In celebration of the memory of Dr. Shivaji Sircar

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I am fortunate to have known Shivaji Sircar for 55 years. He was a splendid man, and his life is worthy of special recognition and celebration (Fig. 1).

I first met Shivaji Sircar in 1965 when he came to the University of Pennsylvania from Jadavpur University in West Bengal. Shivaji completed his Ph.D. in 1970 and stayed on an additional two years as a post-doc, before joining Air Products & Chemicals Company in Allentown, Pennsylvania. Although his primary allegiance was always with Air Products, during the last three decades of the 20th century he and I published joint papers on the thermodynamics of adsorption—and in the process we became close friends and colleagues.

Shivaji's Ph.D. thesis was about adsorption from liquid mixtures—a noteworthy focus because most adsorption processes are concerned with adsorption from gaseous mixtures. In adsorption from liquid mixtures, physical experimentation is key. What you can measure experimentally is the change in the composition of the liquid mixture before and after contact with an adsorbent. That change in composition is proportional to the “surface excess” of components in the adsorbed phase.

The same considerations about surface excess apply to the adsorption of gases on solid adsorbents—but in this case

the excess adsorption of a single gas is measured experimentally, either volumetrically or gravimetrically. The manipulated variable for the adsorbed phase is known as the spreading pressure (for a flat surface) or the grand potential (for a microporous adsorbent). With these two concepts in hand, Gibbs surface excess and grand potential, the adsorbed and gas phases can be treated just like liquid and gas phases for phase equilibrium calculations. Shivaji adopted this thermodynamic approach and incorporated it into novel new designs of adsorptive separations.

One of Shivaji's major research interests was the production of oxygen from air. One method to accomplish this is by cryogenic distillation, a process that is very efficient in terms of operating costs but quite capital intensive. Shivaji focused, instead, on a manufacturing method with a dramatically lower capital cost: pressure swing adsorption (PSA). Shivaji worked on designing portable PSA oxygenators. Before PSA design, supplemental medical oxygen came from heavy and bulky pressurized steel cylinders. Today, you can buy a 5-pound portable Inogen oxygenator that delivers continuous 90% oxygen for \$2300. Shivaji's design work was fortuitous, as he depended on supplementary oxygen for the last 20 years of his life.

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Fig. 1 Dr. Sircar receiving the AIChE Professional Progress Award in 1988. The picture has been reproduced with the permission of Dr. Sircar's family

One of our most successful collaborations was in the 1990s, based on a grant from Air Products to measure heats of adsorption of a series of gases in zeolites. We designed a Tian-Calvet type calorimeter with thermopiles lining the sides of the cubical cell. We didn't have Skype or Zoom so

we had to drive 60 miles in each direction for our meetings: Shivaji would come to my office at Penn or I would go to his home in Allentown. We had lively discussions but mostly we worked, either one or the other arguing his point. I miss those intense but collegial meetings with Shivaji.

Alongside our joint research, we shared a love of tennis. In late August and early September, Shivaji would attend the US Open in Queens. Another pleasure we both had was traveling and attending international meetings, usually in places in Japan, Germany, France, and the USA. Figure 2 is a photograph of a celebration at one of these meetings in Kyoto.

In 2004, Shivaji was elected into the National Academy of Engineering, one of the highest professional distinctions to an engineer. There are currently about 2300 members from all branches of engineering. His citation states: "for contributions to the fundamental science and technology of adsorption separations and their applications in process industries." While Shivaji's accomplishments are many, his uniqueness lies in the range of his accomplishments—from theoretical papers to patents for successful gas separation projects.

Looking back, Shivaji Sircar's life was a classic example of the American dream: a young immigrant who accepted

Fig. 2 Shivaji Sircar seated on the left, with Alan and Irmgard Myers seated on the right

all opportunities, worked very hard, and was rewarded with outstanding success. Shivaji is survived by his wife Shukla. Their son Sanjoy followed in his father's footsteps by obtaining a BS at Lehigh University and a Ph.D. at MIT, both in chemical engineering. Sanjoy now works with the US government in Washington, DC, on issues of nuclear safety. Shivaji lived to see his delightful granddaughter, who is now three years old.

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