

DESALTING SEA WATER*

The problem of procuring drinking water on liferafts in order to prolong survival after shipwreck or air crash is of fundamental importance and considerable attention has been devoted to its solution. Before considering the various methods evolved, resulting in success, it will be useful to note that sea water contains the majority of the common elements in small amounts, the principle ions being chlorine and sodium. Others are calcium, magnesium, potassium and dissolved gases, e.g. oxygen, nitrogen and carbon dioxide. The salinity holds a constant relation to the chlorine content and varies between 32 and 37.4 parts per thousand in the open sea. The mean surface temperatures of the Pacific and Atlantic Oceans is 17° C. while that of the Indian Ocean is 18° C. Maximum temperatures are respectively 32° C., 30° C., and 35° C.

An analysis of sea water shows that it has the following approximate composition :—

		p.p.m.	lb. gall.
Calcium bicarbonate	Ca (HCO ₃) ₂	180 or	1.8/1,000
Calcium sulphate	CaSO ₄	1,220 or	12.2/1,000
Magnesium sulphate	MgSO ₄	1,960 or	19.6/1,000
Magnesium chloride	MgCl ₂	3,300 or	33.0/1,000
Sodium chloride	NaCl	25,620 or	256.2/1,000
Total dissolved solids	.. ..	32,280	322.8/1,000

It was rapidly learned that sea water itself is not potable when taken in quantity, although current work suggests that, taken in very small sips, it has no drastic effect. From time to time expedients such as drinking the expressed juices of fish, urine, etc., have been put forward, but no practical use has or can be made of such liquids. The high protein content of fish juice tends to create thirst while the urine of a subject short of water is scanty, odorous and highly charged with salts. In this respect it is of interest to note that it has been calculated that the formation of 1 litre of urine requires about 700 calories, a factor of some importance if food and temperature conditions are not favourable.

Early work and methods

Early work on rendering sea water potable was naturally confined to physical methods involving the use of stills. These methods are, on the whole, unsuitable for use on small rafts and practically impossible to mount in the rubber dinghies carried by aircraft. Among such methods may be cited the Visscher Body Still, which consisted of a vacuum pump to reduce pressure in the system, and a small boiler strapped to the body, the heat of which acted as a fuel to distil fresh from sea water, condensation being effected by immersing a coil and collecting bottle in the sea. This still needed the expenditure of considerable muscular energy to maintain the reduced pressure, and in low temperature the individual could ill spare to lose the body heat demanded for evaporation of the water. The amount of pure water resulting was low.

It should be noted that the human body keeps itself constant at about 98.4° F., which temperature is maintained by the rate of heat production within the body (from energy of food consumed) and by the rate of heat loss from the body surface. The normal rate of heat loss for fairly sedentary occupations is about 400 B.T.U./hour (about 1/10 therm per day, i.e. about the heat given by a one-inch gas flame from a batwing burner). 20—30% of the heat is removed by insensible perspiration (evaporation of moisture from

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the skin) which may vary from 1/30—1/18 pint per hour, and in the breath. At 85° F. over 75% of the heat is lost by evaporation.

The Armbrust Cup followed last war methods whereby moisture in the breath is condensed in a wet felt-jacketed metal container. The calculated efficiency peak for such a method is 15 ml. of water per hour, but this was never reached in laboratory and field tests. A maximum of 5 ml. per hour was attained but no subject was found who could tolerate the device for 8 hours.

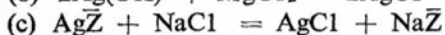
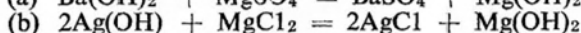
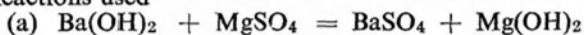
The Delano Solar Still utilizes solar radiation; the sunlight passes through a transparent plastic window and is absorbed by black towelling which backs up the plastic sheet. The towelling is kept wet with sea water, the evaporating moisture condenses on the window and drains into a reservoir. Under ideal conditions the apparatus was capable of producing 300 ml. of water a day, but was much too fragile for use on a life-raft. As the device required to be oriented to the sun, the efficiency greatly decreased on a cloudy day.

Exchange materials

In July, 1941, D.S.R., after consideration of the importance of this problem and its many factors, asked a member of his staff to approach the Permutit Co., Ltd., and request them to investigate the application of exchange materials as a means of solving the problem.

Early work was confined to the improvement of stills for use in lifeboats, where there is reasonable space to carry a special form of still heated by briquettes of coal, and one design has been supplied, through the Ministry of War Transport, to all merchant vessels travelling in dangerous waters. Stills, obviously, are quite unsuitable for use by baled-out airmen and their requirements have been met by a process which does not depend on heat and distillation. Chemical processes were examined, the Government Laboratory, for example, produced a method which showed considerable promise, but necessitated the use of three stages. As a matter of interest, the reactions and method are given :—

Reactions used



The quantities of reagents required for 100 ml. sea water are :—

Barium hydrate $\text{Ba(OH)}_2 \cdot 8\text{H}_2\text{O}$	..	..	0.8 gm.
Silver oxide Ag_2O	0.35 gm.
Sodium aluminate	0.05 gm.
Zeo Carb. Ag	34.0 gm.

Total Weight	35.2 gm.
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Bulk Volume	40.0 ml.
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The sodium aluminate is used as a coagulant.

The method of treatment is to add to the sea water the barium hydrate, silver oxide and sodium aluminate, and to shake for 15 min. The silver zeolite is then added and the vessel shaken occasionally for 30 min. The water is then drawn off through a filter by mouth suction when required.

The yield obtained from 250 ml. of sea water treated with 100 ml. of reagent was 210 ml. water drawn off under a suction of 10 ins. mercury (it was found that 14 ins. mercury was easily attained by mouth suction). This water contained 284 parts chlorine per 100,000, equivalent to 0.46% sodium chloride. Barium and silver were absent.

A full analysis of artificial sea water treated by this method is as follows :—

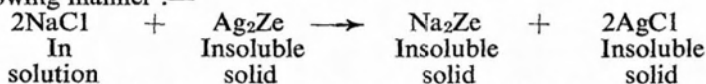
				Parts per 100,000	
				Untreated Water	Treated Water
Sodium chloride	..	..	..	2,710	—
Potassium chloride	..	..	..	33	11.6
Potassium bromide	..	..	..	10	—
Magnesium chloride	..	..	..	101	—
Magnesium sulphate	..	..	..	340	10.9
Calcium sulphate	..	..	..	—	—
Calcium chloride	..	..	..	116	—
Sodium bicarbonate	..	..	..	24	37.0
Sodium carbonate	..	..	..	—	—
Sodium sulphate	..	..	..	—	55.2

First chemical method

A possible first step towards development of a chemical method was made when B. A. Adams and E. L. Holmes, working in the laboratories of the Department of Scientific and Industrial Research, developed resins of two types. When water was passed through a resin of the first type and then through a resin of the second type, dissolved salts were removed from it. When applied to sea water containing as it does approximately 3½% of dissolved salts, the yield of purified water was less than the volume of the apparatus required to produce it and, although this method was demonstrated at the Royal Institution Conversazione in May, 1934, it could only be regarded as of academic interest.

The method finally adopted for the purification of sea water in boats, rafts and rubber dinghies was developed in principle as a result of tests carried out for precious metal recovery by The Permutit Co. before the war, using ion exchange materials. These materials are normally used in water softening, using the reversible exchange two Na/ions for one Ca/ion or one Mg/ion, but have many applications in chemical process work.

An ion exchange material was made having exchangeable silver (silver zeolite). This material was found to react with sodium chloride solutions in the following manner:—



Thus, by treating a solution of a soluble chloride with silver zeolite, an insoluble sodium zeolite and insoluble silver chloride are formed. This process resulted in the complete removal of soluble chlorides from the water. Owing to the insoluble nature of the silver zeolite, an excess of this reagent cannot do any harm and silver ions could not be detected in the water left after treatment. It was found that a percolation technique of passing the water through a column of the silver zeolite was impracticable owing to the formation of the silver chloride precipitate. For this reason a shaking technique was adopted and the chloride solution and powdered silver zeolite was shaken to break up the precipitate formed. This technique gave excellent results for chloride removal.

Similar experiments on sodium sulphate solutions were carried out using ion exchange material containing exchangeable barium (barium zeolite). In this case insoluble sodium zeolite and insoluble barium sulphate were formed and again the shaking technique was essential. This method preserved the automaticity of the chloride removal process in that it was not necessary to be concerned about excess barium zeolite as this did not produce free barium ions in the treated water.

Barium silver zeolite

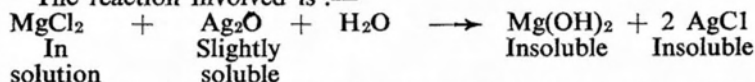
These experiments were then extended to sea water and it was found that a mixture of silver zeolite and barium zeolite would remove the dissolved chlorides and sulphates very effectively. The next step in the procedure was to combine the silver and barium zeolites by making a mixed barium silver zeolite. This is an ion exchange material containing both exchangeable barium and exchangeable silver.

By regulating the proportion of barium to silver ions in the manufacture, this mixed zeolite can be used for removal of chlorides and sulphates simultaneously in the proportions in which they are found in sea water.

One other problem had to be solved in the treatment of sea water and that was the removal of the greater part of the magnesium ions.

It was found that excellent magnesium removal could be obtained by making the mixed silver barium zeolite by passing a solution of barium hydroxide through silver zeolite. In this way the mixed zeolite produced contained also a proportion of silver oxide. This was precipitated *in situ* and was very finely divided, this silver oxide being more effective in the removal of magnesium than an artificial admixture of silver oxide with either the mixed or the separate zeolites.

The reaction involved is :—



The mode of treatment having been settled, the practical details proved a further obstacle, as it was necessary to get a maximum yield of drinking water from a minimum of space occupied. Consequently, the chemical reagents were compressed into compact briquettes becoming rock-hard. A disrupting agent had to be incorporated, a material which, on coming into contact with water, increases its volume and thus breaks up the rock-hard pellets to a powder. The technical difficulties in making these briquettes and in obtaining the correct disrupting agent were considerable, and in this connection credit must be given to the Department of Scientific and Industrial Research for the work in finding a satisfactory disrupter which was subsequently further improved by The Permutit Co.

The disrupter finally accepted for use was an activated Fullers Earth which gives automatic disruption of the chemical charges on coming into contact with water under all conditions.

Swelling and briquetting

During the investigation of the disruption of the briquettes a further advantage of the mixed zeolite came to light. Tests had previously been carried out on various sulphate removing agents, the most notable reagents of this type being barium oxide and barium hydroxide octahydrate. These reagents have the advantage over barium zeolite that they will remove more sulphates per unit weight. When, however, they were incorporated in the mixture it was found that barium oxide gave rise to swelling of the briquettes subsequent to the compression process. This was a great disadvantage since the chemicals must be packed tightly into a container and any swelling results in these being impossible to extract for use. When barium hydroxide octahydrate was used, there was no swelling after briquetting, but after keeping for a few weeks the chemical charges proved to be impossible to disrupt. A considerable amount of investigation was made on this point, but the development of the mixed zeolite described above overcame the difficulties as this reagent neither causes swelling after briquetting nor gives difficulty in disruption.

The final reagent, therefore, consists of mixed barium silver zeolite containing a quantity of precipitated silver oxide together with a disrupter. In addition, a very small amount of activated carbon has been incorporated in the briquettes to produce a clear, bright drinking water at all times. It was found that when the chemical charges were stored under tropical conditions there was a tendency to produce a yellowish drinking water which was somewhat unattractive in appearance. The incorporation of the small percentage of activated carbon in the briquettes has overcome this disadvantage which has a considerable psychological value.

To facilitate the smooth operation of the briquetting process a small amount of graphite is added to the chemical mixture.

The best method of obtaining a clear drinking water was found to treat sea water and briquettes in a flexible bag which was fitted with a permanent filter cloth. After shaking up the sea water and the chemical reagents, the drinking water can be filtered by squeezing the flexible bag so that water passes through the filter cloth. All the suspended precipitates and zeolites are retained, and a clear drinking water is produced. The drinking water is squeezed out into a transparent plastic box and, in view of the fact that the apparatus may be subjected to a range of temperature between -50° and $+75^{\circ}$ C. with possible relative humidity of 90%, it was essential to obtain a material suitable for these conditions. Two types of plastic have been used :—

- (a) Cellulose acetate, and
- (b) Perspex.

The Perspex is the most satisfactory material as it stands up completely to all the physical conditions. The cellulose acetate tends to become distorted at the higher range of temperature and its use has been discontinued. The Perspex has the disadvantage that it is more brittle than the cellulose acetate, but this difficulty has been overcome by careful packing.

The apparatus as finalised contains a flexible purifier made of rubberised fabric, nine chemical charges which are enclosed in a rubberised fabric storage



FIG. 1.— $4\frac{1}{2}$ PINT EQUIPMENT FOR BOMBER AIRCRAFT. WEIGHT 2 LBS.

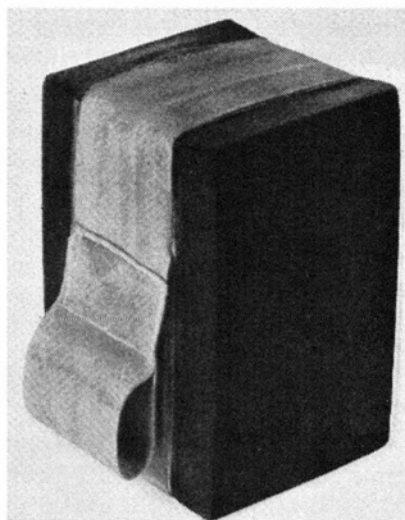


FIG. 2.—BOMBER TYPE KIT IN INDIA-RUBBER BOX FOR STORAGE IN CARLEY FLOATS

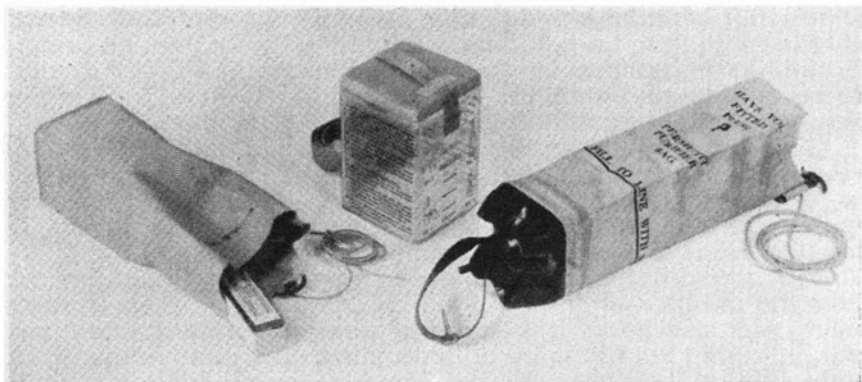


FIG. 3.—BOMBER KIT SHOWING WATER-PROOF PELLET STORAGE BAG, PERSPEX DRINKING BOX AND FLEXIBLE PURIFIER BAG

bag to keep them dry and a Perspex drinking box into which the rest of the equipment is packed (see Figs. 1—4). Each chemical charge will produce $\frac{1}{2}$ pint of drinking water from sea water so that the apparatus will produce $4\frac{1}{2}$ pints of drinking water. Its overall size is 3 in. \times 3 in. \times 4.5/8 in., so it can

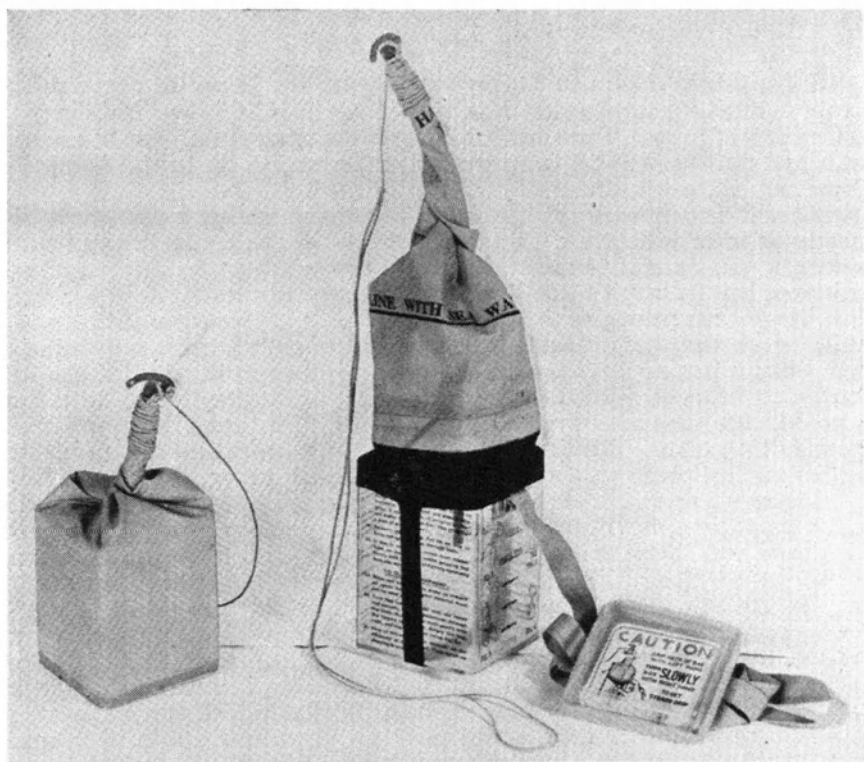


FIG. 4.—BOMBER KIT SHOWING PELLET BAG SEALED, FLEXIBLE PURIFIER ATTACHED TO DRINKING BOX READY FOR FILTRATION AND DIRECTIVE LABEL IN LID OF DRINKING BOX

be seen that it produces several times its own volume of drinking water.

The foregoing and successful method, developed by the Permutit Company Limited, was closely followed by the American Permutit Co. who have developed a form of equipment which has been adopted by the American Army and Naval Air Forces.

So successful has this method proved that an initial order for 340,000 sets was placed on Admiralty and R.A.F. behalf. The need for this equipment can be seen from the fact that in home waters only, in 1943, 1,684 airmen were rescued from the sea after having been ditched from their aircraft. This apparatus has already saved many lives.

A further development is in the equipping of Carley Floats for use in destroyers and other war vessels. Before the cessation of hostilities the highest priority was given to an initial order of many thousands of special packs (7 in. \times 3½ in. \times 1 in.) for the use of fighter pilots. This pack is a modification of the main kit and is about the size of a pocket camera. It consists of a bag containing the briquettes between two sheets of bright aluminium (which latter can be used for reflection purposes if necessary). Each kit is capable of producing three pints of drinking water.
