A Brief Overview of Professor Arun S. Mujumdar's Research Contributions

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Abstract

This paper is intended to provide a brief overview of Professor Mujumdar's research contributions in the area of drying R&D as well as transport processes in general for archival purposes. No pretense is made that this survey is complete. Since his current research activities at the National University of Singapore are already presented in a companion paper, this paper will be limited to his work prior to joining NUS in mid-2000. For references to his papers, books and other contributions the interested reader is referred to his webpage maintained by one of the authors (SD).

Introduction

Four decades of professional working life after the first degree is a long period by any measure and it is hard to pretend to provide a true overview of one's accomplishments over such a long period. In Professor Mujumdar's case it is even harder as no one person, or even a group of persons, can claim to know definitively what he has contributed to in often diverse research areas over an extended period of time. No one person has indeed worked in all the areas Prof. Mujumdar worked in so it is highly unlikely anyone can claim to know about all his work, especially in the first two decades at McGill University. He has made academic publications in the public domain that one can, with some difficulty,

can dig up. He has also made some truly outstanding and very valuable contributions in solving major industrial problems which remain confidential so we cannot have access to them. We will therefore attempt only to summarize in point form; actually in the form of a number of flowcharts he has prepared for several of his keynote and other lectures and seminars. For references to his publications, one may refer to his Website (www.geocities.com/as_mujumdar) or simply search under his name on any search engine.

Basic Approach and Philosophy on Research

Professor Mujumdar selects his research project so as to optimize learning by his students as well as himself. His goal is to produce an accomplished researcher while producing useful research output. His focus is on excellence rather than on "buzz word" research. He thinks that one should create "buzz" about one's research areas rather than depending on others to do this so as to make it easier to find the necessary resources. Although drying was not a "hot" topic of research, he did manage to make many contributions to the subject, and indeed get many others to do likewise on a global scale. As will be seen from this article, Prof. Mujumdar has worked quite extensively in non-drying areas as well. Although the topics are quite diverse the basic theme is transport processes.

Global Summary

Prof. Mujumdar did his M.Eng. and PhD degrees from McGill University under the guidance of Prof. W.J.M. Douglas conducting research on flow through packed beds and experimentally evaluating the effect of turbulence on heat transfer from cylinders, respectively. During this period he also did major independent non-thesis research in his spare time, mainly to keep himself busy in idling periods common to all thesis research. He worked on mixing in stirred tanks, flow past cylinders of various cross-sections, etc., and even published in major journals his work carried out with no funds or other support. Indeed, his work on turbulence measurements and his ideas on turbulent length scales, signal-to-noise ratio in unsteady turbulent flows were picked up by many later researchers leading to a heavily cited paper published in Canadian Journal of Chemical Engineering.

Before completion of writing of his thesis, Dr. Mujumdar went to Carrier Corp. in Syracuse, NY, USA to gain industrial R&D experience. That is where he self-learnt the then-evolving subject of computational fluid dynamics even as computing technology was rapidly evolving but still very limited in capability. There were no texts and the field was pretty much restricted to nuclear and aerospace engineering disciplines. Back at McGill he found ample opportunities

to apply this to study of impinging jets and free convection flows. He also was involved in numerous experimental studies in Prof. Douglas's research group. For Canada, newsprint was (and is) a major commodity. There was thus great interest in developing a new drying system for newsprint to replace century-old multi-cylinder drying cylinders (which are still used in modern paper machines). This is where he made numerous contributions to impinging jet heat transfer and drying, experimentally and computationally, with Prof. Douglas and a number of his highly capable graduate students. Numerous PhD and M.Eng. theses were completed under his direction or co-direction although much of that work remained in thesis form. Only a fraction of work accomplished appeared in public domain for various reasons. Also, papers presented in conferences and books are now out-of-print and now unavailable.

Figure 1 shows a flowchart listing all the drying-related research Dr. Mujumdar and his students, associates and international collaborators accomplished over three decades. He started with drying research on paper and then moved on to grains, foods, ceramics, suspensions, sludges, etc., and covered pretty much all the key areas of material characteristics that are dried industrially. His focus always was on a combined analytical and experimental approach so as to generalize the results and make them more generally applicable.

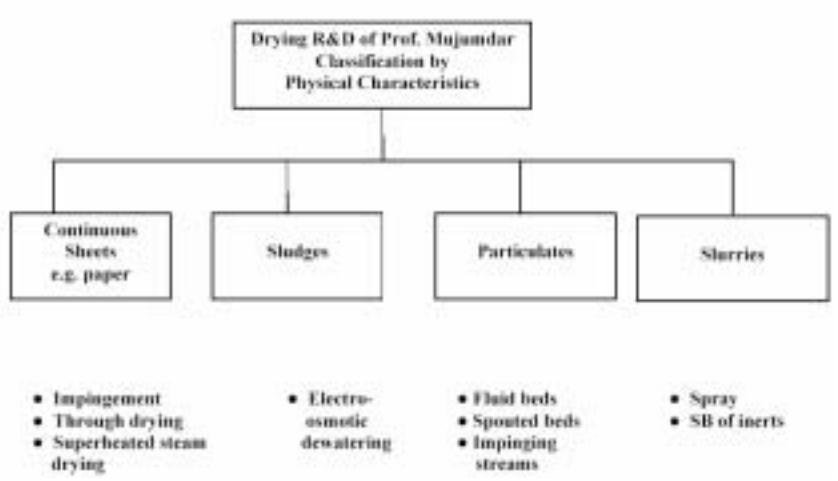

Figure 1 Drying R&D of Prof. Mujumdar

Drying problems are found in most industries. Figure 2 lists the various industrial sectors that Prof. Mujumdar's research has encompassed. He always has noted that drying is a combination of material science with transport

phenomena since the object of drying is not just to remove water but to obtain a dried product of desired quality.

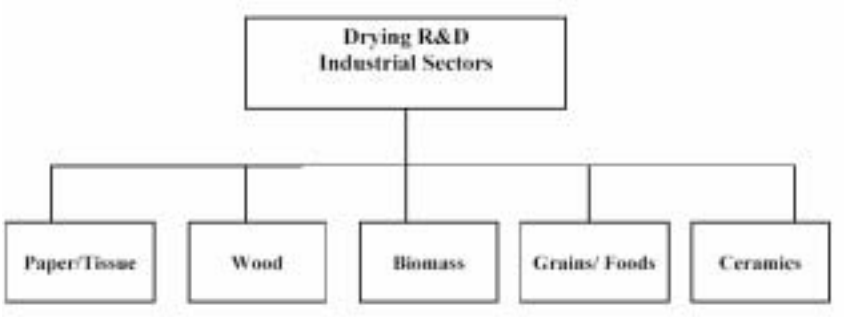

Figure 2 Drying R&D of Prof. Mujumdar in industrial sectors

Innovation has been the mantra of his research effort. Figure 3 lists areas to which he contributed by developing new and innovative concepts, which were later pursued by many researchers around the world. Clearly, they have merit and some are probably already implemented by industry. Superheated steam drying is an area that he has pursued consistently over the past two decades. His pioneering work on superheated steam drying of paper won him Innovation in Drying Award at IDS86 held on MIT campus in 1986.

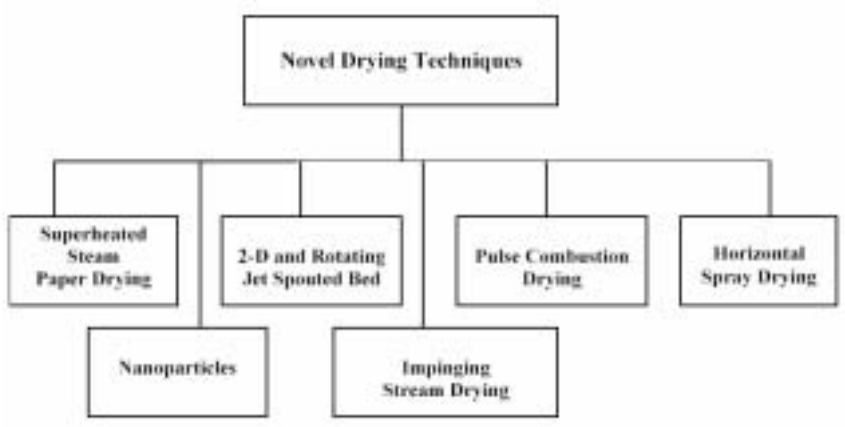

Figure 3 Novel drying techniques with the contributions of Prof. Mujumdar

As mentioned earlier, transport processes under impinging jets have been the subjects of his keen interest for nearly three decades. It is surprising that even after three decades there are things to do in this complex area. Turbulence modeling and two phase jets are a particular challenging problem. The diverse areas his research has contributed to can be seen from the list of parameters listed in Figure 4. Prof. Douglas has been his initial collaborator in this area.

As a related topic, Dr. Mujumdar was probably among the first in the west to initiate basic research on confined opposing jet flows, which have many diverse applications. They are still not common in industrial practice mainly because of limited knowledge about their characteristics. Figure 5 lists the basic types of studies done or under way in Dr. Mujumdar's research group. This is a currently active area.

One area where he has made consistently significant and diverse novel contributions is modified fluidized beds. They range from vibrated beds to two-dimensional spouted beds to rotating jet spouted beds. This area has been mainly experimental for obvious reasons. There are still many opportunities for further research in this area of great industrial potential (See Figure 6).

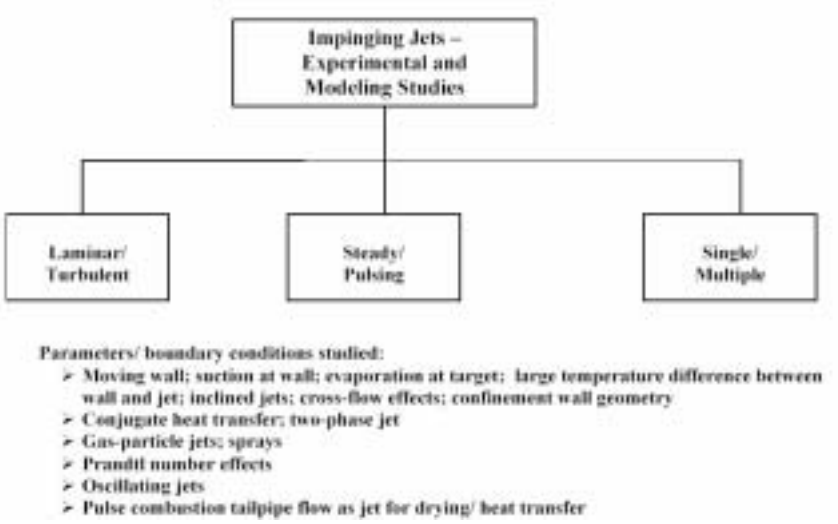

Figure 4 R&D in diverse areas

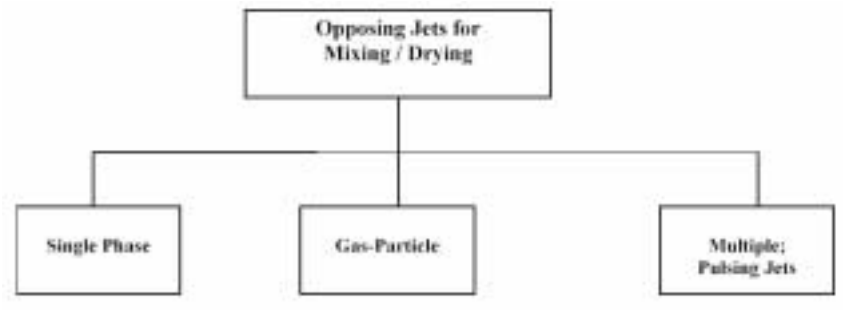

Figure 5 Current projects in research group

Since drying is an energy-intensive operation due to the high latent heat of evaporation and the need to heat up the material being dried and it is typically not cost-effective to recover exhausted energy from dryers, it is best to do mechanical or non-thermal dewatering prior to drying of materials like sludge or filter cakes. Electro-osmotic dewatering provides a very important way of energy-efficient removal of water from hard-to-dewater colloidal materials like sludges. This work was later extended to include in situ decontamination of soils. Indeed, EOD is being considered for treatment of tumors where the cells are killed by dewatering them rather than by freezing or by heating. Figure 7 simply lists the topics he has considered. Current work at NUS will look at EOD of dredged soils. Pulse combustion based drying of slurries and possibly flat materials like high basis weight paper was another area he has initiated research in. Microwave drying, heat pump drying, osmotic dehydration, intermittent drying are some of his recent areas already mentioned in the companion paper.

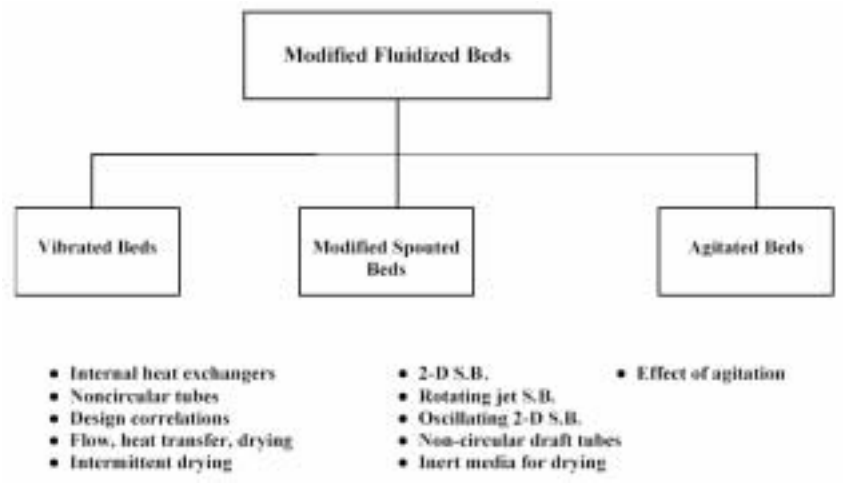

Figure 6 R&D in modified fluidized bed

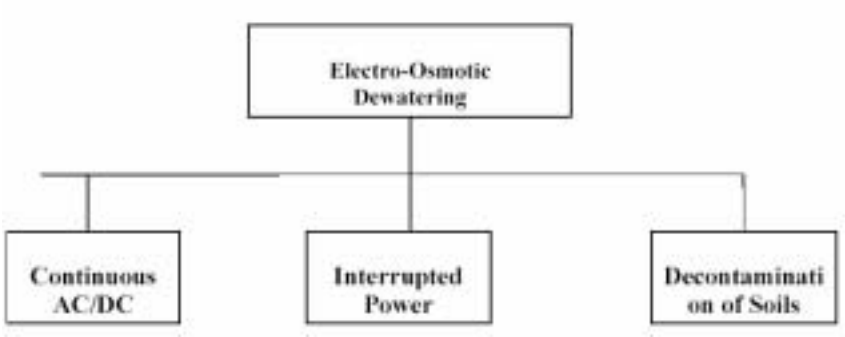

Figure 7 Some topics he is thinking

Figures 8 and 9 list the numerous non-drying research areas Prof. Mujumdar has worked on. They still are not complete. For example, they do not list his many works on vortex-shedding from bluff bodies, gasification of Kraft black liquor, drying of slurries by spray impingement at normal and low pressures, etc. Perhaps he has published more papers on non-drying transport processes than on drying per se. Although it seems odd, indeed there are similarities amongst all the topics he has researched. They all belong to the fascinating field of transport phenomena. The work he and Prof. M.E. Weber did at McGill on cyclic melting and freezing was possibly the first of its kind. It was nearly a decade later that

others followed their line of research ideas in this field of PCM heat transfer. Initially it was driven by the need to store thermal energy for space heating but now Dr. Mujumdar as looking at use of PCMs for thermal management of electronic components used in a transient mode, i.e., used periodically rather than continuously.

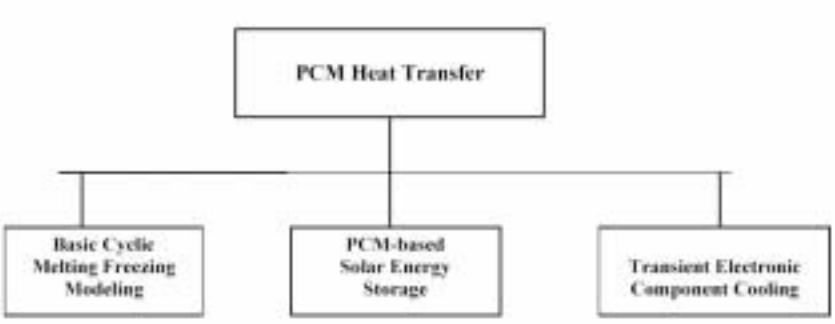

Figure 8 One section in non-drying field

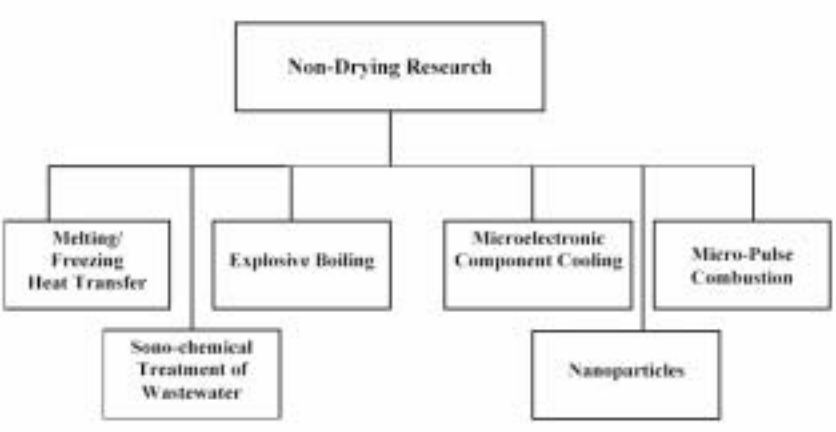

Figure 9 Some other sections in non-drying areas

There are many other topics that Prof. Mujumdar has conducted or supervised research on but are not listed in the extensive flowcharts shown earlier. Among them one may cite: super-critical extraction of oil from nuts; modeling freeze drying, superheated steam-enhanced drum drying of Kraft black liquor, modeling combined radiation-convection drying, spout-fluid beds,

fluidized bed gasification of black liquor, etc. It should be pointed out that Prof. Mujumdar accomplished all of the above while carrying a heavy teaching load (graduate and undergraduate teaching), advising of students and doing more than his share of administrative duties for his departments at McGill and now at NUS as well as rather monumental service to the profession globally. He believes that a real professor must be active in all three aspects of academic life, i.e., teaching, research and service to the university as well as the profession. He has also been careful to instill a sense of ethics in his students and associates- this he considers to be the most important trait an academic must possess.

Concluding Remarks

Clearly it is not possible to do justice even to listing the scores of PhD theses, post-doctoral researchers and research areas Professor Mujumdar has made lasting contributions to. We hope readers will get some idea about the scope, breadth and depth of his research and his ideas about research. He has freely given away his original ideas to researchers from around the world. He has published patentable ideas just to promote their use worldwide without constraints. We hope that this will motivate younger researchers to pursue drying and transport processes as a viable and challenging research area.

It is noteworthy that Prof. Mujumdar chose journals and books for dissemination of his research results based on the readership it is intended for and not impact factors or prestige factors. As is clearly shown on his website there is scholarly evidence that impact factors are a faulty measure to assess impact of engineering research. He also has published some of his work in Chinese, German, Hungarian, Russian and Portuguese. His work is cited in journals in many languages. Most importantly, he did not follow “buzz word” research areas or join “flavor-of-the-month club” in selecting research areas because it was easy to attract large funding or students to these areas. Indeed, he took the hard way of stressing excellence and creating the “buzz” about research areas he believed to be important. Drying R&D is a case in point where he has had to generate interest amongst students, industry and researchers on true global scale.

References

In the interest of brevity no references are cited here. However, many can be found by visiting his Website as well as by conducting computer search of literature. A significant fraction of the work is in the form of book chapters as well as theses which may not be uncovered through most searches.