during his visit to England, of an invention by Cornelius Drebbel (1572-1634) of a still which could produce fresh water from the sea; such a still had been left in heredity to his son-in-law "Dr. Keiffer" (or Kufler) (87) of Stratford-by-Bow. This was portable still, of small dimension, and could produce 145 lbs. of fresh water in 24 hours (88). Kufler's work had apparently not met much success and Drebbel had died without revealing many secrets.

In another part De Monconys reported to have met Henry Oldenburg, the famous first Secretary of the Royal Society of London, and to have been informed of his results on the measurement of the properties of sea water.

To collect the samples of sea water at various depths Oldenburg had developed a cylinder that could be immersed empty and could be opened and filled with water at the desired depth, based on the same principle of the ones used to-day in oceanographic research (89). De Monconys also reported the use of an aerometer for determining the specific gravity of sea water (86; Part II, page 27 of the Lyon edition, 1668).

In 1670 Hauton (90) reported experiments in water distillation and suggested saving the condenser by causing the water vapor to pass in a leaden pipe through the side of the ship into the sea, where the vapor condenses, and finally re-enters into the ship.

"Monsieur Hauton hath now declared his secret of making sea water sweet. It consists first in a precipitation, made with oyl of tartar, which he knows to draw

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(85a) *Philosophical Transactions, Royal Society of London,* Vol. I for anno 1665 and 1666, London, No. 7, December 4, 1665, pages 127-128.

(86) "Journal des voyages de Monsieur de Monconys", Lyon, 1666; Paris, 1677. German translation with the title: "Des Herrn de Monconys Beschr. seiner Reisen; übersetz. von Christ. Juncker", Leipzig, Augsburg, 1697.

(87) Was he the same Jack Kuffler who worked with Fitzgerald at the experiments on his still few years later (104)? We have been unable to control this.

(88) "...Il y a aussi celuy de distiller avec un fourneau fort aisé à porter, et de fort peu de charbon, une si grande quantité d'eau de mer qui se rend par là douce et bonne à estre beüe, qu'en vingt-quatre heures un fourneau peut distiller plus de 145 livres, et on peut operer avec deux ou trois... Le Duc d'York achete de luy ces deux secrets, et il fait faire le fourneau de la distillation de l'eau, qui feront que les vaisseaux ne manqueront iamais de pain n'y d'eau fraische, et les hommes qui vont aux Indes ayant ses deux refraichissements n'auront jamais le scorbut" (86; II part, page 41 of the Lyon edition, 1666).

(89) "...Un cylindre, aux deux fonds duquel il y a une valvule à chacun, qui s'ouvrent toutes deux, quand le cylindre descend, et donnent l'entrée et sortie libre à l'eau: quand il est au fond de la mer et que la derniere eau y est entrée, en retirant le cylindre, ces deux valvules se ferment et cette derniere eau y demeure enclose, sans qu'il y en puisse entrer d'autre en sa place" (86; II part, page 57 of the Paris edition, 1677; pag. 529 of the Leipzig edition, 1697).

with small charges. Next, he distills the sea water; in which work the furnace taketh up but little room, and is so made, that with a very little wood or coal he can distill 24 pots of water in a day: for the cooling of which, he hath this new invention, that instead of making the worm pass through a vessel full of water (as in the ordinary practise) he maketh it pass through one hole, made on purpose out of the ship, and to enter in again through another: so that the water of the sea performeth the cooling part: by which means he saveth the room, which the common refrigerium would take up; as also the labour of changing the water, when the worm hath heated it. But then thirdly, he joyns the two precedent operations, filtration, thereby perfectly to correct the malignity of the water. This filtration is made by means of a peculiar earth, which he mixeth and stirrs with the distilled water, and at lenght suffers to settle at the bottom" (90).

This method, although original, is difficult to put into practice.

In 1682 the great German philosopher and scientist WILHELM LEIBNITZ (1646-1716) (50; Vol. II, page 485) wrote a paper (91) on water desalination indicating its great importance, especially for seamen.

Leibnitz noted that distillation may be used for this purpose but suggests that a better separation of fresh water may be obtained by percolation through sand or, better, through litharge or lead oxide (*Saturni calcem*).

A very interesting page of the history of desalination regards a patent litigation in England during the reign of Charles II.

It must be said that the main obstacle to the development of distillation was that during distillation, and probably when the brine in the still became very concentrated, unpleasant and bitter compounds evolved and these rendered the distilled water not potable, corrosive and dangerous. This may have been due to decomposition of chlorides and formation of hydrochloric acid, the "spirit of salt" frequently referred to in literature.

All the work of inventors, therefore, was directed to avoid at least in part, this corrosiveness of distilled water.

In 1675 WILLIAM WALCOT was granted a patent for a procedure to obtain fresh water from the sea.

The patent granted with the No. 184 on the 28th October, 1675 had the title: "Art of makeing water corrupted fitt for use, and sea water fresh, cleare and wholesome in very large quantities, by such wayes and means as are very cheap and easy, and which may bee done and practised with great speed and expedition" (92).

In the patent no explanation of the process is given; but as regards its success it is said: "Some evident demonstrations whereof we have seen to our great satisfaction, and doe beleive the same may prove very usefull as well to our royal navy as alsoe to all other shipps and vessells belonging to our subjects, and likewise highly advantageous to the trade of our subjects, and may tend to the advancement of our customes".

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(90) "An Extract of a Letter from a learned French Gentleman (Hauton) concerning a Way of making Sea Water Sweet", *Philosophical Transactions, Royal Society of London,* Vol. 5, No. 67, page 2048 (1670-1671).

(91) G.G.L. (Gottfried Wilhelm von Leibniz), "Meditatio de separatione salis et acquæ dulcis, novoque separationum chymicarum genere", *Acta Eruditorum,* Leipzig, *1682,* 386-388.

(92) "Patents for Inventions. Abridgements of Specifications relating to purifying and filtering Water, including the Distillation of Sea Water to produce Fresh Water, 1675-1866", London, 1876.

The Letters Patents were granted for the term of fourteen years, without any stipulation respecting an annual payment to the Crown.

The King, before granting this patent, was curious enough to go and see Mr. Walcot do it, who was distilling in a very large still. In the still he put some ingredients, which were to prevent any noxious quality in the distilled water: but what they were he kept a great secret. In fact the principal thing of the process was only distillation, and Walcot was probably aware of it because in all the printed accounts of such a process he purposely avoided calling the still by its name, but called it a machine or an engine, and distilling he called the working of the machine, not distilling. He was not very successful.

In 1683 ROBERT FITZGERALD, a relative of the famous Robert Boyle, obtained from the King a patent for himself, and for his partners Theophilus Oglethorpe, William Bridgman, Patrick Trant and Thomas Maule to prepare fresh water by distillation of sea water after addition of a small amount of some "ingredient".

The patent No. 226, dated 9th June, 1683 has the title: "A way to render salt or brackish water sweet and fitt for drinking, boyling meate, washing, or any other ordinary use, by the means of a certaine engine or engines not heretofore used or practised in our dominions". No detailed account of the engine is contained in the Letters Patents. The invention is represented likely to prove "of great and public use, both at land and sea... itt being to be putt in use and practise with great ease and safety on shipp board, and soe as to supply the seamen with sufficient quantities of good and wholesome water from time to time". The grant was made for a term of 14 years, and free from annual payment.

The enterprise received great publicity and obtained confirmation by scientific authorities like Boyle and Grew. In the same year a pamphlet was published in various languages (93) (94).

The pamphlet contained a dedicatory letter to King Charles II, opening with congratulations for the happy conclusion of the "horrid conspiracy", that of Rye House, organized in 1683. The authors then claimed their desire to "satisfy all reasonable scruples which have been raised concerning the wholesomeness and cheapness of water thus prepared". The queries and answers follow.

"Question 1. If this water can be made in sufficient quantities to serve the uses of any ship at sea?

Answer. About 90 gallons may be prepared in every 24 hours by an instrument of 33 inches diameter, which will stand under the deck of any ship; and it's computed that less than 3 quarts is a good allowance for any man in that time: and if a large ship, wherein there are many men abroad, should require more water, then two or more of the instruments may be had upon reasonable terms, and one man may attend several of them.

Question 2. In case the operation be by fire, it may require a skiful Chymist, or one known in such operations to be on board every ship, who will require great wages?

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(93) R. Fitzgerald, "Salt-water sweetned or a true Account of the Great Advantages of this New Invention both by Sea and by Land; together with a Full and Satisfactory Answer to all Apparent Difficulties; also the Approbation of the Colledge of Physicians; likewise a Letter of the Hon. Robert Boyle to a Friend upon the same Subject", London, 1683.

(94) German translation: "Das süssgemachte Salzwasser", Hamburg, 1684; see also: *Journal des Sçavants*, Vol. XI, page 380. French translation: "L'eau de mer douce, ou la nouvelle invention de rendre douce l'eau salée... traduit de l'Anglois par le Sieur Guy Miege", London, 1683.

Answer. There will be no occasion for any such person, for any sea-man may be instructed in an hour or two to prepare this water.

Question 3. It's probable that the engine may be frequently out of order, and being so at sea where artificers and tools are wanting to repair it, there must necessarily follow want of water, which will be of ill consequence?

Answer. This engine is of such contrivance, that it's never likely to be out of order...

Questione 6. Will not the charge of this instrument and the materials belonging to it be very great?

Answer. It is difficult to make exact answer to this, but an instrument of the largest size, with all the materials belonging to it, will not amount to above sixteen pound at most, and may last many years, and according to the rates of ships they may be proportion'd both in bulk and price...

Question 8. Will not the ingredients take up much room, and be very chargeable.

Answer. A vessel less than a barrel may contain enough of the ingredients to carry a ship to the Indies and back again; and the ingredients for one hundred gallons of this sea-water will not amount to above fourteen pence at most".

Boyle, after analysing Fitzgerald's distilled water, made a favorable report. In addition the College of Physicians stated that "the said water is very wholesome, and may be safely us'd" (93).

Captain Randolph Macdonnel of H. M. Ship "Greyhound" reported in a letter dated 3rd November, 1683 that in England he had charged some distilled water prepared by Fitzgerald and that his crew had found it good and satisfactory.

Fitzgerald was quite successful in his enterprise. The *London Gazette* No. 1874 of November, 1683, reported that the King had asked Robert Boyle to analyze before him the fresh water prepared according to the new patent. "By which trial His Majesty, finding that the prepar'd sea water, for which he has granted his Royal Patent, was at least as free from salt as the best waters used in this town; received such satisfaction as to the wholsomeness of the said water, that he was pleased to declare his royal intentions both to encourage the said invention, and to have the said water made use in his several maritime garrison, which nature has not furnished with wholsome water".

The *London Gazette* Nos. 1908 and 1909 of March, 1684, reported the publication of the Fitzgerald's pamphlets, already mentioned.

Furthermore in 1684 NEHEMIAH GREW (1641-1712) (51; Vol. 2, page 567), a pioneer in the field of plant anatomy and also Secretary of the Royal Society from 1677, published an account (95) (96) in which this eminent botanist and physician advocated sea water distillation as practised by Fitzgerald and his partners.

Fitzgerald and partners in 1684 published the "Conditions upon which patentees for making salt and brackish water fresh and wholsom, do intend to contract with such persons that will please to agree with them upon the use of this invention either by sea or land" (97).

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(95) N. Grew, "New Experiments and Useful Observations concerning Sea-water made Fresh, according to the Patentees Invention: Discourse humbly dedicated to His Majesty, the King of Great Britain", Ninth edition, 29th September, 1684, London.

(96) N. Crew (*sic*), "De acqua marina dulcorata", London. This is a Latin translation of the above pamphlet. A French translation, again with the indication of the Author as N. Crew, was published with the title: "Nouvelles experiences et utiles remarques sur l'eau de mer dessalée, suivant le secret du Sieur Fitzgerald et de ses Associez", London, 1684.

The conditions were the following: "First. Every person desiring to deal with the said patentees, may have one engine or more, with its appendance, together with directions how to manage and place the same, paying for each engine and appendances, that will make about 90 gallons of water fresh in 24 hours, the sum of eighteen pounds. Every one buying an engine, is also to buy as much of the ingredients for this operation as will keep the same going at least six month, at the rate of one shilling for as much as makes about 90 gallons of water. Every one dealing with the patentees for an engine... at the end of the first six months, or the term for which he has taken the first quantity of ingredients, he shall be obliged to buy of the patentes (at the like rate) a further quantity of ingredients... and not to work the engine without it, less the water... be prejudicial to the healths of the saylors, and consequently bring a disrepute on the invention. Fourthly, that he will pay unto the said patentees, as a praemium for their invention of this beneficial art, three pence the tun yearly (97) (six pence per tun - 98), for the tunnage of every ship, in which they shall carry an engine, the first six months praemium will be paid in hand, and the other at the end of the next six months.

If any engine and ingredients be used on shore, the praemium for each engine shall be proportionably cheap, with respect to the advantages. ...All the above nam'd charges, together with the price of firing and the interest of the first cost of the engine and its appendances, as also the praemium being duely computed, the water will come under one farthing the gallon (97) (under one half penny the gallon - 98), and the room requisite for working the engine, and for the stowage of the fewel, and the few casks to be employed in the making and receiving this prepared water will be less than the tenth part of the stowage now esployed for the cask and water only" (97).

In 1684 other pamphlets (98) (99) (100) dealing with the same subject were published containing the same information as the one referred in note 93, with small additions, like reprints of the articles in the *Gazette* of November 1683 (98) and March 1684 (99) (100).

In the pamphlet 98 the conditions for the use of the patent are reprinted.

Fitzgerald had clearly foreseen the market for his stills. "In the Affrican East and West India voyages, great quantities of fresh water are necessary, wich the

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(97) "Conditions upon which Patentees for making Salt and Brackish Water Fresh and Wholsom, do intend to contract with such Persons that will please to agree with them upon the Use of this Invention either by Sea or Land", London, 1684.

(98) R. Fitzgerald, « The Supplement to a Small Treatise called Salt-water Sweetened, shewing the Great Advantages both by Sea and by Land of Sea-water made Fresh together with the Hon. Mr. Boyle's Letter and the Approbation of the Colledge of Physicians, of the Wholsomness of this Water, and the Conditions on which the Patentees and other concern'd, do intend to contract with such as shall please to deal with them for the Use of this Invention", The eight edition, July 23, 1684, London.

(99) R. Fitzgerald, "Farther Additions to a Small Treatise called Salt-water Sweetened: shewin the Great Advantages both by Sea and by Land, of Sea-water made Fresh; together with the Hon. Mr. Boyle's Letter, and the Approbation of the Colledge of Physicians, of the Wholsomness of this Water", Ninth edition, October 13, 1684, London.

(100) A Latin translation of the above pamphlet was published with the title: "Aqua salsa dulcorata sive accurata novi hujus artificii, quatenus tum maris, tum portuum incolis, utilis, descriptio: accessit præterea plena omnium alicuius momenti contra novum hoc adinventum objectionum solutio: nec non approbatio collegii medicorum londinensis: epistola denique Honorabilis Roberti Boylei hac super re ad amicum conscripta", 2nd edition, London, 1684.

seamen are forc'd to put above deck for want of room... this instrument will be of vast advantage by affording fresh and wholsom water, instead of that which is unwholsom and offensive.

Essex, Kent and all other sea costs, that want wholsome water, may be easly and cheaply supplyed by this means; as also Venice, Amsterdam, Roterdam and all other places that lye near the sea, and either want good, or have brackish water.

In time of war, whole navies may be relieved by this engine" (93; page 12).

"Portsmouth, Rochester, the Fenns of Lincolnshire, and any other places near the sea where waters are brackish, and consequently unwholsome, this engine etc. may be very useful" (98; page 10). These words anticipate what our present problems are.

The *London Gazette* No. 1965 of September, 1684, reported that Fitzgerald had made a public demonstration of his apparatus and that many owners and captains of ships "did easily agree with the Patentees, and subscribed their names in order to be immediately supplied with engines and ingredients necessary for such purpose, some of wich are already put on board".

The *London Gazette* No. 2002 of January, 1685 reported: "Yesterdaw His Majesty was pleased to send to the Lord Mayor closed in a silver box sealed up with His Majestaty's seal, the receits of the several cements used by the patentees for making sea water fresh; as also the receit of their metalline composition and ingredients certified under the hand of the Honourable Mr. Robert Boyle, to be kept so sealed up by the present and succeeding Lord Mayors, lest a secret of so great importance to the publick might come to be lost, if lodged only in the knowledge of a few persons therein concerned" (100a).

The consequences of all this publicity soon came.

Samuel Pepys (1632-1703) (101), who rose to become Secretary of the Admiralty under Charles II, in a letter dated 1684 from Windsor instructed Captain William Gifford, of H.M.S. "Mermaid" to receive on board and to experiment "an engine for producing fresh water (at sea) out of salt", to ascertain if this could be done without danger to the ship through fire (3) (101a).

As a consequence of this rumour, Walcot reaffirmed his priority. In September 1684 he was granted Letters Patents by the States-General of Netherlands to make sea-water fresh and putrid water wholesome (102) (103). Such patent was granted to Walcot and was denied to Fitzgerald and his associates.

In the following years various law suits took place between Walcot and Fitzgerald's partners. Walcot tried to appeal to the King, presenting the evidence of

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(100a) The quotations from the *London Gazette* are possible through the kind cooperation of Mr. G. Ottley of the State Paper Room, The British Museum of London, that is gratefully acknowledged.

(101) Samuel Pepys mantained his social position during the Restoration, which enabled him to make his "Diary" such an interesting account of that period. He served as President of the Royal Society from 1684 to 1686.

(101a) "Memoirs of Samuel Pepys, comprising his Diary from 1659 to 1669, deciphered by Rev. J. Smith from the Original Shorthand MS. and a Selection from his Private Correspondence", London, 1825.

(102) "The Letters Patents of the States of Holland (translated out of Dutch) granted to William Walcot Esq. upon their seeing the Demonstration of his Art of making Sea-Water Fresh, etc. and Putrified Water Wholesome", 14th September 1684.

(103) "The Letters Patents of the States General (translated out of Dutch) granted to William Walcot Esq. upon their seeing the Demonstrations of his Art of making Sea-Water Fresh etc. and Putrified Water Wholesome", 16th September 1684.

persons who had experienced his stills, but apparently the position of Fitzgerald was still very strong.

All this dispute is reported in two pamphlets published by Walcot (104) (105).

All the question seems somewhat complicated. Walcot stated that the patent to Fitzgerald and his partners had been granted on the basis that his own invention had not been exploited for seven years, and stated that they had tried to contact him for an agreement between the parties. Walcot opposed the grant of the patent to Fitzgerald and the Council decided to lay aside the patent of Walcot and to consider Fitzgerald's valid.

In the meantime Fitzgerald's method had met with such approval that a poem was published to celebrate the distillation of sea water for making fresh water (106). The author does not mention Fitzgerald by name and Robert Boyle is credited for the invention. The support given to the inventors by the members of the College of Physicians is acknowledged:

"Great Sons of Heav'n, Props of our human state
Whose skill mantains the life Heav'n did create...
Nor is the blessing life your gift alone,
You give us all that tends to make it one;
You the twin-charms of youth and beauty give,
A bliss that few are willing to out-live.
In those soft streams, distilling from the sea,
To whose first knowledge you prepar'd the way,
The rough-sull skin grows smooth and clear as they".

And later:

"Boyle the bless'd Moses our happy land,
Who from the Ocean does fresh springs command...
He knows each creature's vertue and its use;
And from the worst can excellence produce.
By him the waters, acid and marine,
Are purg'd and freed from their destructive brine:
The sailer now to farthest shores may go,
Since in his road these lasting fountains flow;
The sea, corrected by this wondrous pow'r,
Preserves those now, whom he destroy'd before:
No more with thirst the feav'rish sea-man dyes,
The briny waves afford him fresh supply".

In 1685 silver medals were coined, representing and illustrating the art of this new inventor (104) (106a) (Figure 2).

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(104) W. Walcot, "An Answer to Mr. Fitzgerald's State of the Case concerning the Patent of making Salt Water Fresh", London, 1695.

(105) "A Treatise concerning the Exercise of William Walcot Esq. his Art of making Salt-Water Fresh with a Short Account of the Gain and Advantages that Ships may have by the Exercise thereof" London, 1697.

(106) "Fons Perennis, a Poem on the Excellent und Useful Invention of making Sea-water Fresh... by Edm. Arwaker", London, 1686.

A

B

Figure 2. Medals coined about 1685 to celebrate Robert Fitzgerald's invention of an apparatus for making fresh water from the sea, both on ship-board and on land. Medal A is of pewter; medal B is of brass. Both medals would have been silvered and probably are the "silver medals" referred to by Walcot (104), but there could be other and in real silver.

Stills of Fitzgerald's were set up at Hull and Sheerness, two sea ports, and at Lothbury; by order of the Council in the year 1692, two other stills were to be set up in the islands of Jersey and Guernsey, but with no good result: the distilled water was fiery, harsh and corroding (107).

This story is near to the end. In 1692 Walcot presented a bill to Parliament to reaffirm the validity of his patent and the bill passed the House of Commons and was examined by the House of Lords (107a).

Robert Fitzgerald presented a petition against the bill of 1693, but two other bills in favour of Walcot passed in 1694 (107b) and 1695 (107c).

In the meantime the persons concerned with Fitzgerald, finding themselves extremely disappointed in their expectations, withdrew from their partnership with him: insomuch that his instruments, which were expensive enough before their effect was known, were soon after sold for scrap-iron.

The last information comes from Walcot: "This present Parliament likewise being satisfied, that William Walcot was the first, and only true inventor, did, in the year 1695, pass an act to him, his executors, administrators and assigns, to use, exercise, and enjoy the said art, exclusive of all others, for the term of 31 years" (105) (107d).

The discussions on the Walcot case had great resonance in all Europe, as is demostrated by the new contributions to the problem of water desalination.

Among the works which appeared at the end of the 1600 mention must be made to those of the British physician and naturalist MARTIN LISTER (c. 1638-1712) who reported (108) (109) that it was possible to obtain fresh and good water from sea water by distillation, after having added algae and vegetables to sea water.

"Now that the sea water is made fresh by the breath of plants growing in it, I have elsewhere demonstrated thus. I took a long glass bodie and having filled it pretty full with sea-water, taken up at Scarborough, I put therein common sea weed (alga marina) fresh and new gathered, some with the roots naked, and some growing on and adhering to stones: the glass bodie being full, I put thereon a head

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(106a) In "Medallic Illustrations of British History", published in 1885, Edward Hawkins, the compiler, described the two medals represented in Figure 2, under Nos. 279 and 280 but refers them both to a steam engine invented by Sir Samuel Morland who was concerned with the use of steam for pumping water. The apparatus shown in the medals is certainly not an engine nor it is a pump but a sea water still; this is confirmed by the inscriptions: "Welcome — the water which is unhoped for" in medal A, and: "The art imitating the sky — causes sea to join the fire" in medal B. The connection with Morland seems to be guesswork on the part of Hawkins who had just been describing other medals which were to do with Morland; on the other hand Morland was vain glorious and would certainly have ensured that his name appeared on any medals representing his inventions. A reference to "Dulcyfing of sea water" in connection with medals is found in John Evelyn's "Discourse on Medals", 1697, page 167, but the pieces are not described or illustrated. The identification and correct attribution of the medals is possible thanks to Mrs. Joan Martin, Department of Coins and Medals of the British Museum of London, and we are happy to deeply aknowledge here her kind help and cooperation.

(107a) *Historical Manuscript Commission*, 14th Report, Appendix, part VI, pages 378-379.

(107b) *Manuscripts of the House of Lords*, Vol. 1 (New Series), page 376.

(107c) *Manuscripts of the House of Lords*, Vol. 1 (New Series), page 512.

(107d) Act 6 & 7 William III, c. 24 (Private).

(108) M. Lister, "A Way (which seems to be the True Method of Nature) of distilling Sweet and Fresh Water from Seawater, by the Breath of Sea Plants growing in it", *Philosophical Transactions, Royal Society of London*, Vol. *14*, No. 156, 489-495 (1684).

(107) It may be interesting to remember that one of the first industrial sea water stills was installed in the island of Guernsey in December 1960. It had been manufactured by the British Company Weir and still produces 500.000 gallons of fresh water per day.

with a beck, and adapted a receiver thereto, all without any lute or closing the joints; from these plants did distil dayly (tho' in a small quantity) a fresh, very sweet, and potable water, which hath no empegreuma, or unpleasant tast, as all those distilled by fire necessarily have.

I urge this experiment, as the most natural, most easy, and most safe way of having sweet water from the sea, and which may be of greater use then perhaps some are apt at the first to fancy, even to supply the necessity of navigators.

And I do not doubt but there may be found other plants growing in or near the sea which would better suit the experiment and yeild fresh water in much greater quantity" (108).

At the same time SAMUEL REYHER (1635-1714), after having referred to the previous work by Thomas Bartholin (1616-1680) (110) (111) and by Boyle (112), according to whom the ice formed in salt water has a low salt content, described "a new experiment in which the sweetness of salt water" was examined on the 6th February, 1697 (50; Vol. VIII, pages 230-231) (113) 114).

He broke the ice, which had formed on the sea and which was a foot thick, and found that bits of it tasted sweet. The layer of water between the ice and the sea water was also destitute of salt, but when he siphoned water from much lower down, it proved to be salt. He offered two reasons for this phenomenon. The first was compression of the water and, at the same time, expulsion of the saline particles.

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(109) M. Lister. "De modo eliciendi aquam dulcem ex marina mediante halitu plantarum marinarum... observationes", *Acta Eruditorum*, Leipzig, *1685,* 372-374.

(110) T. Bartholinus, "Observationes de usu nivei medico", Hafniæ (Copenhagen), 1661, chapt. VI, page 42: "De glacie ex marina aqua certum est, si resolvatur, salsum saporem deposuisse, quod etiam non ita pridem expertus est Cl. Jacobus Finckius, Academiæ nostræ Senior et Physices Professor bene meritus, Diss.de Thermosc.th.80. in glaciei frustis e portu nostro allatis".

(111) T. Bartholinus, "Aquæ salsæ edulcoratio", in: "Bartholini Hist. Anatom. Cent. V, hist. 77", page 150.

(112) R. Boyle, "New Experiments and Observations touching Cold", page. 59. Also elsewhere Boyle wrote: "For calling to mind the relations,... which seem to argue, that in some cases the ice of the sea-water may, being thawed, yield fresh water... I began to consider, whether we might not, by cold, free salt-water at some seasons of the year from a great deal of the phlegm, which it is wont to cost much to free it from by fire, and other means", ("The Works of the Hon. Robert Boyle in six volumes", London, 1772, Vol. II, page 640).

(113) Samuel Reyher, "Experimentum novum, quo aquæ marinæ dulcedo 6 Feb. 1697 examinata describitur", Kiliæ Holsatorum, 1697.

(114) Review of the above work: "Samuelis Reiheri... experimentum novum, quo aquæ marinæ dulcedo examinata describitur", *Acta Eruditorum*, Leipzig, *1697*, 397-398.

(115) "Postquam enim multos ante annos ex muliere quadam, quæ tempore hyberno in portu Kiliensi lintea lavare sueta erat, audivisset, aquam marinam, quo tempore glacie premitur, sale destitui; idemque etiam sibi aliisque compluribus persuasum esse, non ita pridem a piscatore, ibidem loci mytilos per foramen glaciei ex fundo maris extrahere solito, accepisset: tentamen eius die 6 Februarii hujus anni, e regione castelli Regii, cui Fridericia nomen est, instituit. Perfracta itaque glacie, pedem unum crassa, deprehendit: 1. frusta glaciei fuisse dulcissima. 2. aquam glaciei proximam itidem sale destitutam. 3. aquam siphone sesquipedali extractam modice salsam. 4. eandem siphone quinquepedali haustam adeo salsam, ut unus cantharus, seu 4 libræ romanæ, istius aquæ igni appositæ, et in vaporem redactæ, unciam unam cum sesquiscrupulo salis reliquerint. Huic observationi innixus Autor de causa dulcedinis disquirit, eique duplicem assignat: unam, aquæ compressionem, et cum ea simul particularum salinarum expressionem; alteram, salis gravitatem, ob quam sponte fundum petat... Edulcorationi etiam aquæ marinæ observationem hanc non omnino nihil conferre posse Autor existimat. Quamvis enim in regionibus calidioribus, intensi frigoris inexpertis, nullum usum habere videatur" (114).

For he believed that, while water could not be compressed by machines, as air could, it was very easily compressed by the cold. The second reason was the weight of salt, which caused the salt to seek the bottom. He added that sea water was not so easily frozen as fresh water (115).

JOHANN GEORGE LEUTMANN (1667-1736) reported (116) the purification of water by distillation, carried out in 1687.

In 1714 Father LOUIS FEUILLÉE (1660-1732), describing his trips to America in the years 1707-1712, reported the results of an unsuccessful experiment to desalt sea-water by filtration through sand obtained from the island of Malta (117) (118). He observed that after filtration the salinity did not diminish, but instead increased, which he interpreted as due to the solution of some soluble constituent of the sand by the water.

In 1717 JEAN GAUTIER (1679-1743), a physician of Nantes, developed a still which was received with great interest and was tested on various ships. A report issued by Gautier (119) contained also the comments of the Navy Commission who controlled the still on the war ship "Triton", and of another Commission who assisted at the operation of the still, and finally, a rather interesting economic analysis of the operation.

One of the merits of Gautier is to have indicated that substantially no addition of reagents was needed to obtain a satisfactory distilled water and that the whole secret was the distillation procedure.

The machine invented by Gautier has been described by Gallon (119 a) and consisted (Figure 3) in a rotating cylinder with a corrugated surface, whose lower part was always immersed in sea water. The cylinder was heated inside by the combustion of fuel placed in the hot plate C. The water adhering to the external surface of the cylinder evaporated; the vapor condensed on the inner surface of the copper fin-shaped plates G and was collected in the throughs MN. The quality of the distilled water was rather satisfactory (119 b).

Gautier has also experimented a solar still (119 c).

An interesting analysis of the state of the art in the field of desalination has been made by A.F.B. DESLANDES (1690-1757), Commissioner to the French Navy, with special regard to the fresh water supply on board ship.

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(116) J.G. Leutmann, "Vulcanus famulans...", Wittenberg, 1735.

(117) "Journal des observations physiques, mathematiques et botaniques fait par l'ordre du Roy sur les Côtes Orientales de l'Amerique Meridionale, et dans les Indes Occidentales, depuis l'annés 1707 jusques en 1712 par le R.P. Louis Feuillée", Paris, 1714.

(118) "Je crus qu'en filtrant cette eau (sea-water) par quelque sable, je pourrois en dégager les parties salines et bitumineuses, que je ne doutois pas être la cause essentielle de l'excés de son poids sur les eaux douces. Pour faire cette experience je remplis à la hauteur de 13 pouces un vase d'un demy pied de diametre, d'un sable fait de la pierre de Malthe; je disposai ce vase en sorte que je pûs mettre au dessous un recipiant. La préparation faite, je passai par ce sable jusq'a trois differentes fois la même eau de la mer dont j'avois dejà observé l'équilibre. A la premiere filtration je ne trouvai aux poids de ces eaux ni augmentation ni diminution; à la seconde je trouvai un demy grain de plus, et à la troisiéme un grain et demy... Je conclus de ces expériences... que l'augmentation de son poids étoit un effet du mélange des petits corps du sable" (117; pages 63-64).

(119) "Memoire sur la maniere de rendre l'eau de mer potable, decouverte depuis peu par Mr. Gautier, Medicin de Nantes", *Memoires pour l'histoire des sciences et des beaux arts, Trevoux, 1717*, pages 1813-1840; *Journal des Sçavants* (Amsterdam edition), Vol. *63*, page 657.

(119a) Gallon, "Machines et inventions approuvées par l'Academie Royale des Sciences, depuis 1666 jusqu'en 1754. Avec leur description", 7 vols., Paris, 1735-1777.

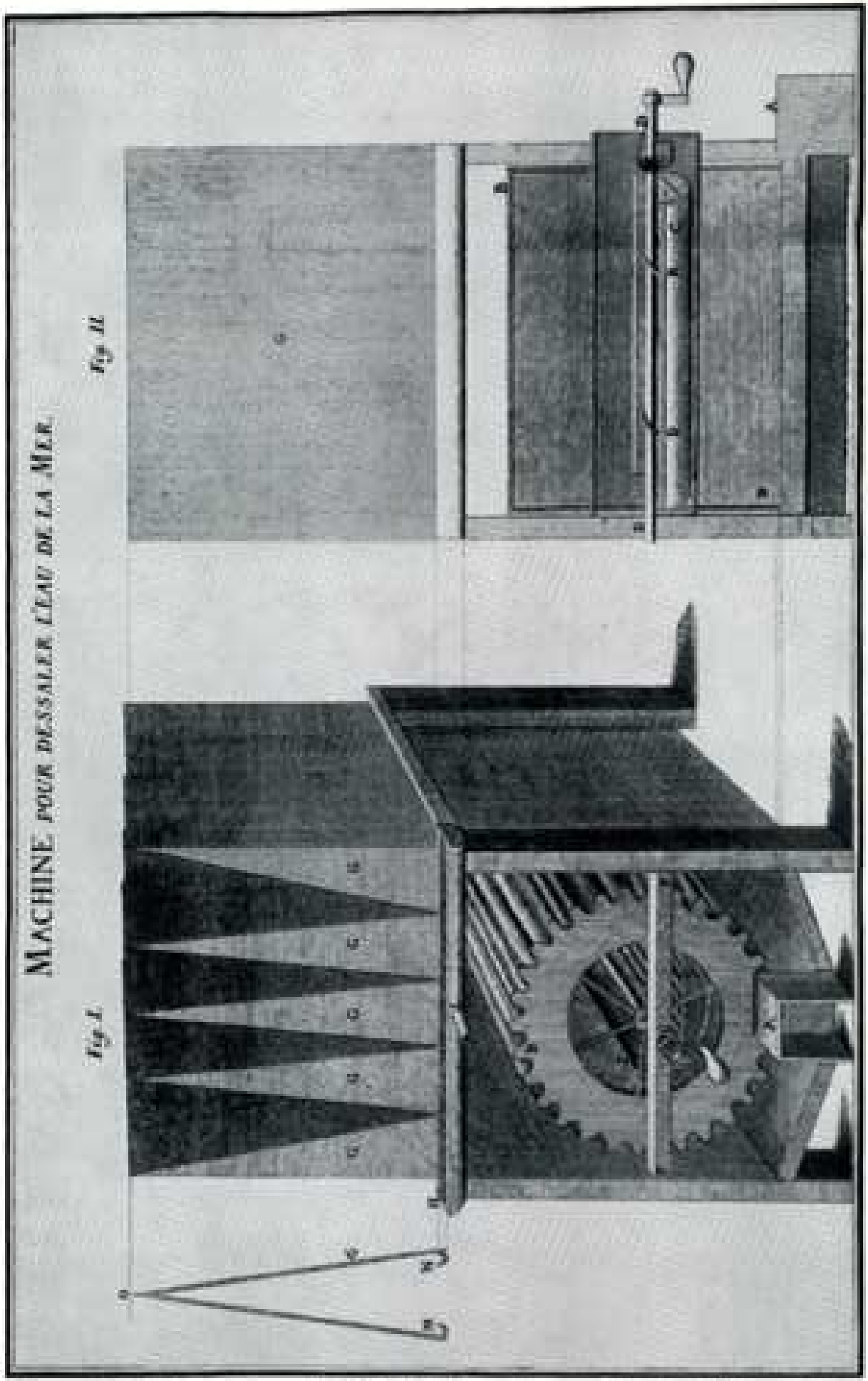

Figure 3. Gautier's sea water still, 1717. This Figure is contained in the "Preface of the translator", preceding the French translation of the Hales' book (134).

His interest in the subject was reported in one of the scientific journals of that time (120) and a chapter of his book was dedicated to the subject (121).

In the first report Deslandes made various considerations on the conservation of fresh water supplies on ships during long voyages. He suggested adding a small quantity of sulphuric acid but the inconvenient of the limited stability of fresh water would be overcome if it were possible to distill sea water; the experience however showed that the distilled water had always a bituminous taste, not caused by the alleged "bitume mines" in the sea, but, he says, caused by the decomposition of organic matter (122).

In his book (121) Deslandes reviewed the problem insisting that the main difficulty was still that of obtaining distilled water which did not contain a bitter taste (123). Many had tried, and the most publicized was the work of Fitzgerald,

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(119b) "Cette machine est formée par une boëte de charpente de figure cubique, dont le fond est fait en goutière. A ce fond est adapté un conduit A. qui sert à insinuer l'eau dans la machine. La partie supérieure de cette boëte est couverte de cinq chapiteaux G.G.G. &c. unis ensemble, & qui ont la même largeur que la boëte; de manière qu'ils couvrent parfaitement cette capacité. Tous ces chapiteaux, sont contruits de feuilles de cuivre exactement soudées. Dans l'intérieur de chaque chapiteau comme M.O.N. sont des goutières M.N., qui sont aussi longues que la chapiteau, & qui se rendent dans une goutière générale H., à laquelle est un robinet L. Le dedans de la boëte contient un tambour canelé B, soutenu par son arbre sur deux traverses, telles que F.F., sur lesquelles ce tambour peut tourner librement au moïen d'une manivelle qui est fixée à une de ses extrémités. Ce tambour creux renferme une quille de rechaud C. dont la longueur est à peu près égale à celle du tambour. Ce rechaud est soutenu sur l'arbre D.D., par les brides P.R.; de manière que le tambour peut tourner indépendamment du rechaud. Ce rechaud est de fer, & contient une grille de même matière, sur la quelle on fait le feu nécessaire. Voilà la construction de cette machine, et voici l'usage. On fait du feu le long du tambour B. dans le rechaud C., ensuite on insinue l'eau dans le fond de la boëte par le conduit A. Le tambour, dont la surface canelée n'est élevé du fond que d'un fort petite quantité, trempe nécessairement ans l'eau, & ce tambour étant egité, lorsqu'on le fait tourner sur lui même, & échauffé par le rechaud, l'eau, dont sa surface est mouillée, s'éleve en vapeurs qui s'attachent de côte & d'autre aux parois intérieures des chapiteaux; se ramassant ensuite, elles coulent le long de ces mêmes côtés dans les goutières, pour se dégorger ensuite par le robinet L. Pendant cette opération, les parties salines et bitumineuses de l'eau se détachent des vapeurs aqueuses & s'exhalent, laissant beaucoup moins d'acreté qu'elle n'en avoit auparavant" (119a; Vol. III, No. 189) (134; pages XXII-XXIV).

(119c) "Mr. Gautier... mit de l'eau de la mer dans une cucurbite de verre assez haute, & couverte de son chapiteau: il l'exposa au soleil, de sorte que cet astre échaufoit la cucurbite, sans fraper sur le chapiteau. Lorsque tout fut distillé jusqu'à siccité, il trouva de l'eau très bonne & très saine dans le récipient, & du sel dans la cucurbite" (119; page 1815).

(120) *Histoire de l'Académie Royale des Sciences*, Année 1722, Paris, 1724, pages 9-10.

(121) A.F.B. Deslandes, "Recueil de differens traitez de physique et d'histoires naturelles", Bruxelles, 1736.

(122) "Il ne faut que jetter dans la barrique pleine de son eau une très-petite quantité d'esprit de vitriol. M. Deslandes assûre que des vaisseux se sont déja servis avec succès de ces deux précautions. Il convient qu'elles seroient inutiles, si on pouvoit rendre l'eau de la mer potable. La difficulté n'est pas selon lui de la dessaler, comme l'on croit communément, c'est de lui ôter une graisse, une onctuosité amere, très-désagréable au goût, et mal saine. Elle vient, non d'un bitume dissout, car se prétendues minieres de bitume ne se trouvent point dans la mer, mais d'une infinité de matieres pourries, bois, plantes, poissons morts, cadavres" (120).

(123) "Beaucoup de personnes ont tenté de dessaler l'eau de la mer. Mais ce n'étoit point là le principal object de leur travail. Ils devoient chercher à la dépouiller de son amertume, d'une certaine huile grossiere qui souleve et irrite l'estomac. Mais cette dernier operation me paroît presque impossible: du moins on n'y a pas réüssi jusqu'à present" (121; pages 259-260).

but all unsuccessfully; many had suggested new solutions and ideas, some of them tested by Deslandes himself, but none brought any significant progress (124).

The only solution that worked, although devoid of practical utility, according to Deslandes, was the filtration of sea water in a wax vessel: and Deslandes stated that he had carried out the experiment successfully (125).

How surprising that this idea actually resisted for 20 centuries!

In 1725 PHILIPPE D'ACHERY (125 a) reported, in a paper published in the proceedings of the Académie Royale, that he had observed a little fresh water penetrating into a tightly closed glass bottle.

Father JEAN BAPTISTE LABAT (1663-1738) reported in one of his travel books (125b) experiments of water desalination by filtration.

LUIGI FERDINANDO MARSILI of Bologna, scientist, traveller, politician and a man of war, is considered the father of oceanography and has dedicated many of his numerous works to the problems of the sea (126).

His scientific value was recognized by King Louis XIV of France (Marsili was nominated a member of the Académie Royale) and by the esteem of Newton who presented him as a Member of the Royal Society of London.

Before his death he gave his very rich collection of books and scientific material to Bologna, where he had founded the Institute of Sciences, which later became the Accademia delle Scienze di Bologna.

His first book, "Observations on the Constantinople Channel" (*Osservazioni intorno al Bosforo Tracio o vero Canale di Costantinopoli*), published in Rome in 1681, was dedicated to Queen Christin of Sweden. In this work he suggested distillation as a means of evaporating water in order to determine the amount of total solids dissolved in sea water, and stated that the experiment had been carried out at Venice in the presence of the professor of anatomy of Padova University. Other main hydrological works were *Danubius Pannonico-Mysicus* (Amsterdam, 1726) and

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(124) "On trouve dans les anciens Mémoires de l'Académie des Sciences, plusieurs experiences pour dessaler l'eau de la mer: les unes par distillation, les autres par translocation ou precipitation: mais il paroît, et que ceux qui proposoient ces experiences, et que ceux qui étoient chargés de les examiner, n'avoient aucune idée de l'amertume de l'eau de la mer... Il s'est presenté en France un grand nombre des curieux, qui ont proposé des machines pour rendre l'eau de mer douce. J'ai été chargé d'examiner plusieurs de ces machines; et quoique je fusse convaincu qu'elle ne pouvoient être d'aucune utilité, j'ai tâché cependant de procurer aux inventeurs des recompenses proportionnées à leur zele et à leur bonne volonté. M. Colbert disoit sensement qu'il falloit payer, avec usure, toutes les nouveautés, toutes le découvertes qu'on apportoit. Une seule qui réüssit, ajoûtoit-il, en recompense vingt qui paroissent chimeriques, qui sont inutiles" (121; pages 261-262).

(125) "Apres plusieurs essais que j'ai fait en divers tems, j'ai trouvé une maniere assez simple de dessaler l'eau de la mer. C'est de prendre de la cire vierge, et d'en composer des gobelets en forme de cul de lampe. On remplit ensuite ces gobelets d'eau de mer, qui en dix-huit heures, ou environ, passe toute au travers. Cette eau qui perd ainsi une partie de son amertume, perden effet tout son sel. Mais le cire s'en charge et s'en impregne tellement, qu'il faut la dessaler elle-même pour s'en servir ensuite. Ce secret, comme on voit, ne peut être d'aucun usage dans les vaisseux; je ne le rapporte ici que comme une simple curiosité" (121; pages 263-264).

(125a) *Mémoires de l'Académie Royale des Sciences, 1725*, page 8 of the Amsterdam edition.

(125b) J.B. Labat, "Un nouveau voyage aux îlex de l'Amerique", Paris, 1722, quoted by Lorgna (165) with the Latin title: "In itinere ad insulas Amer.".

(126) I. Guareschi, "Luigi Ferdinando Marsigli e la sua opera scientifica", *Memorie Reale Accademia delle Scienze Torino*, (2), *65*, No. 10, 1-38 (1914-1915).

(127) L.F. Comte de Marsilli, "Histoire physique de la mer", Amsterdam, 1725.

Osservazioni fisiche intorno al lago di Garda detto anticamente Benaco (Bologna, 1730).

Marsili's most famous and important book is "Physical History of the Sea" (*Histoire physique de la mer*) (127), written in French and published in the Netherlands because in Italy he could not get financial support for the publication.

The book contains the first systematic collection of scientific information and the results of original experiments carried out in a laboratory near Marseille, the first oceanographic research institute. It is divided in four parts: the first deals with the sea in general and with the Mediterranean Sea in particular; the second contains the physical and chemical properties of sea water; the third deals with sea currents and winds, and the last with sea life.

The book is rich with new observations, as the variation of salinity of the sea at different depths, the results of the determinations of the specific gravity with an aeromater: Marsili observed that the salt content varied from 31,000 p.p.m. on the surface to 34,000 p.p.m. on the bottom (128).

In order to experiment if filtration through earth lowered the salt content of the sea water, Marsili filtered sea water through 15 earthen pots, placing one over another (Figure 4); they were then filled first with garden earth, and then with sand, well washed in order to eliminate every possible trace of salt in them; these filtrations had very little effect, though the total depth of the filtering layers was 75 inches: the best effect was obtained with the sand (129).

Marsili also considered the problem of the bitter taste of distilled water and stated that this was very difficult to eliminate (130).

In 1735 Boyle Godfrey (51; Vol. II, page 761), one of the sons of Robert Boyle's assistant, Ambrose Godfrey, stated in his *Miscellaneous experiments* (131) that if one filters sea water through stone cisterns, the first pint that runs through

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(128) "L'eau de la mer... contient de sel en sa superficie la 32. partie de son propre poids, et dans le fonds une 29. partie" (127; page 25).

(129) "Je n'ai pas négligé la filtration de l'eau de la mer, par la terre de jardin et par le sable, afin de connoître combien elle pouvoit perdre, par ce moyen, de son goût salé, et ce que l'on pouvoit conclurre de la circulation de l'eau au travers de la terre. La terre de jardin et le sable destiné à cette experience furent lavez cinq fois; de sorte que je fus bien assûré qu'il n'y restoit plus aucune partie de ce sel; qui peut être dans la terre et dans le sable, que l'on a pris dans un endroit proche de la mer. Pour faire cette opération je préparai quinze vases de terre cuite le la figure exprimée dans le dessein (Figure 4), châcun desquels avoit cinq pouces de largeur et de hauteur. Il étoient disposez de maniere, que la quantité d'eau que l'on jettoit dans le premier vase, pour se filtrer, passoit successivement par tous les autres, et s'alloit rendre dans le recipient, qui étoit mis au bout... Si ces vases avoient été tous unis ensemble ils auroient formé un cylindre de soixante e quinze pouces de long, et cinq de large, dans la quelle étendue, tantôt pleine de terre, tantôt de sable... La premiere experience fur faite de la terre de jardin, de laquelle des vases étoient remplis... Cette diminution du goût salé et du poids, qui se trouve plus grande dans la filtration par le sable, qu'en celle qui se fait par la terre, montre qu'il est le plus propre à purifier l'eau" (127; pages 32-33).

(130) "J'ai reconnu dans les operations que j'ai faites, par le feu, pour chercher la quantité de sel qui est dans l'eau de la mer, que bien qu'elle (distilled water) soit entierement depouillée du sel, l'amertume qui lui reste la rend si dégoutante, qu'il n'est pas possible de la boire. J'ai essayé de corriger ce mauvais goût, par l'infusion de la graine de fenouil... La pratique de la distillation sur les vaisseaux, dans une grande necessité, seroit facile avec des vases de cuivre, particulierement à ces nations, qui ont abondance de charbon de pierre, avec lequel on pourroit faire le lest, et s'en servir dans l'occasion" (127; pages 41-42).

(131) B. Godfrey, "Miscellanea Vere Utilia: or Miscellaneous Experiments and Observations on Various Subjects", London, n.d. (c. 1735); 2nd edition, with additons, London, 1737.

will be similar to pure water, having no taste of salt, but the next pint will be as salty as before.

Almost contemporary of Marsili is STEPHAN HALES (1677-1761) (132), the author of many outstanding contributions in the field of vegetal physiology.

In 1739 he wrote a famous book (133) (134) containing an extensive discussion on all the problems of water desalination, probably the best account of the state of the art at his time.

The book contains an introduction in which a review of the literature is made and detailed references are made to the dispute Fitzgerald-Walcot, to show how unsuccessful all previous attempts had been.

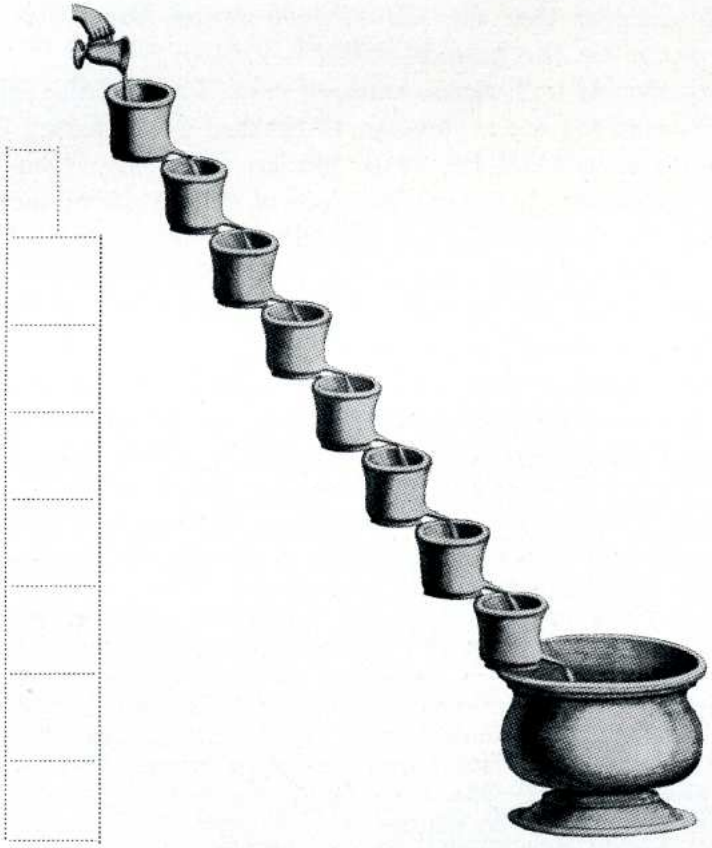

Figure 4. Filtration of sea water through a series of vases tried by Marsili (129).

Reference is made to filtration, by thin bowls of white virgin wax, but just to observe that "this is only a matter of curiosity, because but a very small quantity can be thus prepared; and in order to make those waxen bowls fit for farther filtration, they must be cleansed from the salt, by being washed in fresh water" (133; page X-XI).

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(132) P.M. Dawson, "Stephen Hales, the Physiologist", *Bulletin Johns Hopkins Hospital, 15*, 232-237 (1904).

(133) S. Hales, "Philosophical Experiments: containing Useful and Necessary Instructions for such as undertake Long Voyages at Sea, shewing how Sea Water may be made Fresh and Wholsome", London, 1739.

Hales added that "there have both in England, Germany, France, and Holland, been several attempts made, to make sea-water more wholsome. I am informed that the *lapis mexicanus,* or a soft filtrating stone in the shape of a large mortar or boiling copper, is very much in use among the Hollanders; but will not answer the end. It clears the water from mud, but will not quite clear it from the salt and bitter taste" (133; page 2).

"It has also been attempted by several ways of distillation, as also by precipitation, both with and without distillation, wich was attempted with alkaline powders, as coral, crabs-eyes, etc., with salt and oil of tartar; and also with acid vegetables and mineral substances; but all hitherto to no purpose" (133; pages 2-3).

"And... a person told me, that on board an East-India ship, in which he was; for want of fresh water, the ship's crew was sustained 14 days, with distilled sea-water, which they distilled off a the rate of ten gallons in a day...

An experienced distiller informs me, that with a still that holds 30 gallons, water will distill at the rate of fifteen gallons in seven hours, which will take up half a bushel of Newcastle coals; but in a larger still more will be distilled in equal times, with less fewel, in proportion to the quantity distilled. Therefore 36 bushels or a chaldron of coals will distill 1080 gallons, wine measure, that is above four tuns; or near three tuns beer measure. And as a chaldron of coals, weighs about a tun and half, and a tun of water, Winchester measure 2816 pounds; hence it appears that coals will distill about 3 times their quantity or weight of water" (133; pages 4-5).

Hales described the possibility of applying a still to the ordinary boiler of a ship, with a condenser « aptly fitted: and the joinings closed with a stiff paste made of bean or wheat-flower, with whiting or chalk wetted with salt water" (133; page 7).

"I believe it would be most adviseable to have the pot or boiler of cast iron, but especially the head of pewter: because I suspect that when salt-water is boiling in a copper vessel, the heat may make the salt more corrosive, and thereby more apt to produce, and bring off verdigreece from the copper; which would make the distilled water apt to cause nauseating of food, and sometimes vomiting; which as I have been informed, has happened to the inhabitants of Antegoa; where being in great distress for fresh water, of which they have none but rain-water, they had drank for some time distilled sea-water; which obliged them to disuse their stills" (133; page 8) (135).

"I am informed, that wood fewel is chiefly used in ships, which in many ports abroad, costs nothing but the labour of cutting and fetching. A greater bulk of this will be wanting to distill any quantity of water, than there will of coal to distill the like quantity. Coals might well be laid in ballast, in a little compass" (133; page 9).

"I have been told, that where there has been occasion to keep a fire for many days and nights continuance, on shipboard, for distilling of water, they have by way of precaution from danger of fire, laid a quantity of salt on the planks about the fire-place" (133; page 10).

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(134) A French translation of the above book was published with the title: "Instructions pour le marinier, contenant la maniere de rendre l'eau de mer potable, de conserver l'eau douce, le biscuit, le bled, et de saler les animaux ...Traduit de l'Anglois de Mr. Hales", La Haye, 1740.

(135) We have not been able to locate other reference to this sea water still used on land in the West Indies; the need for water has not changed during the centuries and in 1956 a large still, producing 1,5 million gallons of fresh water per day from the sea, was built in Aruba, Netherland Antilles.

Hales reported that he himself wanted to investigate the real cause of the unpleasant taste in the distilled water which had been reported by many people.

"I distilled several gallons of sea-water in large glass retorts, pouring what came over into the receiver, from time to time, into separate glass vessels; beginning the first pouring off, when it first began to boil, that I might the better know, whether it grew worse and worse, the farther the distillation was carried on, which was sometimes done till the salt in the water became dry.

I found, the little which was distilled off with a more gentle heat, viz. till it began to boil, was pretty well tasted; but the seven next separate portions of distilled water, had a flat, unsalt, nauseous, dry, adust taste; and the last and ninth portion, was more harsh and disagreeable, it tasting more of a kind of spirit of salt; for what came over till all was distilled to a dry salt, was in this ninth portion » (133; pages 11-12).

Hales stated that if sea water was mixed with putrifiable substances and then distilled, it gave a good distilled water, but his most important contribution was that distilled water would be good if only a part of the sea water was distilled.

"Then, if only one third of each still full of water be distilled off, but a small quantity of spirit of salt will arise" (133; page 51).

A few years later Hales published a report (136) on the possibility of increasing the efficiency of the distillation by blowing air through the boiling sea water.

Prof. Schadewaldt (7) has drawn out of the oblivion a contribution by Etienne Chardon de Courcelles (1705-1775) on sea water distillation, prepared in 1754 for ✳ this report has been the theme of a doctor's thesis, few years ago (136a).

De Courcelles also observed the unpleasant taste of the distilled water and attributed it to the decomposition of organic matters.

Caspar Neumann (1683-1737) reported that sea water can be made fresh by filtering it through porous stones, sand and insipid earth, but on board ship it is best done by distillation: "I saw, in the French academy, a drawing of a curious machine of this kind invented by M. Gautier" (51; Vol. 2, page 705) (137).

In 1742 Nicolò Ghezzi (died in 1766) wrote a small treatise (138) where the problem of desalination is extensively dealt with.

Among the most interesting proposals there is a suggestion of using solar heat for distillation (139).

Almost at the same time Jean Antoine Nollet (1700-1770) and René Antoine Reaumur (1683-1757) (51; Vol. 3, pages 60-65) tried the filtration of sea water

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(136) S. Hales, "Account of a Useful Discovery to distille double the Quantity of Sea Water by blowing Showers of Air trough the distilling Liquor", London, Manby, 1756; *Vogels Neue med. Bibl.,* Vol. 4, page 170.

(136a) J.F. Lefur, "Etienne Chardon de Courcelles et le service de santé de la Marine à Brest au XVIIe siècle", Thése medic., Rennes, 1959.

(137) "The Chemical Works of Caspar Neumann ...Abridged and methodized: with Large Additions... by William Lewis", London, 1759. The reference is in the 2nd edition in 2 vols., London, 1773, page 250-251.

(138) N. Ghezzi, "Dell'origine delle fontane e dell'addolcimento dell'acqua marina. Lettere scritte al Signor Conte N.N.", Venezia, 1742.

(139) "Potrebbe adoperarsi un vaso a guisa di storta, sù cui battesse il sole, (che anche ne' climi, e ne' giorni temperati ha non piccola attività per alzar de' vapori) di modo però, che il cappello del vaso fosse difeso dall'azione solare; con che verrebbe ad aversi più copiosa, e più lunga uscita di acqua dolce" (138; pages 210-211).

✳ the Académie de la Marine and which has remained up to now only as a manuscript

through a tube folded many times and filled with sand and did not observe any desalination (139a).

CHARLES ALSTON (1683-1760) tried to precipitate the salts from sea water using quick lime (CaO), but, obviously, with no success (139a).

In 1753 a Durham pharmacist, JOSUA APPLEBY, developed the following process to avoid the bad taste of distilled water: "Into twenty gallons of sea-water put six ounces of a fixed alcali, prepared with quick-lime as strong as *lapis infernalis*, and six ounces of bones calcined to whiteness, and finely powder'd. With a flow fire, draw off in a common still fifteen gallons. Mr. Appleby conceives, that the alkali here employed is the best adapted to prevent the bituminous matter in sea-water from rising by the heat in distillation" (140). The distilled water was tested with various reagents, among which silver nitrate, and no trace of chlorides was found.

In 1755 Dr. T. BUTLER published a report (140a) on sea water distillation, in which he suggested that soap lye should be added to the sea water, apparently with no particular satisfactory result.

In 1757 KEANE FITZGERALD reported (141) the combination of the steam engine with the method proposed by Hales (136), in order to increase the water production by blowing air through the salt water. Fitzgerald observed that a fuel economy and an increase of steam production of the order between 15 and 25 % would result if this procedure was adopted.

Captain WILLIAM CHAPMAN, during a voyage to Northern Russia, being short of potable water, built a very simple still (142) made extempore from such materials as are to be found on board every ship, large or small. It was made using a common pot, with a wooden lid of the usual form in the centre of which a hole was bored to receive perpendicularly a short wooden tube, made with an inch-and-a-half augen. This tube received at its summit, at an acute angle, another tube of wood, which descended until it joined a third tube of pewter, which had been made by rolling up a dish and passing it obliquely through a cask of cold water. With this simple machine Chapman obtained 2 quarts of fresh water an hour, and observed that the expense of fuel would be very little, if the still was adapted to stand on the fire along with the ship's boiler.

By adding wood ashes to the sea water, he obtained fresh water which was completely tasteless. " I am firmly persuaded, that wood-ashes mixed with sea-water will yield when distilled, as good fresh wather as can be wished for" (142; page 638).

DE COSSIGNY proposed desalting sea water by filtration through porous glasses (143). His trials showed that glass bottles, immersed in the sea at a depth of about 200 feet, were broken by the water pressure; if they did not break they were never found filled with fresh water (139a).

(139a) J.B. Fonssagrives, "Traité d'hygiène navale", Paris, 1856, pages 478-498.

(140) W. Watson, "An Account of Mr. Appleby's Process to make Sea Water Fresh: with some Experiments therewith", *Philosophical Transactions, Royal Society of London, 48*, Part I, 69-71 (1753).

(140a) T. Butler, "A Safe, Easy and Expeditious Method of procuring any Quantity of Water at Sea", London, 1755.

(141) K. Fitzgerald, "Experiments on applying the Rev. Dr. Hales's Method of distilling Salt-water to the Steam-engine", *Philosophical Transactions, Royal Society of London, 50*, Part I, 53-57 (1758).

(142) W. Chapman, "An Account of the distilling Water Fresh from Sea-water by Wood-ashes", *Philosophical Transactions, Royal Society of London, 50*, Part II, 635-639 (1759).

JAMES LIND, the founder of naval hygiene (144) (145) and author of various treatises on this subject (147), carried out experiments on water distillation (148).

Lind tested one of his stills in 1761 at Portsmouth (146; page 85, ed. 1762) (147; page 324). In 1762, proposing to experiment several different additives, he first distilled rain water without any additive (as he presumed this rain water would be the purest), and then sea water, which he expected would be the least pure, in order to arrange between these two supposed extremes, the degree of merit of the several ingredients he meant to try. "To his great surprise" — as he confessed — the sea water distilled without any mixture was as pure as the rain water; he continued the experiment and established the fact, that pure and potable fresh water may be obtained from salt water by simple distillation, without the aid of any mixture for firing or precipitating its foreign contents. In 1767 he proposed an extemporary still which, in fact, was Chapman's only substituting a gun-barrel instead of Chapman's pewter tube, and the hand-pump of the ship was to be cut in two, obliquely, and joined again at an acute angle instead of Chapman's wooden tubes boren expressely. He also suggested using a tea kettle (without its lid or handle) to be turned upside down over the mouth of the pot to be used as a still head; the wooden tube leading from the spout to the gun barrel passing through a barrel of water, was tightly closed with equal parts of chalk and meal moistened with salt water.

Lind also carried out experiments using solar energy, concentrated with parabolic mirrors, to distill sea water (146; page 85, ed. 1762).

In 1763 PIERRE ISAAC POISSONNIER (1720-1792), General Health Inspector for the French Navy, developed another still for sea water; alkali was added to the sea water before distillation. This achievement was reported in the treaty of chemistry of Baumé (149), together with the arguments that Poissonnier presented to claim the priority of his discovery upon the one made by Lind.

Poissonnier was given a prize of 6,000 golden louis by the French King and the French Navy Minister ordered the ships in the port of Brest to receive on board sea water stills of the type suggested by Poissonnier (139a).

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(143) De Cossigny, "Expériences réitérées pour s'assurer si les filtrations de l'eau de la mer au travers des pores du verre sont possibles", *Memoires de mathématique et de physique presentés á l'Academie de Paris,* Vol. 3, 1-8 (1760); *Commentaires,* Leipzig, Vol. 10, page 387.

(144) J. Glass, "James Lind, M.D., Eighteenth Century Naval Medical Hygienist", *Journal Naval Medical Service, 35,* 1 and 68 (1949).

(145) L.H. Roddis, "James Lind, Founder of Nautical Medicine", New York, 1950.

(146) J. Lind, "An Essay on the most Effectual Means of preserving the Health of Seamen in the Royal Navy", London, 1757; 2nd Edition, London, 1762. German translation, Leipzig, 1760.

(147) J. Lind, "Essay on Diseases Incidental to Europeans in Hot Climates, etc., to the Whole is annexed a Simple and Easy Way to render Saltwater Fresh", London, 1768. French translation: "Maladies des Européens dans les pays chauds", Paris, 1761. The passage regarding the distillation of sea water is in Vol. II, page 220 and following, and page 267, of the French translation.

(148) J. Lind, "Vorschlag, dem Mangel des süssen Wassers auf der See, leicht abzuhelfen", *Neues Bremisches Magazin zur Ausbreitung der Wissenschaften, Künste und Tugend,* Bremen, Vol. *3,* pages 37-42 (1770). See also: *Universal Magazine of knowledge and pleasure,* page 245, November 1768.

(149) A. Baumé, "Chymie expérimentale et raisonnée", 3 vols., Paris, 1773. German translation with the title: "Erläuterte Experimental-Chemie", Leipzig, 1775; Italian translation: "Chimica sperimentale e ragionata del Sig. Bome (*sic*)", 3 vols. Venezia, 1781. The reference to the work of Poissonnier is in Vol. III, page 576, of the Paris edition, 1773.

Louis Antoine de Bougainville (1729 - 1811), who travelled extensively in the Atlantic Ocean and in the South Seas in 1763-1769, left a famous description of such voyages (150) and he reported having used a still, very successfully, which had been contrived by Poissonnier, to guard against the water being spilt by the rolling of the ship. In this still one singularity was, that the furnace was in the middle of the boiler, so that it heated the water on a much larger surface. This still, however, was expensive and occupied much room.

An account of the distillation method proposed by Hales was published in 1768 by J.N.S. Allamand who recommended such method for Dutch ships and ports (150a).

In 1768 Bernardin de Saint-Pierre used a sea water still on the ship "Marquis de Castries" during his voyage to Île de France, with not too satisfactory results (150b).

The celebrated chemist and professor Pierre Joseph Macquer (1718-1784) (51; Vol. 3, pages 80-90), in his dictionary of chemistry (151) (151a) reported that, round about 1750, a gentleman had proposed a secret for water desalination on board ship to the Minister of the French Navy. Macquer with others, assisted at the experiment, consisting in a distillation after addition of some secret ingredient to the sea water.

Macquer prepared a distilled water in his laboratory without any additions and presented the two different types of distilled water to the proposer, asking him to identify the one that had been prepared with his secret. The gentleman was unable to distinguish one from the other and gave up.

This century is noteworthy, for the continuous attempts to improve the desalination processes.

In 1765 Hoffman invented a still, however very large and bulky, and added an ingredient to the sea water, but unsuccessfully.

Almost at the same time Dove attempted other distillation experiments, equally without success (see paper 153).

Captain Samuel Wallis, who had been in Tahiti a few years before Cook and had journeyed round the world in the ship "Dolphin" in 1766-1768, used a sea water still of the type devised by Lind and was able to obtain 42 gallons of potable fresh water in 5 hours from 56 gallons of sea water, at the rate of 8 gallons per hour, with 9 lbs. of wood and 69 lbs. of pit-coal. This is described in his log-book on February 1768 (152; chapter XII).

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(150) L.A. de Bougainville, "Description d'un voyage autour du monde", 1771-1772.

(150a) "Neuer Versuch das Seewasser trinkbar zu machen, erfunden von dem Herrn Hales und mitgeteilt von J.N.S. Allamand", *Neues Hamburgisches Magazin*, Hamburg, Band 4, 19 Stuck, *1768*, pages 184-186; German translation of a paper appeared in *Abhandlungen der Harlem. Gesellschaft der Wissenschaften*, Vol. 2, page 380. See also *Crells Chymisches Archiv*, Vol. I, page 26, 1783.

(150b) "Quant a la machine à dessaler l'eau de mer, les marins la croient peu salutaire; d'ailleurs il faut embarquer beaucoup de charbonne de terre, qui tient beaucoup de place, qui est sujet à s'enflammer de lui-même, et elle a l'inconvénient dangereux d'entretenir un fourneau allumé nuit et jour". J.H. Bernardin de Saint-Pierre, "Oeuvres completes", Paris, 1839, page 53.

(151) P.J. Macquer, "Dictionnaire de Chymie", 2nd Edition in 4 vols., Paris, 1778. English translations, London, 1771 and 1777. talian translation, Napoli, 1784. The quoted passage is at pages 158-159, Vol. I, of such Italian translation.

(151a) R.G. Neville, "Macquer and the First Chemical Dictionary, 1766", *Journal of Chemical Education, 43*, 486-490 (1966).

(152) We have seen a French translation of the report of this voyage, published in Paris in 1774.

Another ship, the "Dorsetshire", in her passage from Gibraltar to Mahon in 1769, made 19 quarts of pure water from 22 quarts of sea water in 4 hours with 10 lbs. of wood, and the "Slambal", in 1773, between Bombay and Bengal, with a hand-pump, a gun barrel and a pot of 6 gallons of sea water, made 10 quarts of fresh water in 3 hours.

ANDREW SPARRMAN (c. 1747-1820), the Swedish naturalist who travelled to Far East and Africa in the years 1765-1776, reported on the purification of sea water to obtain fresh water (152a).

On 6th December, 1770 BARTHOLOMEW DOMINICETI was granted the British Patent No. 972 for an invention of a special arrangement of many alembics for obtaining fresh water from sea water (92).

In 1771 GEORGE JAMES IRVING (1722-1798), putting together Lind's idea of distilling without an additive, Chapman's still and Dr. Franklin's method of cooling by evaporation, developed a sea water still which won a prize of 5,000 pounds from the British Parliament in 1772 (153) (154) (155).

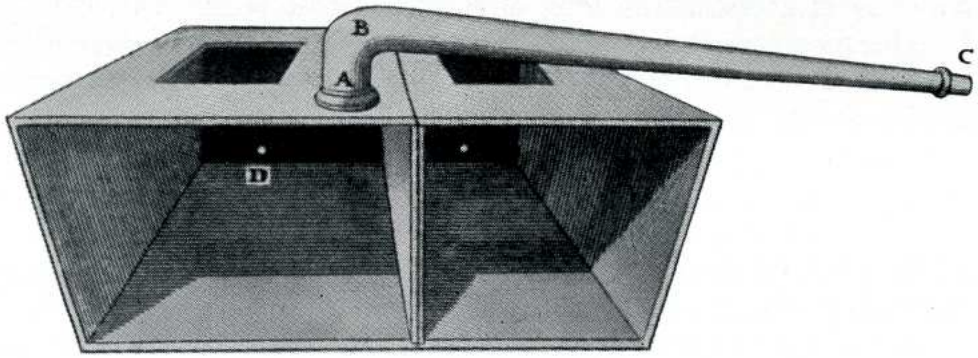

Figure 5. Irving's sea water still, 1779 (153).

He constantly wet his tube with a cloth, instead of passing it through a barrel of water, he enlarged its bore holes, in order to give free passage to the vapor, and thereby increased its quantity by lessening the resistance or pressure to the evaporating surface (Figure 5).

(152a) A. Sparrman, "Försök med saltsjö-vatten, uphämstadt, ifrän större djup til besparing af färskt vatten", *Kongl. Vetenskaps-academiens handlingar för år 1777*, Stockholm, Vol. *38*, pages 21-25 (1777). German translation: A. Sparrman, "Versuch mit salzigem Seewasser aus grösserer Tiefe behoben, süsses Wasser zu ersparen", *Der Köninglich Schwedischen Academie der Wissenschaften Abhandlungen aus der Naturlehre, Haushaltungskunst und Medizin auf das Jahr 1777. Aus dem Schwedischen übersetzt*, Leipzig, Vol. *39*, pages 20-24 (1782).

(153) "Description de la méthode du Docteur Irving, pour dessaler l'eau de la mer par distillation", *Rozier, Observations sur la physique, sur l'histoire naturelle et sur les arts*, Paris, 1779 316-324.

(154) The work of Irving is reported in a letter written by the British astronomer and physicist Stephen Charles Triboudet Demainbray (1710-1782) on the 16th April, 1777. "Nachricht von Herrn Irwins Erfindung das Seewasser trinkbar zu machen, aus einem Briefe Hrn. Demanbray... aus dem Engl. übersetzt", *Deutsche Schriften von der Köningl. Societät der Wissenschaften zu Göttingen*, Göttingen, Vol. *1*, pages 202-203 (1771).

(155) The *House of Commons Journal*, Volume 33 for 1772, contains a petition of Irving for a reward and two petitions against Irving's claim by Daniel Scott and Bartholomew Dominiceti. There is also the report of a committee which investigated Irving's discovery and the resolution of the House of Commons dated 11th May, 1772 to award L. 5,000 to Irving.

This last improvement was his own and it doubtless contributed to the success of his process.

Captain JAMES COOK, during his second voyage around the world (1772-1775), had observed the possibility of obtaining fresh water by melting the ice formed from sea water (January 1773) (156); during the same voyage he used a still of the type developed by Irving and obtained 30-40 gallons per day of fresh water from the sea (157) (158).

In 1772 Captain NEWLAND described another still which operated after addition of wood ashes or soap to the sea water, and produced 8-10 gallons of distilled water in 12 hours (159) (160).

A sea water still of the type developed by Irving was used during the exploration to the Artic, undertaken by the Royal Society of London with the vessels "Racehorse" and "Carcass" in 1773 under Captain C. J. PHIPPS, later Lord Mulgrave (1744-1795) (161). He obtained about 150 liters of fresh water per day.

RICHARD WATSON (1737-1816), Bishop of Llandaff and professor of chemistry at Trinity College, Cambridge, has dealt with desalination in his classical *Chemical Essays* (162).

On 19th July, 1777 the British Patent No. 1163 was granted to ALEXANDER MABYN BAILEY for his invention of "a machine for making fresh water from sea water or brine springs without boiling... and for making salt from sea water, or from brine springs, with much less boiling than in the common way of boiling it" (92). The invention consisted in a modification of the usual scheme of distillation.

At the end of 1700 a very interesting and little known achievement was obtained by a professor in Verona at the Military School of the Venice Republic, ANTON MARIA LORGNA (1735-1796) (163) (164), author of scientific papers, many of which on hydraulic problems and one on a project to connect the Mediterranean with the Red Sea.

Lorgna reported the results of his scientific investigation on water desalination by freezing in 1786-1790 (165) (165a) (166).

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(156) J. Cook, "A Voyage toward the South Pole and round the World", Vol. I, London, 1784. French translation, Paris, 1778, Vol. I, page 114.

(157) J.R. Forster, "Observations faites pendant le second voyage de M. Cook dans l'hémisphère australe et au tour du monde", Paris, 1778, Vol. 5, page 50.

(158) J.R. Forster, "Physische Erdbeschreibung", Berlin, 1773, page 553.

(159) Newland, "An Easy Method to distill Fresh Water from Salt Water at Sea", *Philosophical Transactions, Royal Society of London, 62*, 90-92 (1772).

(160) Nelland (*sic*), "Méthode simple et aisée de rendre l'eau de la mer potable, en la dépouillant de toute sa salure et de son âcreté", *Rozier, Observations sur la physique, sur l'histoire naturelle et sur les arts,* Paris, Vol. II, *1773*, 257-260.

(161) C.J. Phipps, "Voyage on the North Pole", London. French translation: "Voyage au pôle boreale fait en 1773 par ordre du Roi d'Angleterre", Paris, 1775, page 24.

(162) R. Watson, "Chemical Essays", Vols. 1 and 2, Cambridge, 1781; vol. 3, 1782; Vol. 4, 1786; Vol. 5, 1787. The article on desalination is contained in Vol. 2, page 141.

(163) F. Iacoli, "Intorno alla vita ed ai lavori di A.M. Lorgna", *Bullettino di Bibliografia e di Storia delle Scienze Matematiche e Fisiche, 10*, 1-74 (1877).

(164) Accademia di Agricoltura, Scienze e Lettere di Verona, "Anton Maria Lorgna", Verona, 1937.

(165) A.M. Lorgna, "Nuove sperienze intorno alla dolcificazione dell'acqua del mare", *Memorie di Matematica e Fisica della Società Italiana* (Verona), *3*, 375-405 (1786).

(165a) A.M. Lorgna, "Nuove sperienze intorno alla dolcificazione dell'acqua del mare", *Opuscoli scelti sulle Scienze e sulle Arti* (Milano), *10*, 3-29 (1787).

(166) A.M. Lorgna, "Appendice alla memoria intorno alla dolcificazione dell'acqua del mare", *Memorie di Matematica e Fisica della Società Italiana* (Verona), *5*, 8-16 (1790).

In his first paper (165) (165a), after having reviewed the previous experiments, he concluded that it was impossible, by simple filtration, to remove the soluble constituents of water (167). He considered it strange that the fact of ice separating with a small salt content when formed in sea water, had not been used by anybody to obtain fresh water from the sea (168).

In Verona Lorgna carried out his experiments on freezing the sea water (the sample had been taken at Venice), using a salt-ice mixture at about $-20^{o}C$.

He observed that the ice block always contained a central core of liquid water in which most of the dissolved salts and of the impurities of sea water were concentrated (169).

Starting with sea water having a dissolved salt content of 36,200 p.p.m., he made the following series of five successive freezings (165a; pages 16-18), each time freezing the liquid obtained by melting the ice of the previous freezing.

1st freezing

54 parts of sea water,
total dissolved salts (TDS) 36,200 p.p.m.

26 parts of ice, TDS 15,000 p.p.m.	28 parts of liquid brine, TDS 58,000 p.p.m.

2nd freezing

24 parts of saline water,
TDS 15,000 p.p.m.

17.5 parts of ice, TDS 3,250 p.p.m.	6.5 parts of liquid brine, TDS 41,300 p.p.m.

3rd freezing

17 parts of saline water,
TDS 3,250 p.p.m.

13 parts of ice, TDS 800 p.p.m.	4 parts of liquid brine, TDS 10,500 p.p.m.

(167) "Non è mezzo il feltrare, per quanto sieno angusti e tortuosi i meati del feltro, valevole a spogliare da' suoi sali l'acqua marina, e non altro al più può egli rattenere fuorchè le immondezze, la parte terrosa, o ciò ch'è sospeso meccanicamente, non già disciolto chimicamente, nell'acqua" (165a; page 4).

(168) "Sembra strano, che non avendovi forse chi non sappia, che l'acqua marina perde alquanto di sua salsedine nel congelarsi, non siasi alcuno avvisato giammai di trar profitto da questo fenomeno, e di tentarne la totale purificazione per una via, ch'era pur indicata dalla natura in qualche modo" (165a; pages 13-14).

(169) "La parte gelata nel fondo del vaso era più salsa assai della parte superiore. Queste due osservazioni cominciano sin da bel principio a indicare col fatto, che nell'atto del gelare prendono a cacciarsi le sostanze straniere contenute nella acqua marina dalle sponde verso il mezzo, come appunto dalle sponde verso il mezzo prendono a formarsi i primi filamenti del gelo" (165a; page 15).

In the fourth and fifth freezing he observed that the ice had just a trace of dissolved salts.

In another series of experiments, carried out at -15^{o} to -20^{o}C he obtained the following results (165a; pages 18-19):

1st freezing

40 parts of sea water,
TDS 36,200 p.p.m.

25 parts of ice, TDS 10,500 p.p.m.	15 parts of liquid brine, TDS 81,000 p.p.m.

2nd freezing

20 parts of saline water,
TDS 10,500 p.p.m.

15 parts of ice, TDS 1,600 p.p.m.	5 parts of liquid brine, TDS 32,500 p.p.m.

3rd freezing

10 parts of saline water,
TDS 1,600 p.p.m.

8 parts of ice, traces of salt	2 parts of liquid brine, TDS 9,700 p.p.m.

Lorgna analyzed and drank the desalted water, finding it pure and pleasant to taste.

The work of Lorgna had resonance in Europe and the British physicist EDWARD NAIRNE, who had already published the results of his studies on the freezing of sea water (170), reported (171) his own experiments on water desalination by freezing.

Lorgna was not satisfied with Nairne's results and in 1790 published his second paper (166) reporting another series of experiments of purification by freezing various liquids; he tested the turbid water of the Adige river, urine and impure liquids collected from stables. After one or more freezing he always obtained pure water.

Lorgna carried out his experiments for obtaining fresh water from urine during the very cold winter of 1788-1789; he left the vessels containing the urine out in the cold of the night. In the morning he found the liquid partly frozen; the upper part was ice which, after being washed and melted, gave almost pure water; the liquid underneath was urine concentrate (172).

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(170) E. Nairne, "Experiments on Water obtained from the melted Ice of Sea-water, to ascertain whether it be Fresh or not; and to determine its Specific Gravity with respect to other Water. Also Experiments to find the Degree of Cold in which Sea Water begins to freeze", *Philosophical Transaction, Royal Society of London,* 66, 249-256 (1776); *Crells Chymisches Archiv,* Vol. I, page 212; *Edinburg. Commentaries,* Part 4, page 273.

(171) E. Nairnes, *Giornale di Parigi,* n. 74, year 1789. The paper is so quoted by Lorgna (166); probably it is published in the *Journal des Sçavants,* of Paris. We have been unable, so far, to locate the collection of the *Journal* of that year — the one in which the French Revolution began — in most of the libraries to which we have had access.

This experiment is interesting because it has been proposed again in recent times as a system for obtaining fresh water from urine on space vehicles (173).

The method of water desalination by freezing had not been in the past of much practical interest, as it could be resorted to in the coldest regions and seasons. The interest has increased after the development of the refrigerating machines and of new freezing processes (173a).

About 1790 a certain JACOB ISAACS of Newport, Rhode Island, presented a petition for a sea water distiller to the United States government.

The petitioner set forth, that he had discovered, with considerable labour and expense, by various experiments, a method of converting salt-water into fresh water, in the proportion of 8 parts out of 10. He claimed a process so simple that it could be performed on board of vessels at sea with the common iron caboose, with small alterations, by the same fire which is used for cooking the ship's provisions, and offered to convey to the government of the United States a faithful account of his art or secret, to be used by, or within, the United States, on their giving him a reward suitable to the importance of his discovery, and in the opinion of government, adequate to his expenses and the time he had devoted to the bringing it into effect.

By resolution of the House of Representatives of the 25th February, 1791 the matter was brought to the attention of the Secretary of State THOMAS JEFFERSON (1743-1826), the artifex of the independence of the United Stated and of the Declaration of Independence (July 4, 1776) and of the American Revolution (1776-1783) and President of the United States from 1801 to 1809.

After a survey of the available information on the matter Jefferson submitted to the House of Representatives the following report, dated 21st November, 1791 (174) (174a) (175) (176).

"As the merit of this (discovery suggested by Mr. Isaacs) could be ascertained by experiment only, the Secretary of State asked the favour of Mr. Rittenhouse, President

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(172) "Nel verno rigidissimo nel 1788-1789 essendo il mercurio 12° sotto il gelo nel termometro di Reaumur, esposi una sera all'aria aperta in vase di terra verniciata dell'urina umana. La mattina trovai agghiacciato il liquore, e nel muovere il vase accorgendomi che la parte di sotto era rimasta liquida, riconobbi che l'esperimento era a dovere. In fatti praticai un foro nella lastra superiore, ch'era grossa poco men di un pollice, e fattone uscire il liquore sottoposto, l'osservai rosso cupo come il mattone pestato, e denso assaissimo. Estratto il gelo, lo lavai tre volte in acqua pura. Rotto poscia e messo in vase di vetro lo feci liquefare, e filtrare per doppia carta non collata. Non era che acqua schietta e limpida senza odore, senza sapore, e non distinguevasi dall'acqua di fonte che nell'essere men vivace, floscia, e non tanto scorrevole" (166; page 12).

(173) Thomas Crook, a chemist of the American Company Minneapolis-Honeywell, probably without knowing the previous achievement of Lorgna, has developed a method for zone freezing of urine which is similar to the one described 170 years before. See: *Chemical and Engineering News, 40*, (38), 138 (1962).

(173a) It may ben interesting to recall that one of the first desalination experiments in this century was by freezing and was performed in the years 1938-1942 by the Istituto Superiore di Sanità of Rome, in a test station few miles from Rome, along the sea-shore (See: E. Vacino and B. Visintin, "Acqua potabile mediante il congelamento dell'acqua del mare", *Annali di Chimica Applicata, 35*, 181-222 (1945)).

(174) "National Archives Record Group 59: Report Book, Volume 1", pages 324-336, National Archives and Records Service, Washington, D.C.

(174a) "Writings of Thomas Jefferson", Vol. 7, 445-460, Taylor and Maury, Washington, D.C., 1854.

(175) "The Complete Jefferson, containing his Major Writings, Published and Unpublished, except his Letters, Assembled and Arranged by Saul K. Padover", Duell, Sloan & Pearce Inc., New York, 1943, page 970-974.

of the American Philosophical Society, and Dr. Wistar, professor of Chemistry in the University of Pennsylvania, to be present at the experiments. Mr. Isaacs fixed the pot, a small caboose, with a tin cap and straight tube of tin passing obliquely through a cask of cold water; he made use of a mixture, the composition of which he did not explain, and from 24 pints of sea-water, taken up about three miles out of the Capes of Delaware, at flood-tide, he distilled 22 pints of fresh water in four hours with 20 lbs. of seasoned pine, which was a little wetted by having lain in the rain.

In a second experiment of the 21st of March, performed in a furnace, and five gallons still at the college, from 32 pints of sea-water he drew 31 pints of fresh water in 7 hours and 24 minutes, with 51 lbs. of hickory, which had been cut about six months.

In order to decide whether Mr. Isaacs' mixture contributed in any and what degree to the success of the operation, it was thought proper to repeat his experiment under the same circumstances exactly, except the omission of the mixture. Accordingly, on the next day, the same quantity of sea-water was put into the same still, the same furnace was used, and fuel from the same parcel; it yielded, as his had done, 31 pints fresh water in 11 minutes more of time and with 10 lbs. less of wood.

On the 24th of March, Mr. Isaacs performed a third experiment. For this, a common iron pot of three and a half gallons was fixed in brick work, and the flue from the hearth wound once around this pot spirally, and then passed off up a chimney.

The cap was of tin, and a straight tin tube of about two inches diameter passing obliquely through a barrel of water, served instead of a worm. From sixteen pints of sea water he drew off fifteen pints of fresh water, in two hours fifty-five minutes, with 3 lbs. of dry hickory and 8 lbs. of seasoned pine. This experiment was also repeated the next day, with the same apparatus, and fuel from the same parcel; but without the mixture, sixteen pints of sea-water yielded in like manner fifteen pints of fresh in one minute more of time, and with 1/2 lb. less of wood. On the whole, it was evident that Mr. Isaacs' mixture produced no advantage either in the process or result of the distillation".

The report of Thomas Jefferson concludes:

"The obtaining fresh water from salt-water was for ages considered as an important desideratum for the use of navigators. The process for doing this by simple distillation is so efficacious, the erecting of extempore still with such utensils as are found on board of every ship, is so practicable, as to authorize the assertion that this desideratum is satisfied to a very useful degree. But though this has been done for upwards of thirty years, though its reality has been established by the actual experience of several vessels which have had recourse to it, yet neither the fact not the process is known to the mass of seamen, to whom it would be the most useful, and for whom it was principally wanted. The Secretary of State is therefore of opinion that since the subject has now been brought under observation, it should be made the occasion of disseminating its knowledge generally and effectually among the seafaring citizens of the United States. The following is one of the many methods which might be proposed for doing this: Let the clearance for every vessel sailing from the ports of the United Stated be printed on a paper, in the back whereof shall be a printed account of the essays which have been made for obtaining fresh from salt-water, mentioning shortly those which have been unsuccessful, and more fully those which have succeeded, describing the methods which have been found to answer for constructing extempore stills of

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(176) *Journal of Chemical Education, 20,* 574-576 (1943).

such implements as are generally on a board of every vessel, with a recommendation in all cases where they shall have occasion to resort to this expedient for obtaining water, to publish the result of their trials in some gazette on their return to the United States, or to communicate it for publication to the Office of the Secretary of State, in order that others may, by their success, be encouraged to make similar trials, and be benefited by any improvements or new ideas which may occury to them in practice".

The last quotation of this review is to JOHN WILLIAM OTTO (1753-1814) who reported in 1792 the results of trials to obtain fresh water from sea water, claiming to have been able to collect a small quantity in a wax vessel (177; page 80).

In the survey of the literature we have found a reference to another paper (178) quoted by Boehmer (179); we have not been able so far to find such work.

We have decided to conclude our story at the end of the 18th century. The story of desalination certainly does not finish at this point, but it changes, and, beginning with the 19th century, follows a new trend.

The introduction of steam propulsion on ships, the new development of trade, communications and science, gave the desalination processes more scientific and industrial bases.

The 20th century, expecially, has seen, and is seeing desalination as playing a fundamental role in humanity's water supply.

The present story would like to indicate to the reader that what engineers are doing, and doing successfully, has its roots in a small group of people who made trials and errors, but always deserve our admiration and interest.

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We acknowledge the help kindly given us in many occasions by Mr. Luigi D'Aurizio of the University Library, Bologna.

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(177) J.F.W. Otto, "Abriss einer Naturgeschichte des Meeres", Berlin, 1792.

(178) Iordan de Pelerin, "Tentamina aquam dulcem conservandi a putredine, marinamque dulcem reddenti", in: "Gautier, Observ. sur l'Histoire Naturelle", Part. XIV, pages 79 and 108.

(179) G. R. Boehmer, "Bibliotheca scriptorum historiæ naturalis, œconomiæ, aliarumque artium et scientiarum. Pars V. Hidrologi", Leipzig, 1789.

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