Transition

SRI NIVASA SOURIRAJAN (1923–2022)

Dr Srinivasa Sourirajan, the co-inventor of the reverse osmosis (RO) membrane, died peacefully in Ottawa, Canada, on 20 February. He was 98.

He was born in a small rural village in southern India and was in the first generation of young Indians who received a PhD in chemistry in the post-colonial nation. His research caught the attention of Johns Hopkins University Professor Paul Emmett, which led him to Yale University in the US in the mid-1950s, where he received a second doctorate in chemical engineering.

Dr Sourirajan joined the UCLA Department of Engineering in September 1956 and, at the suggestion of Professor Samuel Yuster, began research on the Gibbs Adsorption Equation, which indicated the possible presence of a pure water layer at salt water-air interfaces. It was there he met Sidney Loeb, who, two years later, joined him in his research on commercial ultrafiltration membranes, by modifying them to suit their needs. They filed their patent application for the Loeb-Sourirajan anisotropic, cellulose acetate membrane in November 1960.

In 1961, he moved to Ottawa, Canada, with his family, and worked as a research scientist at the National Research Council (NRC) for the next 25 years.

His work on the characterization and modeling of synthetic membranes at NRC reached well beyond water desalination, and focused on process development and energy efficiency of liquid and gas separations, including those in industrial, medical, health care and environmental applications, all of which attracted worldwide attention.

After retiring from NRC, he founded the Industrial Membrane Research Institute (IMRI) at the University of Ottawa, and in 1991, moved to Singapore to establish a membrane research laboratory at the National University of Singapore. He also served as a visiting lecturer, and taught classes and conducted workshops at Dartmouth College in New Hampshire.

Dr Sourirajan received an honorary doctorate from the University of Ottawa in 1994. His research, and over 290 publications, have been lauded by many professional organizations, including the Canadian Society of Chemical Engineering, and he was inducted into the American Membrane Technology Association’s (AMTA) Hall of Fame in 2017. Along with Sidney Loeb, he was also a three-time nominee for the Nobel Prize in Chemistry.

His wife Kamala, son Krishna, daughter-in-law Chitra, three grand-daughters, a grand-son-in-law, and one great-grandson survive him.

WDR asked several of Dr Sourirajan’s friends, colleagues and membrane professionals about him, and the impact that he had on the membrane industry and their careers:

D. Dean Spatz, Osmonics’ founder, US: I first met Dr Sourirajan—he asked us to call him Souri—when he came to Dartmouth to teach us the basics of his new reverse osmosis technology in 1963. He was a great teacher and mentor, and he visited Dartmouth from Ottawa many times between 1963 through 1968, when we finished our Office of Saline Water (OSW) research contracts.

I remember leaving New Hampshire for my first job working for Aqua Technologies, Inc. in Minneapolis. On the way there, my new wife, Carol, and I drove through Ottawa to visit Souri. We spent time in his lab and had dinner at his home with him and his wife. We discussed his philosophy of life and creating things for mankind and how that had led to his discovery of how to make a skinned membrane when he was at UCLA.
Souri was a great researcher, but he had no idea about developing a product or building a business. From those discussions, I determined that I would carry Souri’s technology forward to a product and try to build a business in the RO/NF/UF industry. About one year after this dinner, we started Osmonics, Inc. in our garage in Minnetonka, Minnesota.

Souri came to visit Osmonics several times. One of his last visits was in 1984, to our new 100,000 square foot headquarters building, where he lectured to my R&D group the same as he had done to me some 16 years before. Souri was very proud to see the 200-employee company that his invention of RO membranes had helped to build.

One only has a few real mentors in one’s life and Souri was a key mentor to me. 

*Editor’s note:* Dr Sourirajan was a consultant and advisor on two OSW research project grants awarded to Dartmouth’s Thayer School of Engineering, and on which Spatz was a co-principal investigator. The first, *Research and Development on Low Pressure RO Membranes and Design of a Small Unit for Brackish Water*, was awarded in 1965 and published in March 1968, and the second, similarly titled project, began in 1967, and was published in June 1969. In 1998, Spatz announced Osmonics’ Sourirajan Membrane Research Award, donating $10,000 to help cover tuition and research costs for a graduate student working in membrane technology, and “honoring Souri’s pioneering membrane technology work”. Osmonics was acquired by GE Water for over $250 million in 2003. Years later, when Spatz was inducted into the AMTA Hall of Fame, he said that he considered his own career calling was “to take Souri’s work and bring it to the marketplace”. When Souri was inducted in the AMTA Hall of Fame, it was Spatz who made the presentation.

**Professor Emeritus, Dr James M. Dickson, McMaster University, Canada:** I first met Souri in 1972 when, as a co-op undergraduate student on a work term, I got a job working in his laboratory. I knew almost nothing about him or reverse osmosis. He was sitting at his desk, writing and, strangely enough, his desk was right in the middle of a busy laboratory with several RO systems, with their loud pumps running, and analytical equipment all crammed in.

After the usual pleasantries, he held up a wet membrane sample and asked me what I noticed about it. I said something about it being semi-permeable. He hated the phrase ‘semi-permeable’ – his expression was something like ‘it says something while explaining nothing’. So, he offered up, ‘It has two sides.’ Huh? So, he described briefly how, in early work, the membranes would sometimes work well and other times not so well, and that he and Sidney Loeb were able to work out that this was due to the asymmetric structure of the membrane. This was a strange introduction and I wondered ‘What is going on here?’

Of course, this led to a long relationship with Souri, Dr Takashi Matsuura and the NRC Ottawa personnel and laboratories working on RO, and to my life-long career studying membranes.

Souri was a truly great man. His pioneering work was felt the world over as people were able to produce clean drinking water from his joint invention with Sidney Loeb. As Souri predicted, the membrane technology would extend far beyond desalinating seawater – during his pioneering work at UCLA, he could only work on water desalination, which was the source of funding. So, when he moved to NRC, Ottawa, Canada, the first thing he did was to try removing potassium chloride from water to show the more general applicability of the process. Soon, again as he predicted, membranes were used for everything from gas separation to organic separation systems and others.

He was great mentor, as well. I owe much of my career to the early training in his laboratory, about science, engineering, and about life, too. He was a deeply spiritual man who never drank alcohol or ate meat. He thought that discovering science was his way of seeing God. He was such a caring person and loved all that he did in his work. A truly great person.

I was deeply saddened to hear of his passing last month. He was a major inspiration to me, and to so many others. In my own career, I often wondered, ‘What would Souri do in this situation?’ That was often a wonderful guide to me.

He will be missed.
**Professor Meny Elimelech, Yale University, US:** His transformative discovery made a huge impact on our world. I’ve always felt that he deserved two Nobel Prizes, one for science, and one for peace.

**Professor Tony Fane, University of New South Wales, Australia:** Dr Sourirajan should be considered as one of the fathers of membrane desalination, whose vision may not have been fully appreciated in the early days. For example, he proposed that RO worked with flow through nanopores, rather than the ‘solution-diffusion’ mechanism. This idea was not well accepted by the pioneers of the day. However, in retrospect, it is interesting to see discussion of ‘mean free volume hole radius’, etc, as identified by Positron annihilation lifetime spectroscopy (PALS) in TFC polyamide RO membranes, and the work by Masaru Kurihara and Benny Freeman, who used PALS to show a correlation between boron rejection with nominal nanopore size. Sourirajan should be acknowledged as one of the true membrane pioneers. Many thought that he and Sidney Loeb should have received the Nobel Prize for their breakthrough. Maybe it was too ‘applied’ chemistry?

**Dr Gulshan Dhawan, Applied Membranes, CEO and founder:** I first met Dr Sourirajan while working in Canada in the 1970s. During that meeting, I commented on the thick book that he had written, titled *Reverse Osmosis*. He responded that the reason the book was so thick [580 pages] is because there was not a complete understanding of how membranes work, adding, “When we understand them fully, the book would be much thinner!” He also told me that it is easy to make a cellulose acetate membrane, but to make the same membrane again is not quite as easy. His work made RO possible, and we are grateful to him for this wonderful invention.

**Professor Emeritus Dr Takeshi Matsuura, University of Ottawa:** After completing a PhD at the Technical University of Berlin, I went on to do postdoctoral research at the University of California, Davis. In September 1969, after completing that work, and while deciding whether to stay in North America or return to Tokyo, I was accepted for a research position with Dr Sourirajan at the National Research Council of Canada.

Prior to meeting Sourirajan, I had read the manuscript of his forthcoming book, *Reverse Osmosis*, and felt that I had learned quite a lot about RO, including the PS-CF [Preferential Sorption-Capillary Flow] transport model which was the underlying principle for the development of the RO membrane at UCLA. Upon meeting him, we began discussing RO, and I told him that although RO was an excellent tool for desalination by removing electrolytes very effectively, some anions, such as nitrates, could not be separated very well.

Upon hearing my rather negative remarks, he immediately replied with a voice full of confidence, “Matsuura, you are wrong. Reverse osmosis can do everything!”

It was a striking moment for me. It was as if a door had suddenly been opened. Until then, I had been filled with anxiety, regarding an unknown future where I would live in a country far from home, yet where I also intended to find a research subject to which I could dedicate my life.

Looking back on that discussion, I now realize that Sourirajan was speaking broadly about membranes and separations. In his mind, there were no boundaries between porous and nonporous, between RO and NF, UF and MF, or pervaporation and membrane distillation. When I look at the present scene where various membranes and membrane processes seem to be emerging like mushrooms, I now admit that he had foreseen the future.

Ottawa was the Mecca of RO in those days, due primarily to the presence of Sourirajan. We received guests from all over the world, and had many interesting, and sometimes heated discussions regarding the presence or absence of pores in RO membranes and other esoteric aspects of membrane separations. It was an extremely creative and innovative time.

Sourirajan retired from NRC in 1986, but his research activities did not stop. He soon founded the Industrial Membrane Research Institute (IMRI) at the University of Ottawa, where graduate and undergraduate students were educated. Research-
ers from around the world joined IMRI for collaborative research, and many went on to become prominent professors and scientists.

We are now witnessing the diversification of membrane research at an accelerating speed. But despite all this progress, we should not forget that all the basic membrane separation concepts had been presented by the end of 1980s, in which Loeb and Sourirajan had made a tremendous contribution.

Sourirajan was not only a great researcher, but also an excellent educator with a rich philosophical background. He emphasized that RO serves the well-being of mankind by addressing the three important pillars of sustainable development, i.e., water, energy and food. It does not, and should not, serve the destruction of human civilization.

As for myself, Sourirajan not only saved a young scientist who was wandering around the globe, filled with anxiety, but also provided him with firm guidance throughout his whole life. Thank you, Dr Sourirajan.

Dr Jim Birkett, West Neck Strategies, US: It used to be that if you considered yourself a serious membrane guy, it was a rite of passage to sit through one of Souri’s papers at a desal conference. He lived on another intellectual plane, apart from the rest of us. He was less interested in data and experiences from the field, and more focused on theory. Whilst at the Office of Saline Water, (OSW) he was vital to their early funding of RO research. At the time, attention was focused on MSF, which was rapidly displacing MED. Souri fought for funds for RO. He foresaw the infant RO as the ‘Next Big Thing’, and he was right!

Professor Emeritus Enrico Drioli, University of Calabria, Italy: Dr Sourirajan has been a pioneer in the field of membrane science and membrane engineering with his studies. I met him at various international conferences and have had the opportunity and the pleasure of discussing the future developments of membranes and membrane systems with him over the years. His contributions to membrane science have been significant, and students will remember his name often for decades.

Dr Masaru Kurihara, Toray Industries, Japan: DuPont’s 1967 announcement to enter the reverse osmosis business became an incentive for other Japanese industries. At that time, many Japanese textile and chemical companies were very eager to develop new fields of business. So, in the early 1970s, as a member of Toray’s Pioneering Research Laboratory, I was asked to lead a team of Japanese industries to visit NRC in Canada. Researchers considered it to be the Mecca of RO, due to the presence of Dr Sourirajan, who was a great scientist, inventor and philosopher. We were unable to clearly visualize the Preferential Sorption-capillary flow (PS-CF) mechanism developed by Dr Sourirajan, due to the lack of appropriate analytical method. However, with today’s advanced analytical methods, we are now able to do so, and we clearly see the existence of pores, their sizes and membrane thickness, which clearly support Dr Sourirajan’s proposed mechanism! He was a great man.

Dr Thomas Peters, Consultant, Germany: I started my career as a research assistant at the University of Erlangen-Nürnberg in 1974. One of my many water industry career highlights was a 1982 congress where we met Dr Sourirajan. While the delegates discussed heavily, and rather emotionally, the different approaches of how to proceed with the development of membrane technology, he left the room for a short while. He came back with a sheet of paper in his hand, on which he had noted his opinion in this matter, asking in his modest way, to please focus on realistic and feasible procedures. I was very pleased to discover this valuable, signed document signed in our archives recently and would be more than happy if it could contribute to the history of desalination with membrane technology.

Below, courtesy of Dr Peters, is an excerpt from that paper in which Dr Sourirajan proposes an international membrane research foundation:

“As I said yesterday, membrane research touches many vital areas of everyday life. Membrane research is truly a process of endeavour in uplifting our physical, mental and intellectual environment in its broadest sense. Membrane research is truly an area of activity which serves all life – and it is good for everybody, everywhere, at all times.
If the attitude is right, and if the approach is right, dedicated work in basic membrane research must lead to success, joy and happiness – there is no alternative.”

Srinivasa Sourirajan first considers desalination

While preparing a WDR story on ‘Desalination’s Founding Fathers’ following Sid Loeb’s December 2008 passing, Dr Sourirajan was contacted to see if he had any comments that might be included. Although his remarks at the time were brief, he followed up with a five-page, hand-written letter. In that letter, he summarized his work at UCLA, and his discussion with Professor Samuel Yuster that led to his desalination research.

The following is an excerpt from Dr Sourirajan’s letter:

“I commenced my work at UCLA under Prof. Yuster who (on 26 Sept. 1956) called my attention to Gibbs’ adsorption equation, which indicated the possible presence of a layer [of] pure water (in molecular dimensions) at salt water-air interfaces; Dr. Yuster wanted me to explore the possibility of skimming that pure water layer from saline water by some means; but he himself had no practical suggestions on how that can be accomplished, except to give me a report of one of his former graduate students who reported his unsuccessful attempts.

However, the scientific validity of the proposed project appealed to me, and hence, I agreed to work on this project with no hesitation; and within a few days, I embarked on a program of Membrane Research for Water Desalination.”

Souri meets Sid

In that same 2008 letter, Dr Sourirajan also related his first meeting with his RO membrane co-inventor, Sidney Loeb. A photocopy of that portion of the original letter follows:

One day in June 1958, Sidney Loeb walked into the lab where I was working alone, and introduced himself to me, and then told me that he was looking for an Experimental Research Project for his M.S. Degree Thesis (which he wanted to submit by May 1959), and wanted to know what I was doing.

I welcomed his interest enthusiastically, and explained to him what I was trying to do, and why, and I also added that, if he was interested, I would be most welcome to work with me on the project. He expressed his interest in the project with equal enthusiasm, and our joint work in the project began the same day.

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