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Editorial

In memory of Sidney Loeb

This special issue of *Desalination* is dedicated to the memory of Sidney Loeb, founder of the modern membrane technology. The historic event that led to the growth of a multi-billion dollar membrane industry was the development of the Loeb-Sourirajan asymmetric membrane. By providing high permeate flux coupled with high salt rejection, the asymmetric membrane opened the path for the development of reverse osmosis desalination. Reverse osmosis was soon recognized to be the most economical way to desalinate water. The growth rate of desalination by reverse osmosis has been truly impressive. Over 40% of desalination plants are based on the reverse osmosis principle. Global production of desalinated water by reverse osmosis exceeds today 15 million cubic meters a day.

Another major outcome of the work undertaken by Loeb and Sourirajan was subsequent recognition that the manufacturing method used in the preparation of the asymmetric membrane was a special case of "phase inversion processing". Phase inversion is one of the most widely used methods in the preparation of synthetic polymeric membranes for reverse osmosis, ultrafiltration and nanofiltration with endowed tailored properties. A complementary giant invention which consolidated the reverse osmosis membrane technology was John Cadotte's development of the thin film composite membrane by in situ polymerization.

The revolutionary impact on the desalination market of the reverse osmosis technology initiated by the work of Loeb prompted aggressive development of membranes of diverse properties. This resulted in the birth of an entirely new industry—the membrane technology industry which encompasses today a host of applications in the beverage, food, pharmaceutical, chemical and biochemical industries. Membranes are also applied in drug delivery devices, and energy conversion systems. The yearly growth rate of the membranes industry is estimated to exceed 8%.

Sidney Loeb was born in Kansas City, Missouri in 1917 and passed away in Beersheba, Israel in 2008. After graduating in Chemical Engineering at the University of Illinois in 1941, he embarked on an industrial career. After almost 20 years in industry, when he was over 40 years old, he took the courageous step of resigning from his work and enrolling as a graduate student at the University of California at Los Angeles (UCLA). He earned an M.Sc. degree in 1959 and a Ph. D. degree in 1964. Loeb chose to carry out his research in the laboratory of Professor Samuel Yuster which was heavily involved in desalination research. He began working with Srinivasa Sourirajan on the problem of synthesizing a cellulose acetate membrane that has the two major attributes required for a viable desalination process—high permeability and high salt rejection. The Loeb Sourijan membrane breakthrough was achieved in the course of Loeb's thesis research.

Loeb's industrial endeavors clearly indicate that he looked at science and technology as tools for improving the quality of life of people. Having developed an improved desalination tool, it did not take him long to put his findings for human benefit. He led a group that designed, constructed and operated in 1965 the first commercial RO plant producing about 20 m^3/day drinking water for a small community at Coalinga, California. It is interesting to read Loeb's Coalinga's paper which he published in Issue 1, Volume 2 of *Desalination* as it highlights the tremendous progress of RO technology since its inception:

> Since June, 1965 a 5 kilogallon per day (kgpd) reverse osmosis desalination pilot plant has been providing a needed supplement to the potable water supply of the city of Coalinga, California. This plant utilizes 112 "composite tubular assemblies" arranged in series for the containment of brine passing through in turbulent flow. Each assembly consists of a tubular cellulose acetate desalination membrane wrapped in a porous sheet, and retained within a perforated copper support tube, one inch in diameter, ten feet long, and having flare-type end fittings. The plant operates at 600 psig, at which pressure nominally 50% of the feed brine (containing 2500 parts per million dissolved solids) is recovered as fresh water passing through the membranes.
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> Based on the Coalinga results, estimates were made, in accordance with the Office of Saline Water format, on costs of fresh water produced from Coalinga-type feed brine plants employing the composite tubular assembly geometry. Water from the Coalinga plant, a combination experimental tool and production unit, costs 1.94 dollars per kilogallon ($/kg). Production-only plants of the same capacity, 5 kgpd, and of 50 kgpd capacity, would produce water for 1.33 and 0.50 $/kg respectively. Estimates were also

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> made on a 50 kgpd plant utilizing moderately advanced but unproven assembly components, namely two-inch fiberglass-reinforced plastic support tubes having flanged ends. The estimated water cost from this development plant would be 0.37 $/kg.

Shortly afterwards, Loeb was engaged in the construction of the second commercial desalination plant. This plant, built by the Negev Institute for Arid Zone Research in Beersheba, Israel, supplied 200 m^3/day drinking water to the Kibbutz Yotvata community by RO desalination of 2400 mg/L TDS well water.

Loeb settled in Israel in 1967 and continued his researches first at the Negev Institute for Arid Zone Research and then as Professor of Chemical Engineering at the Ben-Gurion University of the Negev, until his retirement in 1986.

Loeb's continuing efforts to apply membranes for pressing human needs led him to develop two new processes for energy production by osmotic permeation of water from a dilute solution to a concentrated solution. The two processes are reverse electrodialysis (RED) and pressure retarded osmosis (PRO). Both processes rely on osmosis with ion specific membranes. In RED, a PRO, the spontaneous passage of water from a dilute to a concentrated solution through the membrane generates a pressure difference that can be harnessed to generate power. In RED, a salt solution and fresh water are let through a stack of alternating cathode and anode exchange membranes. The chemical potential difference between a salt solution and fresh water generates a voltage providing electric power. The physical concepts of these processes have been confirmed in laboratory experiments. Engineering difficulties are still to be overcome but the tremendous potential of harnessing vast energy amounts from salinity differing solutions of rivers and sea waters is attracting commercial developmental work in Norway (PRO) and the Netherlands (RED).

I met Sid over 50 years ago at the First European Symposium on Fresh Water from the Sea held in Athens Greece on May 31–June 4, 1962. I believe this was the first presentation of Loeb's work to a European audience. His paper "*Sea water demineralization by means of a semi permeable membrane*" was published in the Conference Proceedings by the *Dechema Monograph*. At the time, most Desalination workers focused their researches to amelioration of evaporation processes. Loeb's work influenced many researchers, including myself, to shift their interest to the highly promising field of reverse osmosis.

High regards to Sidney Loeb are due not only for his ground breaking achievements but also for his gentle unassuming personality. Despite his accomplishments and awards he radiated friendliness and warmth and readily shared his knowledge. His memory will remain an inspiration to future generations.

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[1] Guest editor of the Sidney Loeb Memorial Issue.