

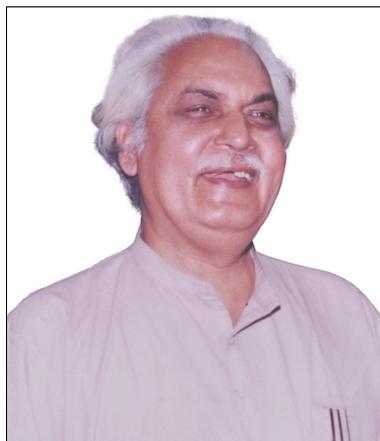
Rajinder Kumar (1934–2022)

Professor Rajinder Kumar, an eminent chemical engineer, passed away after a brief illness on 7 February 2022. Kumar was born in rural Punjab on 9 September 1934. His father was a schoolteacher while his mother was a home-maker. Kumar did his schooling in Bajwara, a village near Hoshiarpur in Punjab. Then he joined DAV College, Hoshiarpur, to earn B.Sc. Honors degree in 1954 and obtained his M.Sc. (Tech) degree in 1955 from Delhi Polytechnic. Both degrees were awarded by Punjab University. In 1956, he joined the Department of Chemical Engineering, Indian Institute of Science (IISc), Bengaluru to pursue a Ph.D. His doctoral thesis was on electrolytic production of heavy water under the joint supervision of Prof. E. Weingaertner and Dr R. L. Datta. Kumar received his Ph.D. degree in 1965 from Punjab University. While working on his thesis, Kumar joined the staff of the Chemical Engineering Department at IISc in 1958 and became a professor in 1970. Except for a year in 1971–72 when he visited Leeds University, UK, Kumar served IISc all his life. He was Chairman of the Chemical Engineering Department (1976–79), Chairman of the Division of Mechanical Sciences (1980–83), and Dean of Engineering (1990–92).

Only those researchers who either say the first word or the last word are remembered. Kumar always endeavoured to say the first word. ‘What’s new?’ was a question he constantly posed to himself and others. He moved from the complex to the more complex; from bubbles to foam, a collection of bubbles; from lonely drops hanging onto nozzles in quiescent liquids to the freely suspended and fiercely interacting entities in agitated liquids. He travelled the reverse path to provide solutions to intricate problems: coaxing complex continuous variations in the shapes of bubbles and drops to fall in line with simple multistage descriptions. His research was characterized by strong physical and mechanistic backing, vivid imagination, and a quest for novelty. Here are some illustrations.

First, let us discuss Kumar’s pioneering work in bubble formation. Prof. John Davidson, University of Cambridge, UK was a pioneer in modelling bubble formation, but his model could not describe features observed in the industrially relevant range of operations. Kumar visualized the forma-

tion process using high-speed imaging and proposed a two-stage process. In the first stage, surface tension anchors the bubbles to the nozzle, and their radial growth and upward rise are resisted by inertia of the liquid surrounding them. In the second stage, the bubble, while still being fed, leaves the nozzle due to buoyancy and terminates contact with it that prevents



coalescence with its predecessor. The two-stage model was highly successful in explaining a large body of experimental findings using a single framework and was highly cited. It brought him attention worldwide and made the Chemical Engineering Department at IISc a destination for researchers to visit while in India. The same imaginative quest led him to postulate the curved plateau borders of foam bubbles to be triangular rather than the overly simplified circular. The same was used successfully to model foam columns.

Kumar’s work on breakage and coalescence of drops in turbulent stirred vessels started with the aim of unravelling the mystery of phase inversion. When liquid *A* is dispersed in liquid *B* in a well-stirred vessel, as volume fraction of *A* is increased slowly, there comes a point where suddenly *B* becomes the dispersed phase: phases invert. The transition is so sudden that when Prof. G. K. Batchelor (University of Cambridge) witnessed the experiment in Kumar’s laboratory (IISc), he jumped and said, ‘Let me know when you find how this happens!’ Kumar viewed inversion as a sudden increase in coalescence that beats breakage. Breakage was described till then mostly from an energy viewpoint, but examining its dynamics was Kumar’s idea. This model was simple yet novel. The

drop deforms under the influence of turbulent fluctuating forces for a period of life of an eddy, and deformation is opposed by viscous forces and surface tension. The breakthrough idea was that surface tension opposes deformation in the initial stages, but aids breakage at the end. The model was highly successful in a wide range of rheologies of the drop and was used to predict breakage frequency also. Kumar’s drop breakage models are some of his widely cited papers.

Kumar’s focus on phase inversion shifted to the field of hot superconductors, which was grabbing the attention of all. The idea was to use emulsions to make such fine particles of the components needed to synthesize superconductors to avoid diffusion limitation during the reaction between them. This is an alternative to the heat and beat method. It became obvious that nanoparticles are needed and microemulsions must be used in place of emulsions. In view of their small size, the microemulsions were viewed as well-stirred reactors, and formation of overbased calcium carbonate nanoparticles was successfully modelled. This work also led naturally to stochastic modelling of small systems, and fruitful collaboration of Kumar with Prof. D. Ramkrishna (Purdue University, USA). Work on calcium carbonate particles led Kumar to look at gold nanoparticles which have wide applications in detection and diagnostics. The focus was on reduction of gold salt by citrate to produce gold nanoparticles in aqueous medium. He envisaged an entirely new role to citrate molecules – that of organizing a collection of gold atoms as a precursor to the formation of nuclei. His model is widely quoted.

Kumar was able to see what everyone else saw and think of what no one else thought. And that’s what he did in the field of sonochemical reaction engineering. If an aqueous solution of KI is sonicated, it produces iodine at a constant rate. Chemical engineers know this as a batch reactor, and it cannot produce products at a constant rate. Kumar proposed a new idea. Bubbles that collapse under the influence of ultrasound act as reactors and produce reactive intermediates. Detailed modelling of bubble collapse and thermodynamic analysis of reactions of the contents of bubbles showed that hydroxyl radicals reduced iodide to iodine. As collapsing bubbles are a constant source of radicals, the product

could be produced at a constant rate, and that resolved the paradox. The model could be used in many other contexts and is one of his widely cited works.

In the mid-seventies, IISc started a cell on Application of Science and Technology to Rural Areas. Energy was one of the focus areas. Kumar took up the challenge of developing fuel-efficient wood stoves which simultaneously are smokeless, thereby protecting rural women from exposure to harmful flue gases. The stove attained 45% energy utilization efficiency. Ten lakh stoves were installed in Karnataka with support from Government of Karnataka.

The following is part of a poem penned by Ramkrishna that beautifully summarizes Kumar's research contributions:

*For a graduate degree and scholarship
He travelled south to Bangalore
For there he found his life's friendship
Drops and bubbles in papers galore.*

*Equations for fluids, he kept them simple
For in those days there was no CFD
Nor BEM for drops with a dimple
Detaching drops dealt his PhD.*

*On he went to bubbles that burst
Coalescing pairs of drops to boot
On foams that drain he was the first
And of ceramic particles in hot pursuit.*

*Phase inversion he was early to explore
He fancied the bubbling fluidized bed
Then hounded bugs fed on sulfide ore
And on sono-chemical reactions he led.*

*For several years he earnestly strove
In technology to serve the rural folks
He made the world's best wood stove
And bore so well the eggheads' yokes.*

Excellence and relevance were the hallmark of Kumar. As an astute and creative consultant, he made a huge impact. He set up a fluidized bed roaster to directly produce copper sulphate from chalcopyrites, and set a record for the largest diameter at that time. He set up units for producing activated carbon and manganese sulphate.

Kumar was a consultant for Reckitt and Coleman and Marico Ltd, where he brought deep science into the business of nutraceuticals. He was consultant to the Government of Karnataka on the safety of chemical industries, and toured Karnataka giving lectures on Hazard and Operability Analysis (HAZOP).

Kumar was a teacher par excellence. He taught an immensely popular course on modelling in chemical engineering. He strongly emphasized visualization of physical phenomena and imagination of mechanisms behind them. Simple and intuitive mathematical formulation was encouraged. He was an early believer in chemical engineers bringing knowledge from other fields and lectured on borderless chemical engineering.

As Director General of Council of Scientific and Industrial Research (CSIR) during 1995–2006, one of us (R.A.M.) relied heavily on Kumar's astute advice and guidance. He chaired CSIR's largest network programme on discovery and development of bioactive molecules with participation from 19 laboratories. His inspirational message to creating the first word in science inspired the setting up of a unique New Idea Fund, where out-of-the-box ideas with a chance of success of one out of 100 were supported. Kumar chaired the selection committee. He also chaired several research advisory councils, and various selection committees. CSIR benefitted immensely from his uncompromising value systems and his highest benchmark of excellence. He was the member of the Indo-French Centre for over a decade, when he pioneered the idea of 2 + 2 partnership between Indian academics and industrial research partners. His contributions to the Centre for High Technology, Ministry of Petroleum and Natural Gas, Government of India, were phenomenal.

The following part of Ramkrishna's poem summarizes Kumar's contributions to institution building:

*Now from Bangalore, a grey-haired sage
A man with a mission that travels afar*

*Heading committees spreading his message
Hail to our speaker Rajinder Kumar!*

Kumar received the Bhatnagar Prize (1976), Vasvik Award (1986), K.G. Naik Gold Medal (1988), Syed Hussain Zaheer Medal of Indian National Science Academy (INSA) (1989), Alumni Award by IISc for excellence in research awarded (1991), Om Prakash Bhasin Award (1991), FICCI Award for physical sciences (1994), Nehru Birth centenary fellowship of INSA (1995), Shanti Swarup Bhatnagar Medal of INSA (1997), and Lifetime Achievement Award of Indian Institute of Chemical Engineers (2008). He was Vice-President of INSA, Indian Academy of Sciences and Indian National Academy of Engineering. He was awarded the Padma Bhushan in 2003.

Kumar was an extraordinary human being. His joyful nature, childlike mischievousness and amazing sense of humour, lightened many a serious moment. His affection, compassion, and empathy knew no bound. Many came to him seeking advice: young and old, famous and unknown. He spoke with a touch of humour, while saying all that needed to be said. He was gentle and ever smiling, loved and respected. He was also a gentle conscience-keeper. He used the simplest of words and straightest of the constructions; yet one sensed unfathomed depth in them. In his demise, the S&T community has lost a giant, but he will remain an inspiration for generations to come.

Kumar is survived by his wife Andal, son, daughter and grandchildren.

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