THE DEVELOPMENT ON MULTISTAGE FLASH DISTILLATION

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Contents

Summary

Distillation of seawater for the provision of freshwater, including the most widely used process of multi-stage flash distillation, is a branch of engineering to which many Members of this Institution have made notable contributions. This paper summarizes the general history of distillation briefly, and then gives an essentially archival account of the introduction of the multi-stage flash process. The main technical problems and features of the process are described, including a discussion of some fundamental aspects in two Appendices. The contribution which the development of the process has made to desalination is reviewed, and the importance for water supply generally is discussed. A third Appendix gives illustrations of some of the installations which have been built.

1. Introduction

The subject of this paper is one to which various Members of the Institution of Mechanical Engineers have made major contributions, and yet which has curiously featured but little in the Transactions. I am advised by the Secretary that the most recent paper presented to the Institution on the subject of desalination of seawater was in 1889. There was one previous to that, given in 1862 by a Mr George Russell, which referred to distillation generally and in that context offered a device called in the paper, a "distil-aerator". The main objective was to aerate distilled water to improve the taste. One of the main contributors to the discussion is named simply as Dr McQuorn Rankine. The 1889 paper dealt specifically with seawater distillation, it was given by Mr Charles Lang and described the evaporator which had then recently been developed by James Weir, in the early days of the Company G. and J. Weir Ltd. Mr Lang was then of course a young engineer with the firm. Fifty years later, in 1939 when I joined Weirs, he was still about the place, and the central figure of many anecdotes. It was another 18-20 years later, in 1956-58 that the development occurred which is the main subject of the present paper, and by that time Mr Lang's son, Mr J.R. Lang, was Managing Director and then Chairman. Now, a further 22 years later I present this paper.

Thus there is a connecting thread through these 92 years since the 1889 paper to the Institution. It is a thread of endeavour in time, but centred in space, centred in fact in Glasgow. Yet its significance has been world-wide. The ideas developed in Glasgow in 1956-57 have been used by manufacturers in all the major industrial countries to provide desalination plant in most arid areas of the world. The first commercial units of multi-stage flash distillation were commissioned in 1960 and by 1965 the installed capacity of MSF had already exceeded the total installed capacity of all previous desalination methods. The subsequent growth rate is remarkable by any standards. It has been estimated that the world-wide value of all MSF order by 1965 was somewhat over £11M, while by 1977 this had increased to £850M. An archival paper on the origins of a process which gave rise to such a growth rate would be suitable topic to present to any engineering Institution. But for the Institution of Mechanical Engineers, located in the city where the process was developed by some of its members, on a foundation laid by an earlier generation who were also members, it is surely particularly appropriate.

That is why, although I have contributed many scientific papers and several general review articles on desalination to the vast literature which the subject has generated, I felt particularly honoured to be asked to give a review paper to this Institution. I decided - with I hope your approval - that in these special circumstances it would be appropriate to do something which has not been done previously, and include in the review an archival record of my involvement and that Company for which I worked.

To set the background it will be useful to summarize briefly the history of seawater distillation prior to the invention of the MSF process.

2. History of Distillation by Boiling

During the whole of man's time on the earth most of his fresh water has been obtained by distillation. The heat and pump source has been the sun, evaporating water from the sea, creating wind currents to carry the vapor to condense in the upper air and transport cloud to precipitate as rain or snow to form rivers or lochs.

Aristotle was aware that rain came from the sea and suggested that pure water could be made artificially from the sea. More than 300 years after Aristotle, Pliny described a still in which the condensation occurred on wool fibres placed above the boiling section. Evidently it was easy to understand, from seeing the mists rising, that heat supply was needed to evaporate, but less easy to realise that heat extraction was needed to condense. But a book on gold-making by a Greek lady called Kleopatra in the first century A.D. does indicate metal portions which may have been water cooled. Water cooling of alembics seems to have been known to the Arabs in the beginnings of chemistry in the Middle Ages but the awareness seems to have been lost for centuries. European chemists used only the familiar retorts with long narrowing necks - for air cooling - until the introduction of the Liebig condenser in the nineteenth century. Long before that our wiser and more practical ancestors in the hills and glens of Scotland had put the whisky serpent into the burns to get water-cooling. The success of distillation whether of plain 'uisge' or of 'uisge-beatha' depends on good heat transfer for both evaporation and condensation.

From the eighteenth century onward the development of larger range sailing made water supplies on board ship of vital importance and it is certain that many people must have tried to distil fresh water from the sea. Among the famous names who are definitely known to have attempted it are Robert Boyle - of Boyle's Law - in the seventeenth century, and, in the eighteenth century, Captain Cook and Benjamin Franklin. Some years ago a lady who had heard a radio programme on desalination sent me a volume of an eighteenth century publication called the Universal Magazine. In the issue of January 1754 there was a report of the approval by the Admiralty of a process devised by a Mr Joshua Appleby of Durham, which was said to produce 15 gallons of sweet water from 20 gallons of seawater. To do so it used 6 ounces of Lapis Infernalis and 6 ounces of calcined bones and one peck of coals.

However, it was the coming of the steamship in the nineteenth century which initiated the most serious efforts towards distillation of seawater. It provided both a new incentive and a new convenience. The new incentive was of course to get make-up for the propulsion boiler. The new convenience was the availability of steam for the heat supply.

Up to about 1850 boiler pressures were sufficiently low to allow salt water to be used in the boilers, but after that, as boiler pressures rose, the incentive became an imperative; fresh make-up had to be provided. Because this was absolutely vital there was originally no great emphasis on economy of operation. The need was for a reliable assured supply of make-up water of good purity. Given steam heating and water cooling, boiling the seawater and condensing the vapor was quite an elementary physical process and emphasis in early design was on two main aspects:

(i). On operation, i.e. a major problem of design was to ensure that no droplets of seawater or brine were carried over into the product water;
(ii). The maintenance of performance over a satisfactory period. Evaporators which started off quite well would rapidly scale up and lose output.

Most of the early attempts at boiling distillation solved the first problem reasonably well by allowing disengagement height and using inertial type separators. The Weir evaporator of 1884 was the first to solve the second problem in a more or less satisfactory way. This was done by arranging the steam heating coils which were submerged in the brine in a spiral formation. As in every other evaporator, the performance fell as scaling occurred, but the operational procedure was to remove the scale by thermal shock. This was conveniently done by emptying the brine out of the vessel, allowing steam into the heating tubes, and then allowing cold brine to run into the vessel. This process could be repeated for several shifts with the scale collecting at the base of the vessel. Ultimately a stage was reached when it had to be closed down to remove the accumulated scale from the base.

This relatively simple technique was amazingly successful in practice, and this distillation equipment was supplied all over the world to merchant shipping and to various other navies besides the Royal Navy. The inertial separators were also satisfactory and a high purity was obtained, and this enabled the continual advance of boiler pressures. With accumulating experience larger units were also built. The first unit was for about half a ton production per day but by the period of the 1914-18 War units up to 5 tons per day were in existence.

Distillation was of course being used in other industries. One particular field was in sugar processing, and in other branches of food manufacture. Here the requirements for economy were substantially greater and this instituted the surge towards improving the performance measured approximately by the amount of distillate provided per unit of steam used. The obvious line of development was multiple effect operation and, by the beginning of the twentieth century double effect distillation was quite common in these industries. As experience with this developed triple and quadruple effects were used and the benefits of this increased economy were also applied to marine seawater distillation. Unit size also increased. For the major passenger liner developments which occurred between the Wars, such as for example the Queen Mary and the Queen Elizabeth, the distillers were triple effect and producing 200 tons per day.

The nineteenth century also saw the first land based installations. De Lesseps had two units built at Port Said in 1860 during the construction of the Suez Canal. (The capacity is not stated in the reference.) It is probable that marine units were adapted for land use in many of the military expeditions of the time. One was certainly used by Lord Napier in his Abyssinian expedition in 1867. The first Weir plant specifically supplied for land use was to the Safoga Phosphate Company in Egypt, somewhere about 1890, and was for about 100 tons per day. There were probably a few other installations before 1914, and there were certainly some in the nineteen-thirties, but the major expansion began after 1945, with the oil-field developments in the Caribbean and in the Middle East.

The figure of 100 tons per day, which was quite substantial for marine boiler feed make-up, is only 22 000 gallons per day, which is negligible compared with land practice for water supply. Hence those land installations intended for water supply had to consist of units in parallel. The largest such development was reached in 1955 in the Caribbean Island of Aruba. This plant had a total production of 2 Mgpd, obtained from five units in parallel, each unit being of sextuple effect, giving a performance ratio of about 4.5 lb of water produced per lb of steam used. Such a plant therefore required about 30 separate vessels, each producing about 66 000 gpd, and much complicated interconnecting pipework. The vessels were cast and the cost was substantial.

Moreover the operational problems had become quite acute. The need for economy had driven to the sextuple effect but this of course reduced the operational temperature difference on any one effect, unless the overall temperature range could be increased. The size of the units had long passed the stage where the primitive method of thermal shock could remove scale. During the post-war years much experimental work had been done on scale prevention, and a method of acid treatment based on the use of ferric chloride had been effectively used in marine and naval applications, and this was applied to the new land installations also to extend the top temperature to 125°C. In Aruba the 5th effect in each of the five trains was split into two shells to accommodate the scale treatment so that actually there were 35 shells instead of 30. Even with the improved temperature range however, the operational temperature difference available across the tubes in any one vessel was by now very small. When a large production rate was expected from a vessel the number of tubes which had to be packed in below the water line was such that quite a substantial depth of water was needed. This meant that the tubes near the bottom of the vessel were now under substantial hydrostatic pressure, thus raising the boiling point and reducing the effective temperature difference for these tubes. For all of these reasons it had become apparent that the exploitation of the boiling process, at least in the form of submerged tubes, was at the end of the road.

It is convenient to leave the history of distillation by boiling at this point and give the history of flash distillation, which is less extensive.

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Bibliography and Suggestions for further study

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