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Viewpoint

Fireside Chat with Man Mohan Sharma: Catalysis for Sustainability

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Cite This: https://doi.org/10.1021/acssusresmgt.4c00502

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KEYWORDS: *Sustainability, Catalysis, Resource Management, Bioresource Valorization, Waste Management*

Prof. Man Mohan Sharma, popularly known as M. M. Sharma, is a doyen of chemical engineering. He is one of the most successful chemical engineers of our time who elegantly balances multiple roles; a teacher of lasting influence, an impactful researcher, a much sought-after consultant, and someone who synthesizes encyclopedic data. He has influenced the path of resource management in chemical industry and therefore has a comprehensive view of the diverse issues facing the planet. We sat down to talk to him on his views of catalysis and its importance on sustainable chemical processes and resource management. M. M. Sharma shared his academic background and research contributions in chemical engineering, emphasizing his self-motivated pursuit of the field and his significant contributions to carbon dioxide (CO_2) absorption and reduction of energy consumption in chemical processes. He also discussed the importance of catalysis in achieving sustainability in various industries and potential solutions to the CO_2 crisis, including transitioning to nonfossil, renewable energy sources, and exploiting agro-waste. The conversation ended with a discussion on the extensive use of electricity in modern society and the need for sustainability and reducing demands for better living standards.

Editor: The first question focuses on your background. Could you provide a brief overview of your academic journey and research interests? In a recent article published in *I&ECR*,[1] you were described as a "knowledge and action seeker par excellence". It is clear that your work has contributed significantly to advancing chemical technology. Could you also share your thoughts on the evolution of chemical engineering as a discipline and its critical role in nation building?

M. M. Sharma: Well, I was born in 1937 and grew up in the desert city of Jodhpur (Rajasthan), the city which created polo as a game. Although my town had an engineering college that offered different disciplines such as civil engineering, I was driven by a different passion. My interest in chemistry and mathematics naturally guided me towards chemical engineering, even though I had no formal guidance. It was a self-motivated decision, driven by a desire to apply these subjects in a practical way. At the time, in contrast to electrical, mechanical, and civil engineering, chemical engineering was an unknown or unfamiliar discipline to many in India. My grandfather kept on asking me: What is this branch that you are studying?

Thus, in 1954, when I was 17, I came to Bombay to study chemical engineering. Interestingly, by the time I graduated with a bachelor's degree, jobs were available in chemical engineering, and one could have multiple job offers even before graduation. However, I was bent upon doing research, so I did not appear for a single interview to sway my decision. Although I could not pursue a Ph.D., I was lucky to get a full scholarship to go to Cambridge in England to work with Danckwerts. Afterwards, in 1961 to 1964, I did my Ph.D. in Cambridge. In the first year of my Ph.D. career, I had done enough work to earn my degree. I was the first one to show that the existing amines at that time were too slow in absorption processes, and there were much faster reacting amines, which can bring down the size of absorption columns. We also published a monograph[2] to show how we can complete a process design of a large absorption column for CO_2 removal from first principles. This was validated in practical industrial processes. At the same time, to reduce the energy consumption in desorption, we propounded the idea of using hindered amines which later, Exxon picked up. In line with these ideas, in recent years, innumerable papers have been published on the efficiency and performance of different amines. I also worked on carbonyl sulfide which had an excellent potential to be implemented in industry. My supervisor had strong industry connections, and through his support, Shell approached me with interest in my work. They took a preliminary patent on my idea, and I was paid handsomely for the rights to it. This marked a significant milestone, as it was the first time in the history of chemical engineering at Cambridge that something had been patented and sold for commercial use. It was a pivotal moment that not only validated my research but also demonstrated the practical, real-world impact of chemical engineering innovations. This is just before I left Cambridge to come back to teach in ICT Mumbai, although I knew there was no money in there for research in those days. Thus, I decided to conduct idea-oriented research. Our first breakthrough came when we devised a method of measuring interfacial area in any liquid–liquid system by chemical methods. Although, the Dutch people were doing lots of work on this, they could not succeed in it then. This indeed brought us international fame. And then we did the microphase work, in which we studied how particles smaller than diffusion film thickness can make a world of difference.[3] We called them microphases. And one process studied had something to do with flue gas desulfurization. Here, we found that when the particle size becomes smaller than diffusion-film thickness, the rate of absorption goes up markedly.

That was some of our works in my early career, with no funding from any agency. We then created a *mantra* in our institution: that is, our priority is teaching, there is absolutely no compromise on it, ever. Then, we had to conduct high quality research and publish papers in renowned journals. At this point, I became an editor of the *Journal of Chemical Engineering Science*. And finally, we had to initiate interactions with industry to make a difference in applied science. Afterwards, our people became consultants to industry, which created a live pipeline for our graduate students to be employed. Before this, there was no culture of hiring Ph.D. graduates in chemical industry. Thus, we created that culture of how Ph.D. graduates can contribute to the growth of chemical industry in India. All in all, my journey has brought me various honors and awards, including the distinction of being the first engineer from India in history to be named a Fellow of the Royal Society in 1990.

Editor: Great! You have a very interesting background. I am sure you have more to say. Let's move to the next topic, which is about the relationship between catalysis and sustainability. Every large-scale chemical process is driven by catalysis. Examples include petroleum refining and polymerization reactions. In the era of sustainability, valorization of natural products is made possible, for example, by catalysis. In your view, what is the role of catalysis in sustainable resource management?

M. M. Sharma: Let me start by giving you a very classic example, that is, how to remove hydrogen sulfide (H_2S) from natural gas. If you remember in Middle Eastern countries such as Iran, they used to flare. Today all the sulfur used in industry is recovered sulfur and not mined sulfur. Today, mining sulfur is no longer a primary method of obtaining it, even though sulfur mines still exist in different parts of the world. If these mines were to be exhausted, we would still have a significant supply of sulfur through modern processes. Currently, by processing around 4 billion tons of crude oil annually and an additional 1.5 billion tons of natural gas, we can recover substantial amounts of sulfur. This sulfur comes from H_2S captured during natural gas processing and through hydrodesulfurization in oil refining.

I want to quote this as a classic example of sustainability. The entire sulfur today is from recovered sulfur, which was otherwise burned and created environmental problems. Now, hydrodesulfurization is a breakthrough in the history of catalysis because one could have a feed, for example, for diesel with sulfur content anywhere from 0.25 to 1%. But the exit had as low as 50 ppm, in a single reactor. This is both the wonder of catalysis and reaction engineering. Now, hasn't this made processes sustainable because you now get gasoline as well as diesel almost completely free from sulfur? So, when you burn, there is no SO_2 emission from cars and from trucks.

With the help of catalysis, sustainability has been greatly advanced by reducing emissions from gasoline-powered vehicles. If you look at the impact of automobile exhaust catalysts, it is remarkable how effective these have been. Today, with the honeycomb catalyst technology made from noble metals, we see virtually no emissions of unburned hydrocarbons. All the exhaust gases are efficiently treated before being released, demonstrating how catalysis has played a crucial role in enhancing sustainability. But for catalysis, how could you have gotten H_2S conversion to sulfur almost at vanishing levels?

In Canada, there are several natural gas fields which have up to 20% H_2S, and even more in some other fields. These wells used to be sealed. But today they are utilized as it has been made possible to make sulfur from these resources, thanks to catalysis technology. These days, catalysis also plays a crucial role in removing and converting CO_2. Another example is hydrogenation. Currently, no hydrogenation process exists without a catalyst, as hydrogen must be activated. Another example is the conversion of ethylene to ethylene oxide which was only 65% efficient during its start in 1930. Science and practice of catalysis has made this an extraordinary process with 85% efficiency. Thus, the amount of CO_2 that is released in this process has come down drastically.

Editor: In your view, what catalysts have the greatest potential in addressing the carbon dioxide crisis? Should we be investing more into transformation or capture?

M. M. Sharma: Capture is a necessity. Let me give you my very strong view on this subject. Indeed, too much hype is being made for converting CO_2 to chemicals. If we are emitting ~40 billion tons of CO_2 by burning fossil fuels, coal, and hydrocarbons, there is no way this amount can be converted to chemicals—only a minute fraction of it can be. The maximum amount of chemicals being made is 350 million tons per year. Indeed, catalysis play a big role in converting CO_2 to ethylene, methanol, dimethyl ether, etc. However, the total amount of CO_2 that is needed to make chemicals is roughly 500 million tons per annum. Indeed, the most viable solution to address the environmental challenges caused by CO_2 is to use clean and renewable energies. However, due to the intermittency of renewable energy sources like wind and solar, maintaining a consistent power supply and backing up fossil fuel-based power stations remain a challenge. As a result, currently, the continued utilization of fossil fuels is indispensable. Therefore, avoiding the emission of ~40 billion tons of CO_2 annually is, unfortunately, inevitable. As I mentioned, CO_2 conversion is not the solution to the problem. However, one area that is very encouraging, and is about to be industrialized, thanks to the pilot plants in BASF, is dry reforming of methane. Instead of mixing methane and steam, it is reformed with CO_2 in this process. In this process, CH_4 plus CO_2 will produce CO and hydrogen. But still, the problem exists, that is, the production ~40 billion tons of CO_2. China alone burns about 2 billion tons of coal per annum, and there is still thermal power stations based on coal and hydrocarbons everywhere, including in the USA. Even if we replace coal with methane burning, production of CO_2 cannot be avoided. Indeed, like SO_2 and H_2S, there has been excellent advancement in the removal of CO_2. But, where are we going to use this huge amount of collected CO_2?

https://doi.org/10.1021/acssusresmgt.4c00502
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The other challenge is the cost of hydrogen. None of the CO_2 conversion process can become economically viable unless the cost of hydrogen decreases drastically. Indeed, production of chemicals from agro-waste is also possible. Even fuel production for automobiles from agro-waste is possible. But, at a heavy cost! Thus, CO_2 conversion with the aid of catalysis, much like many other processes, is possible, however, at a high price. Still, the maximum utilization of renewable and nuclear energies is the most viable solution to address the challenges caused by CO_2 emissions.

Editor: What do you see as the key focal themes that industries should prioritize to enhance sustainability and resource management?

M. M. Sharma: Valorization of agro-waste. No crop is possible without lignin, which is a phenolic substance. Millions of tons of lignin are potentially available from sources such as sugar cane and corn. Sucrose, another example, is available at a very low cost—around 40 cents per kilogram —and serves as a multifunctional feedstock. Therefore, the valorization of agricultural waste and its conversion to chemicals, such as ethanol, should be a priority for sustainable resource utilization. Cellulose can be also converted to fermentable sugars, and then, it is converted into different chemicals. Via fermentation technology, ethanol, acetone, isopropanol, etc. can be produced. However, still costs and agro-waste collection costs pose a significant challenge. For instance, millions of tons of polyethylene are needed each year. Production of this amount via utilization of hydrocarbons, as they exist in massive quantity in one single location, is drastically more cost effective compared to production of the same amount from agro-waste or other renewable resources in different locations.

Yet, there will be agro-waste as long as we need food. Agro-waste also exists naturally, such as leaves collected during autumn in countries such as Canada, that can be used as raw materials. For instance, Don Scot in Waterloo did a lot of work on the pyrolysis of agricultural waste collected during autumn, as one of the early persons.[4] All in all, we need to focus more on valorization of raw materials, such as lignin and cellulose, derived from plants and agro-waste. Indeed, with today's knowledge, we can convert agro-waste into any desired materials.

Editor: Do you have any advice to young researchers in this area?

M. M. Sharma: As I mentioned, there are unlimited options in valorizing the agro-waste. In this regard, functionalization is not easy—similarly, defunctionalization is also a challenge. For instance, novel enzymes and directed evolution are needed. Indeed, more research is required to effectively valorize agro-waste and address challenges in this field. For instance, lignin features different chemical and physical properties based on the feedstocks; i.e., lignin from corn is different compared to lignin from sugar cane. If the petroleum industry can develop harmonious catalytic cracking processes for sophisticated advancements, there is no reason we wouldn't be able to apply catalytic cracking of lignin. This would require extensive research and the development of new catalysts, which should be done by our young scientists.

Editor: Lastly, the greed of humanity is the reason for the current climate crisis; in your view, do we have enough for everyone on the planet to enjoy the western way of life? And what can catalysis do to enable that life with sustainability?

M. M. Sharma: What is not in the hand of catalysis is extensive production of electrical power. Everybody wants air conditioners, heaters, and a comfortable life. If we really want to sustainably manage our cities, we must find better ways of heating and cooling. In India, and other countries with a dry climate, such as Iran, there is a quantum jump in the consumption of power in summertime. The bulk of the supplied energy is based on fossil fuels. Thus, if we want to discipline ourselves, we must reduce our demands. Unfortunately, people are generally not willing to do so. Society consistently seeks a higher standard of living. We want to wash our garments very quickly. We want to use fashionable materials. We want to use more clothes than we need. Finally, they all get linked to the production of them. Then comes the question, what do you do with the utilization of all the waste we generate constantly? What do you do with the shirts and trousers made of polyester? I believe a circular economy aided with catalysis to enhance the chemical processes is crucial to keep the planet under control.

M. M. Sharma: In closing, I complement the journals *ACS Sustainable Resource Management* and *ACS Sustainable Chemistry & Engineering*, the latter I regularly follow. And now that you have this new journal, I have started following it. Thanks!

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https://pubs.acs.org/10.1021/acssusresmgt.4c00502

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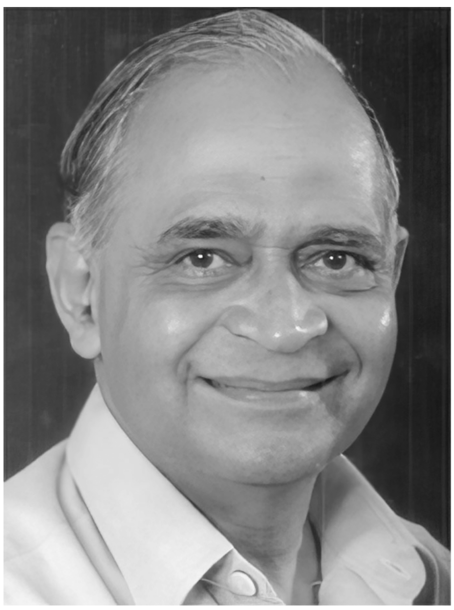
The authors declare no competing financial interest.

Biography



https://doi.org/10.1021/acssusresmgt.4c00502
ACS Sustainable Resour. Manage. XXXX, XXX, XXX−XXX

Man Mohan Sharma. I received my education in Jodhpur, Mumbai, and Cambridge, England. I was appointed as Professor of Chemical Engineering at the University Department of Chemical Technology, Mumbai University, just at the age of 27 years, in 1964. I got many honors and accolades which include the S. S. Bhatnagar prize in Engineering Sciences in 1973. I became a fellow of the INSA in 1976 and was President during 1989−1990. I have received from the President of India the second highest civilian award of Padma Vibhushan in 2001. I became the first engineer from India in 350 years of the Royal Society to become a Fellow, which I consider as my highest honor.

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