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FLUIDIZATION—PAST & FUTURE

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ABSTRACT
With the understanding on paradigm shift in sciences as well as on the relationships between science and society, the footmarks of fluidization research and its present situation were briefly revisited so that the future directions can be defined and discussed in the fluidization society in a wider perspective.

INTRODUCTION
Any scientific area has a time of transition and a time of confusion. In the case of fluidization science/ engineering, it made a splendid appearance in the 50s based on the 10 years accumulation of data and knowledge since the first erection of FCC plants at Baton Rouge in 1940. ‘Fluidization’ thus emerged into the academia as a new realm of chemical engineering science. Its real impact was made further at around 1960 with the dramatic finding of bubble hydrodynamics. ‘Bubbles’ in fluidized beds are sort of moving fluid pocket in a bed of solid particles suspended by the fluid. The finding was quite new not only in terms of its uniqueness but also of its demonstration of the power of fluid mechanics and transport phenomena that were about to be seriously introduced into chemical engineering principle. However, just ten years later, i.e., early in the 70s, among some young researchers who studied fluidization at least in Japan, there was an antiphony of asking if somebody was still studying fluidization because it was believed that fluidization has no more future as an exciting area of academic research. It was a time of confusion after substantial development was completed both theoretically and practically. But actually it was the dawn of a new era of research as discussed more in detail later.

Fluidization has been effective in quite a variety of industries from metallurgical roasting to coal conversion, petroleum refinery, agricultural and food processing, pharmaceutical processes and material processes. In terms of the mode of solid suspensions, 'fluidization' now covers quite a wide variety of suspensions, ranging from settled beds, homogeneously fluidized beds, bubbling beds, clustering suspensions, pneumatically transported solids, a lean but rather slowly moving suspension in the freeboard above a bubbling bed to another lean but rapidly moving jet region with gas velocities close to the sonic velocity.

Fluidization is a technique as well as phenomenon of the substantial reduction of internal friction in a bed of solid particles caused by external forces, mostly gravity but sometimes buoyancy or magnetic force, with other counter forces, basically fluid drag force but sometimes mechanical or sonic vibration so that the bed can flow like a fluid. In general, a fluidized bed is a liquid like phase of a bed of solid particles.

This is because 'liquid' is a state of materials in which normal stress is not tensile force but pressure, and in whose stagnant condition no tangential stress, i.e., internal friction, can exist (Imai [1]). It is an immortal contribution of fluidization scientists to the scientific society that they unveiled the whole continuous spectrum of phase changes of a particle suspension from the densest condition to the leanest. The spectrum includes a phase called fast fluidization that corresponds to a super-critical state of the solid suspension as discussed in the next section. Of course, such achievement could have been done by other disciplines. But it is only natural that it was made by fluidization people who have long been working with strong industrial intentions and demands and with columns in which different artificial suspensions can be created quite easy.

Nevertheless, the fluidization society now seems to be in the time of confusion when new enthusiastic developments are rather hard to find. It may be a similar situation as in the early 70s mentioned above, but may be not. Since the social requirements of raising engineers having preparation for fluidization principle and those for supporting research activities exist definitely, it is anyway important to organize a new environment for fluidization research and education to keep up the fluidization principle further in the academic and industrial societies. Also potential importance lies in popularization in civic societies and primary/secondary educations and in the collaboration with other disciplines. Moreover, the latest change in innovation atmosphere, i.e., from traditional to greener innovation, could bring about new stimulation for almost all disciplines including fluidization. The present article intends to provide some points of arguments on the future of fluidization.

PHILOSOPHICAL PRINCIPLES ON SCIENTIFIC UPS AND DOWNS

Three Stage Law of Paradigm Shift

Among the philosophical ideas of Japanese physicist Mitsuo Taketani the one in the paper entitled as 'On the formation of Newtonian mechanics' [2] has been quite helpful in organizing and planning the direction of my research in fluidization. As I have cited in my work before [3, 4], he says that scientific knowledge develops itself in three stages, i.e. 1) Phenomenology stage, 2) Entity stage and 3) Essentiality stage. For a long time it has been believed that a researcher investigates phenomena just searching for the very essence behind them. This is the two stage understanding on the progress of knowledge. Taketani's point is that although a research starts from phenomenology and anyway ends up with finding some essence or general principle behind the phenomena, there actually exists a middle stage in between that is decisive to step forward to the essence. The term 'entity' and the term 'essence' were easily mixed up but the former has some image of a set of components in the phenomena. In my understanding the second stage could better be called as the structural stage. In the process of the formation Newtonian mechanics, without the idea of Solar orbit system proposed by Johannes Kepler and Nicolaus Copernicus the law governing celestial motions and the laws governing earthly ones would never be comprehensively summarized by Newtons law of motion and the law of gravity. The knowledge on the structure, once figured out, accentuates the essence behind the phenomena helping us to proceed to the final stage. In the case of phenomena that can be described by differential equations, once the first principles are found, the system can be expressed by differential equations. Here, it is often forgotten that to get solutions we need to define the domain and the real components acting in the system and their boundary and initial conditions. Accordingly, the second stage corresponds to the task to make clear the domain, components and boundary conditions.

The Taketani's three stage law together with Thomas Kuhn [5]'s 'paradigm' theory, would help us to review and forecast the development of fluidization science over a little longer time span.

Science and Technology in the Society

Ups and downs of a branch of a science are very much affected by its financial situation since modern sciences are very much counting on instrumental measurements, sophisticated experiments and computer simulation and without substantial financial back-ups it is hard to conduct research and higher education. Science is now a significant part of social activities of human being in two folds, i.e., 1) in relation to private sector's R&Ds and 2) publicly funded R&Ds.

In the former the collaboration between academia and industries has good reasons that it provides academic researchers to expose themselves to real unknown phenomena and tackle them since, in the most advanced developments, already known scientific laws should be completely applied and, accordingly, any troubles in achieving the objective as aimed at can contain phenomena that have not been made clear, new and exciting. It was almost a tradition of fluidization researchers to get involved in developments and trouble shooting in collaboration with industries. However, it should be noted here that new and exciting unknowns exist not only in those advanced developments but also in many other places where no developments are made up to now.

In the latter the government funding to promote a) research at scientific forefront, b) research to support the forefronts of industrial technology developments including genetic engineering, information, robotics, space and other, and c) research for public interests such as health, energy and environment. However, it is easy for researchers being spoiled by the political and/or peer review systems to get fixated on the power unless fair and strong evaluation systems function, which seems quite difficult in practical situations. It is also difficult to avoid spending on R&D plans unrealistic from either economics or energy balance. The latest efforts to cope with the global warming are more conscious on the LCA and economy than before and are more under the public intervention. Researchers will be more requested to prepare themselves for the justification of their R&D proposals and results to convince the common citizens. In this respect, sometimes instead of advanced technologies more emphasis should be placed on appropriate, alternative and/or intermediate technologies [6,7,8]

PARADIGM SHIFTS IN FLUIDIZATION RESEARCH

In fluidization science the first stage of phenomenology was in the 40s when people just measured effective diffusivity, effective thermal conductivity and/or reaction rates just by treating the bed as a black box and by applying ideas developed in the preceding reaction engineering study. The results were that those parameters determined based on the classical context were almost all extraordinary and paradoxical. Toomey and Johnston's two phase theory [9] divided the bed into bubble and emulsion phase and introduced the gas interchange between the phases. Two phase models boomed in the 50s helped to quantitatively analyze the performance of fluidized beds by determining gas interchange coefficient and other transport properties unique to fluidized beds, but it was only a sort of intermediate stage since no theoretical explanation was given why and how they take values as determined. It was John F. Davidson who brought the explanation. With his bubble model [10] of 1961 he successfully explained the gas interchange in terms of bubble gas fluid mechanics. The 60s was a decade of exciting bubble study when Davidson's model was extended, modified and applied to chemical reactor modeling to heat transfer and or solid mixing. This sequence described above exactly agrees with the Taketani's three stage law. But by some reasons each stage took some ten years.

Already around the year 1970 almost all exciting work on bubbling bed models had been done and the feeling that there's nothing left was true to some extent. However, it was only a time of a short break and the next challenges of fluidization science were already started as widely known by Geldart [11] on a wider perspective of powder characteristics, Werther [12] exploring a broader area of bubble distribution patterns, Yerushalmi et al. [13] for fast fluidization all in around 1973-76 and industrially more extensive work on combustion, polymerization and other non-ordinary catalytic process developments. The paradigm on bubble was turned on only in the early 60s and Davidson bubble model provided a sure but only small handhold. Knowledge was still much behind the real industrial practice and some young scholars' view mentioned above that time lacked the capability of creating the next paradigm.

The second 30years of fluidization science, from early 70s to early 2000s, all issues consisting of bubbling fluidized bed, i.e., from minimum fluidization, bubbling, gas jetting, solids mixing, entrainment, transport and feeding, to scaling law, and the issue of turbulent and fast fluidizations were investigated fueled strongly by alternative energy applications. Again, as already discussed in my chapter of Circulating Fluidized Beds [4] the second 30 years also have experienced almost exactly the three stages.

In the second 30years we reached almost the full perspective of fluidization including the completion of phase diagram of particle suspension in gas from homogeneous, bubbling, turbulent and fast fluidizations to pneumatic transport (cf.

Figure 1), more systematic approach to cohesive particle fluidization and direct numerical simulation. It is interesting to note here that since at least all issues relevant to fluidization were structuralized., the second 30 years could be called as the structural stage in a higher sense.

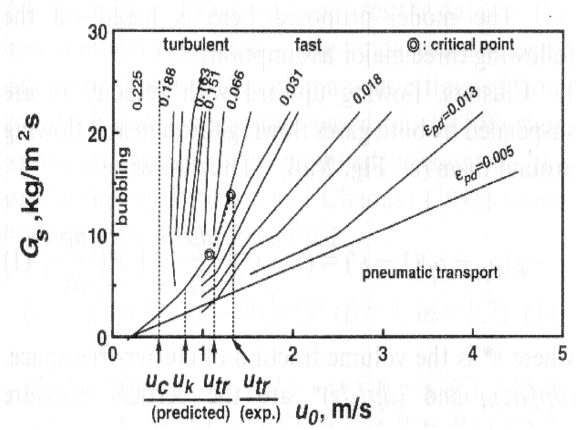


Figure 1 G_s-u_0-ε_{pd} phase diagram drawn from Hirama et al. [14] data (Horio-Ito [15]).

A CRITICAL SITUATION

The chemical engineers' interest, particularly in Japan, has been shifting from fluidization to some other as shown in Table 1.

Table 1 Trend of Japanese contributions to Engineering Foundation Conference

Year	83	92	98	04	07
Fluidization	III	VII	IX	XI	XII
Contribution of Japan	17	11	10	5	3

This shift could have been just by contingency, say, by the lack of sufficient human resources or by the temporary overflow with other subjects. However, if one looks closer into the chemical reaction engineers' behavior in Japan, some necessity could also be seen behind it. Here with the word 'behavior' I would imply first the tendency of appreciating the capability of changing ones research focus and even major area and second the tendency of not being involved in fundamental issues too much but more in development. The latter tendency has become a big wave since the 70s originated from a strong desire of combining engineering science research with technological developments. This is because for a long period of post war reconstruction the chemical engineering activities were much separated from real developments, actually there were not many developments that time but some starting ups of imported technologies, and were concentrated in the university teaching to raise young engineers.

Now the chemical engineering principle does not stick solely around the petrochemical applications and have been tested in a variety of industries. Compared to our knowledge in the 60s we now cover quite a wide spectrum of processes in the industry. Indeed chemical engineers have been finding themselves at a core, or SCC (strongly connected components), of bow tie structure [16] of engineering information flow (cf. Figure 2), with which they have been able to switch subjects easy. Now to become a good chemical engineering scholar one has to establish ideas from molecular interaction issues, to plant design and further to global environment and social issues.

The fluidization principle has also been one of the SCCs of bow tie structure to which quite a few genres of information and people have been coming in and coming out.

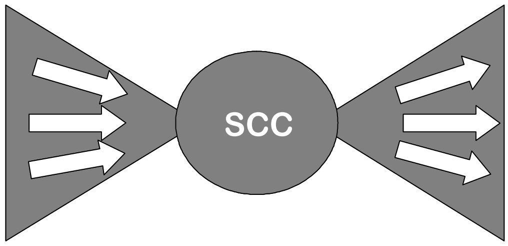


Figure 2 A bow tie structure

However, another aspect, i.e., the interaction between academic activities and industrial developments has not been quite healthy during the last decades due to the shrinkage of developments such as silicon CVD etc. and the market shrinkage of FBC boilers.

In such circumstances a strategy of just chasing new developments does not work at all. Instead, staying on one place and developing rather a deep, strong and attractive theoretical structure is now becoming more important in chemical engineering than before. This is particularly so in fluidization. The area the fluidization science covers is now quite wide and obtaining a comprehensive view is not as easy as before. Moreover, the particle dynamic formulation and numerical computation skill are necessary for the comprehensive description for which one has to spend some substantial time to manage. If scholars just chase new knowledge and new developments avoiding tedious modeling and fundamental investigation and avoiding reflections on their footmarks to reach more universal understandings, their footmarks shall be buried sooner or later and have to wait decades for rediscoveries by people in other disciplines.

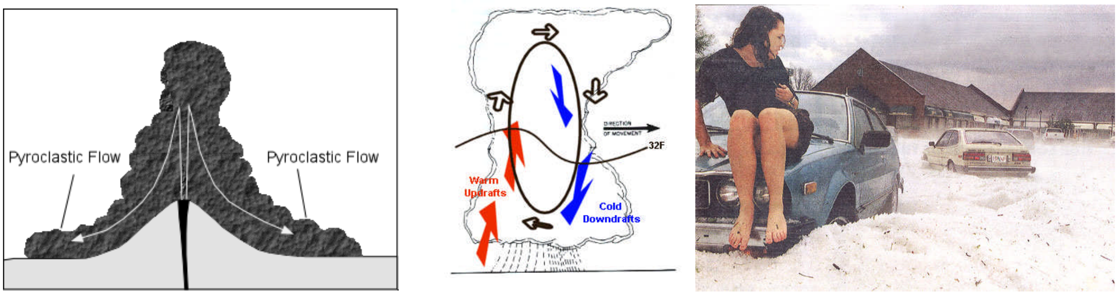
FUTURE DIRECTIONS

After 60 years of research, fluidization phenomena in ordinary industries have been much clarified. The future directions of fluidization science, if we sketch them, should be found in a much wider perspective. The concept of ‘fluidization’ should be much extended into all kinds of solids, into all kinds of interaction forces and into all kinds of human and nature’s activities.

‘Fluidization’ in the wider sense could be defined as:

Natural phenomena or human practices in which particulate solids including bodies of any sizes, are made free from internal friction caused either by external or intraparticle forces

The forces causing internal friction in deforming a bed of particulate solids could be gravity, electro-magnetic and/or cohesive interaction force. The mechanisms that unlock the internal friction could be upward lift effect by fluid drag, electro-magnetic force including super conductivity effect, vibration and/or ionic charge and any other repulsive forces. The fluid drag includes that caused by vaporization of liquids by hot particles such as the one in hydration of CaO, pyroclastic flow and/or the strong convection flow in the hailstorm (cf. Figure 3).



(a) Collapsed eruption column and pyroclastic flow formation [17]

(b) Hail storm cloud [18]

c) Columbia November 5, 2007 [19]

Figure 3 Fluidization in nature

Then the potential role of the third 30year period, if it really exists, could be to reach the essence in a higher sense. From scientific view point, the essence of fluidization phenomena should still lie in the force-deformation and force-[deformation rate] relationships. Among the issues the drag relationship for a variety of arrangements of particles of different sizes and shapes is the toughest and most significant. Another is to provide full description of particle-particle interactions in a way that it can be appointed to practical discrete particle simulation. There have been continuous challenges made on this matter but the big breakthrough is yet to come.

Now, where should we find new players? Corresponding to the wider perspective discussed above the new players could appear from different disciplines. But ‘necessity is the mother of invention’. I may not have to worry too much about it.

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