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## CURRENT INTERESTS IN FLUIDIZATION RESEARCH

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**Summary**

*Recently, interests in fluidization have been reinforced by the world-wide problems of energy costs and energy savings. Indeed fluidization presents a very interesting field of study in thermal properties which can be exploited to solve many different problems. This promotes the development of new researches in that field as well as those connected with the theoretical bases for pilot plant developments.*

*For gas-solid chemical reactions or catalytic reactions, the problems involved in flulidization are always acute. Bubbling is a complicated phenomenon that remains poorly known. The right approach for research in industry seems to be to study particular cases, to accumulate experimental evidence and to try to discover empirical rules.*

*Liquid fluidization is evidently much more simple than gas fluidization; bubbles are avoided. However, little is known on the subject which has not been extensively studied. This situation is apparently changing in the last few years. Most of the interest have been devoted to the fundamental study of mass transfer which are introduced in many industrial operations such as dissolution, crystallization, ion exchange, and adsorption.*

**Introduction**

Fluidization is a process of working with a granular solid and a fluid whose properties often present original characteristics that not only attract the attention of researchers, but also are capable of numerous practical exploitations. Scientific interest and industrial or economic interest are keeping pace together in this field. It is probably this conjunction that explains the diversity and the volume of research work effected in the domain of fluidization[1,2]. Mechanical operation of classes of solids, chemical reactions, heat transfer and mass transfer–all of these subjects have been studied and are still the object of attention of laboratories. Certainly we have no wish here to present a precise and exhaustive review of all this work. We are simply interested in presenting the actual situation of research, evolution since the International Congress on "Fluidization and its applications" which took place at Toulouse in October 1973[3] and the prospects for the future. In this analysis, we take into consideration the recent economic upheaval which has agitated all the world, particularly the rise in the cost of energy and raw materials. The objectives and the conditions of work have been reconsidered and research therefore cannot remain indifferent to this modification in the industrial sector that it serves.

Concerning fluidization, the recent worries about economics and raw materials expressed by various governments of industrialised countries, and particularly by the French government, have constituted a new impetus to the development of research work and have aroused a renewal of interest of industrialists in this process from which we may expect an elegant solution for many other actual problems.

We would like to develop some ideas that have interested us most in this domain, by grouping them in three items:

1. Fluidization and heat transfers
2. Fluidization and chemical reactors
3. Fluidization by liquid.

Some examples were selected from among themes of research developed in the laboratories of the Institute of Chemical Engineering in Toulouse[4,5].

*1. Fluidization and heat transfer*

Among the properties of the fluidization which the experts exploit, certainly the most remarkable are those related to thermal phenomena. We can state briefly three proposals. Firstly, heat transfer between the gas and solid particles is extremely rapid and the equilibrium between the two phases constituting the fluidized bed is generally very soon affected, for bed heights not exceeding a few centimetres. Secondly, a fluidized bed constitutes an almost perfectly isothermal surrounding. Finally, the thermal transfer between a fluidized bed and any wall in contact with it is much more intense than if the exchange occurred between the gas only or between a fixed bed alone.

These three properties have been known for many decades, although certain detailed mechanisms of the phenomena remain unraveled. Naturally, these phenomena have been exploited in diverse industrial operations. Nevertheless the inherent difficulties in the operation of all new technology have limited, in the context of low priced energy situation, the practical development in quite a lot of domains, and research was not thus stimulated.

The recent upheavals in the oil markets have changed this situation, starting a new impetus in industrial development and reactivating all levels of research, from the most speculative work relating to the conception and to the modelization of mechanisms, to the most adaptable studies of the settlement of new forms of exchangers and related technologies, and to developments of diverse applications.

We have to emphasize here that fluidization must naturally be envisaged every time operation works are concerned with a solid phase in a granular form. In addition, it is possible to utilize the fluidization in many other cases that do not involve solids directly, but in which we can introduce the caloproter annexes. In this way, it is possible to increase the efficiency and to diminish the volume of numerous apparatus dealing with one or many gaseous phases by intensifying artificially the mediocre properties of transport of gas through the utilization of suitably conceived fluidized beds.

The possible applications of this technique are considerable and diverse, ranging from the problems of drying, refreezing or heating of solids, to the recovery of calories from passing smoke by tempering of the gas. These applications have interested industrial sectors as varied as those from the traditional chemical industry, the food and agriculture industry, the nuclear industry (which could aim to replace traditional thermal circuits by fluidized circuits) and even the metallurgical industry (for hardening, chilling or treating thermally diverse pieces). We think then that this is a domain where expansion will be very important in the immediate future. In a very short term, the domains in the research sector will have carried out the establishment of semi-empirical correlations, permitting the provisional design of new apparatus, and the development of new technologies of exchangers.

One of first themes that the Institute of Chemical Engineering in Toulouse developed in collaboration with the Laboratory and Technique of Languedoc envisaged the intensification of heat transfer between a fluidized bed and a wall by the utilization of mechanical agitation apparatus[6, 7]. For example we started the necessary studies on the fluidized exchangers of the plate type which have already proved efficient for the transfer between liquids. This technology will permit the realization of compact and economical apparatus.

We would like to suggest that fluidization which has been utilized up to the present in the heavy chemical industry, will tend to enlarge its applications to other domains. A sector particularly attactive appears to be the food and agriculture industry, where the problems of handling and of treatment of solids are apparent. Specifically, a number of problems concerning the drying or thermal treatment of grains can be tackled effectively by fluidization. We take for example the drying of cereals, wheat, rice, coffee roasting or the handling and the mixing of diverse powders constituting ingredients of animal feeds. Therefore, these are a number of themes that could contribute to more development in fluidization.

## 2. *Fluidization and chemical reactors*

It is again the thermal properties of fluidization that are often utilized in industrial reactors for the treatment of solids by gas, or for reactions in the gaseous phase heterogeneously catalysed by a solid. In fact, a chemical transformation is generally carried out optimally at a precise temperature which is suitable for maintaining the best volume of the reactor; because of their isothermicity the fluidized beds are particularly well adapted for the resolution of this problem. Moreover, the intensity of transfers with all the wall in contact with the bed allows addition or withdrawal of heat at a high flux and facilitates the control of the operation.

We have to add to these advantages of the fluidizations, the possibility of organizing the circulation or handling of simple solids and of continuous operations. These advantages of the fluidized reactors, undeniably, are balanced in the field of the chemical reaction by the difficulty to conceive operations and the provisional calculation, for which, to our knowledge, there exists no precise and reliable method.

This situation stems from our poor knowledge of the bubbling phenomenon of a gas in the middle of the beds. We recall that bubbling is the phenomenon of the formation, at the base of fluidized beds, of a space almost empty of solid, similar to the appearance of a gas bubble in a liquid, which goes up through the bed, coalesces, enlarges and then breaks up at the surface.

This extremely complex phenomenon is difficult to treat theoretically as well as to observe experimentally. It has been the object of number of important works reported in the literature[7–10]. The progress in research in this domain is very important and considerable work still has to be established and modelized. Nevertheless the problem is so complex that it will be some time before sufficient knowledge is gained.

We also think that fundamental studies, absolutely indispensable for the realization of progress in the long term, will have to develop along a more semi-empirical character, and on the pilot scale, corresponding with the new processes which the industry can adapt and commercialize.

Thus we are satisfied with the double objective. First of all, we render an immediate service to the industry in their search for economy in raw material and energy. Next, we accumulate a large amount of various experimental results which may certainly constitute a solid basis for the formulation of a whole new theory.

Work in progress at the Institute of Chemical Engineering in Toulouse in the domain of chemical reaction also involves the attempt at tuning, for some special diverse cases, of fluidized apparatus to a sufficient performance that they would be of interest to the industry.

We quote two characteristic examples. The first concerns the catalytic oxidation, on fluidized catalyser, of butane by oxygen in the air, in the preparation of maleic anhydride[11]. The object of this work is not only in the development of the fluidization itself but also in the vaporization of butane, an abundant raw material which should be more effectively utilized. The second example is related to the depollution of the atmosphere, more particularly the elimination of sulfur dioxide by chemical adsorption on particles of copper oxide[12].

### 3. *Fluidization by liquids.*

Liquid fluidization constitutes a phenomenon less complex than that of gas fluidization. In effect, the bed obtained are much more regular and uniform, and the phenomenon of bubbling does not exist.

Of course, different bed structures correspond to different properties. In particular, the thermal characteristics are not as interesting as in the gaseous fluidization. Therefore, interest in the process stems from other characteristics and the domain of the practical application concerns the operation of a different nature.

The essential advantage of the process is linked to the suspension of solid by liquid which permits, on the one hand, the easy circulation of solid and the continuous operation and, on the other hand, to obtain in each fluidized bed a class of solid determined by its size or by species, often resulting in simple and efficient possibilities in the control of operation.

A rapid survey of the possibilities of the utilization of the process shows that the operations concerned are all accompanied by variations of composition. It can be, for example, the question of dissolution, crystallization, liquid-solid extraction, adsorption, ion exchanges, chemical reaction or electrochemistry. All these physico-chemical operations, more or less complex, possess their proper kinetic laws, but it appears clear that they operate indentically in the mass transfer step in the middle of liquid phase.

This is a theme of research of general interest, which deserves the priority of attention. The analysis of each operation that we have quoted ought to be the object of further work. The reality of the present research unfortunately does not correspond to the ideal situation that we have just imagined. In fact, only a few specialized laboratories in the domain of fluidization have been preoccupied or are being occupied by the problems concerning liquid. The result is that, in spite of the greater simplicity of the field, the progress of knowledge in the domain of the liquid fluidization is less satisfactory than the domain of gaseous fluidization. The information of a fundamental nature is scarce and the methods of provisional calculation are practically non-existent.

This situation constitutes a vicious circle because the absence of knowledge freezes every possibility of development in the industrial application. This lack of activity in the latter sector discourages in its turn all the initiatives in the research. The conjuncture of economy in energy and especially of raw materials ought to allow us to get out of this vicious circle. In fact, the various treatments of minerals by humid processes, for example, will have to be improved in order to permit the attainment of a higher extraction yields or to facilitate the treatment of poorer mineral ores. The advantages offered in this domain by the fluidization, which was not apparent in the period of relative abundance, will have to be reconsidered.

Therefore, we think that the need will appear and that the research should satisfy it within a reasonable period. The demands will be expressed at first at the level of the methods of provisional calculation and technologies of apparatus. But very rapidly, these themes of an adaptive nature will raise the problems which possess more speculative essence; in this domain, the priority would be concerned with the analysis of the fine properties of the liquid flow in the middle of the bed, average velocity, fluctuations around this average, and characteristics of turbulence.

Arising from this analysis, the Institute of Chemical Engineering in Toulouse orientates her work in two distinctive ways. For the utilization in a short or medium term, it searches the semi-empirical correlations representing the phenomenon of mass transfer between solid and liquid and sets up the methods for the provisional calculation of apparatus. For an amelioration in the longer term of scientific knowledge, the Institute of Chemical Engineering in Toulouse has initiated work in the domain of the study of the hydrodynamics in the utilization of anemometrical technique[7, 13].

## Conclusion

Fluidization is a new process whose utilization at the industrial stage has been in existence for less than thirty five years. After an initial spectacular development, came a period of stagnation during which the difficulties of development were compounded by the lack of reliability at the level of conception and/or the incidents of operations.

It seems to us that the time for renewal of effort is at hand. The considerable amount of research has permitted reasonable solutions, and moreover external economical constraints has necessitated the research for new solutions and the development of more sophisticated techniques.

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## บทคัดย่อ

ความสนใจเกี่ยวกับฟลูอิดไดเซชั่นมีมากขึ้นเป็นลำดับจนถึงขั้นที่จะนำไปแก้ปัญหาการลดปริมาณการใช้พลังงาน และการนำพลังงานไปใช้ประโยชน์ให้มากที่สุด โดยเฉพาะปัญหาเกี่ยวกับคุณสมบัติของความร้อน วิธีการนี้สามารถนำมาประยุกต์และแก้ปัญหาต่าง ๆ ได้อย่างดี มีการสนับสนุนให้ดำเนินการพัฒนางานวิจัยตั้งแต่งานทางทฤษฎี จนกระทั่งสามารถนำไปใช้กับเครื่องมือใหม่ ๆ ในอุตสาหกรรม

ปัญหาของก๊าซและของแข็งที่ทำปฏิกิริยากัน หรือปฏิกิริยาที่ต้องมีตัวเร่งจะสามารถแก้ได้ด้วยดีด้วยขบวนการฟลูอิดไดเซชั่นนี้ ถึงแม้ว่าความรู้เกี่ยวกับลักษณะการเกิดฟองก๊าซในหอทดลองยังมีน้อยก็ตาม งานวิจัยที่นำไปใช้ในโรงงานอุตสาหกรรมเฉพาะอย่าง บางครั้งสามารถนำผลการทดลองที่ได้มาผูกเข้าด้วยกันแล้วตั้งเป็นกฎง่าย ๆ ขึ้นได้

ฟลูอิดไดเซชั่นที่ใช้ของเหลวจะมีคุณสมบัติดีและง่ายกว่าใช้ก๊าซ เพราะไม่มีฟองเกิดขึ้น อย่างไรก็ตามความรู้ทางด้านนี้ยังมีน้อยอยู่ ความสนใจมีเพิ่มขึ้นเพียงเล็กน้อย ในระยะสองสามปีที่ผ่านมา งานวิจัยส่วนใหญ่มักเป็นการศึกษาทางพื้นฐานของการถ่ายเทของมวลสารซึ่งจะนำไปใช้ทำงานในโรงงานอุตสาหกรรม เช่น การละลาย การตกผลึก การถ่ายเทของอิออน การดูดซึมเป็นต้น