# FLUIDIZED BED TECHNOLOGY: IT'S CHALLENGES IN INDUSTRIAL APPLICATIONS

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**ABSTRACT**

After fluidized bed technology was first applied in the Winkler process for coal gasification in 1930's, then the development of fluidized bed technology growths very fast. In the recent years, fluidized bed technology has been applied in various industrial processes such as fluid catalytic cracking, gas-solid reaction, drying, particle classification and separation, dedusting, waste treatment, bioprocess, etc. The rapid permeation of fluidization technique in Malaysia in the production of chemicals, petroleum and petroleum product, medicine, foods, pharmaceuticals, nuclear, polymers, fertilizer, powder, plastics, metals from their ores and their separation, new fine and conventional materials as well as conservation of energy, and disposal of waste and environmental protection etc. has demonstrated its viability in present and future technology of our growing economic construction.

However, our expectation to improve the efficiency of the processes has created the need for fresh innovations of the equipment and processes involved, which need adequate understanding of fundamentals. This paper shows several applications of fluidized bed technology in industrial processes and explains the advantages and disadvantages of the process, which offers innovation touch to obtain better result.

**Key words**: Fluidized bed technology, Challenges, Application

## INTRODUCTION

Malaysia is endowed with rich mineral resources, which are generally characterized. However, by their complex nature and low mineral contents the exploration and production of the resources need special designed process to produce suitable products. Parallel to the development of industries in Malaysia, people have become more aware of its serious drawbacks, namely environmental problems. So far, almost all types of pollution abatement installations have just been added to the conventional processes, sacrificing energy and economical benefit.

The utilizations of the natural resources to produce some kinds of products need specific processes. One of the famous technologies, which have been widely used in the chemical processes, is fluidized bed technology. This technology involves fluidizing media and bed media in its operation. Several industrial processes have applied this technology due to its great advantages and little disadvantages.

## THE APPLICATIONS OF FLUIDIZED BED IN INDUSTRIAL PROCESSES

The applications of fluidized bed technology in industrial processes increase rapidly after the Winkler process for coal gasification in 1930's got a successful result [1]. The following fields represent the potentials of fluidized bed technology applications in industrial processes:

### Fluidized Bed Reactor

The earliest application of fluidized bed technology is in chemical reaction processes. The major types of reaction, which can be carried out using fluidized bed reactor, are: catalytic gas phase reaction, non-catalytic gas phase reaction, and gas-solid reaction [1]. The several problems associated with application of fluidized bed reactor are related to the needs of better gas-particle mixing and heat and mass transfer. The gas-solid mixing in the fluidized bed reactor is much more higher than both in the continuous stirred tank reactor and rotary kiln. The difficulties in solids removal from and addition to pressurized vessel in gas phase polymerization, fluid bed process for high density and easily

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agglomerating fine powder, preparation of amorphous silica and its products are the serious problems in fluidized bed reactor. While the application of internals for multi stages fluidized bed and for fast fluidization is expected can achieve better mixing pattern in the fluidized bed reactor. Then, the arrangement of novel reactor regenerator-configurations is also expected can reduce the catalyst deactivation and to carry out purification and separation of the catalyst and products [2].

**Fluidized Bed Calcinations**

The fluidized bed calcinations process may be considered as a well-mixed system, which consists of solid flow and mixing system [1]. The process of calcinations is a multi compartment process at high temperature and designed for endothermic reaction. To carry out the endothermic reaction, fuel is needed to supply the energy [11]. The compartment is designed to ensure that energy consumption can be minimized, while the energy recovery can be possibly done. Particle separation by entrainment and elutriation, and cyclone are used to separate the entrained particle from the gas stream.

**Fluidized Bed Dryer**

Tiny particle drying has become increasingly important in the drying process of raw materials, intermediates, and finished product. Fluidized bed dryer for chemicals, polymers, fertilizer and granular materials is now well established. Fluidized bed dryer is also considerable for pharmaceutical, food and chemical process industries. Batch fluidized bed drying of paddy has been reported and operated in Thailand. The fluidized bed dryer consists of a well-mixed fluidized bed dryer and a plug flow fluidized bed dryer. As the collaboration of the two types of fluidized bed dryer, installation cost, space requirement, and heat consumption are reduced very much [3]. When several types of granular are very difficult to dry in a stationary fluidized bed dryer, thus a vibrated fluidized bed dryer is applied. Vibrated fluidized bed dryer is used extensively in food and dairy industries such as milk, whey, cocoa, tealeaves, coffee, and some particulate materials such as formic crystal and styrene polymers. Nowadays, the drying process is also conducted by the collaboration between fluidized bed concepts and microwave heating. That new drying process offers better performance than the formers due to its liability to dry the sensitive materials to the high temperature.

**Fluidized Bed Incinerator**

Following the new government environmental regulation in the limitation and prohibition about the landfill and sea dumping of sludge waste, then the application of fluidized bed incineration is an effective way to substitute the conventional method of sludge waste disposal. The fluidized bed incineration of combustible gas effluents, industrial wastewater sludge and municipal solid wastes is generally conducted simultaneously with recovery of heat energy. The intimate mixing between the waste and the fluidizing gas in the incinerator ensures that combustion of the waste is completed within the media bed. Several types of fluidized bed incinerators have been developed such as rotating fluidized bed incinerator that has higher combustion intensity, a higher turndown ratio, and a shorter start up time [4] and Stoker type incinerator [5] etc. However, the common fluidized bed incinerator has several limitations. They produce the noxious odors flue gas and cannot handle large sized solid wastes and hard to grid materials. Thus, the bulky solids must be shredded into small uniform size before being fed into incinerator. This process of waste pretreatment is both costly and troublesome. Therefore, a study about development and design of fluidized bed incinerator to suit all size of wastes is a must. The study will include the solid-gas-liquid mixing phenomena, air pollution control, and optimization of combustion system.

**Fluidized Bed Combustor**

When applied to the environmental problems, fluidized beds demonstrate the advantages in high throughput, low-pressure drop, and good inter-phase contacting [1]. Fluidized bed combustor is an alternative combustion system suitable for low-grade fuel (peat, coal, anthracite, lignite, char coal and oil shale). Since coal combustion releases considerable amount of sulfuric gas, which is environmentally hazardous, conventional technology is commonly not liable of reducing the sulfur related to pollution problems. Since it is a trend that every country wants to limit further emission of solid and gaseous pollutants from coal and oil fired power generator. Fluidized bed combustor of coal is a good choice to solve this problem. The growing shortage and increasing cost of high-grade fossil fuel, has forced engineers to utilize the fluidized bed combustor.

Coal combustion is very complex and involves interplay of chemical reaction with heat and mass transfer. The process is mainly involves the transfer of gas from and in to the particle surface and reactions take place at the particle surface. Coal combustion produces ash in the form of small particles that can be elutriated in the exhausted gas. Cyclones are used to remove the ash particles from gas stream. Large ash particles, which remain in the bed act as bed inert material. Its simplicity of design, versatile, stable continuous combustion, uniform temperature and low air pollution emissions are the advantages of the fluidized bed combustor [6-9]. While the disadvantages of the fluidized bed combustor such as its difficulties in solid handling, SOx and NOx emission, equalization of coal feed, low carbon conversion, erosion problems, and the particle elutriation that causes high level dust carryover in the flue gas and losses of unburned materials are always encountered in many fluidized bed combustor operations [1].

**Fluidized Bed Granulator And Coater**

Spray granulation is a simultaneous drying and particle forming processes, which is carried out in a fluidized bed by spraying a liquid feed in the form of solution, suspension or melt into the fluidized layer of already dried or partially particles. The fluidizing medium is the drying air, and the fluid bed is normally kept under vigorous fluidization [10]. The granulation process involves reaction, mixing, and agglomeration, coating, drying and cooling. Fluidized bed granulator especially batch wise has been widely used in the pharmaceutical industries, where there is a requirement for non-dusty, well-defined and strong granulation for tabletting process. The coating process has also been applied in the production of fertilizers, salt and to solidify the radioactive wastes [11]. The granulation process has also been applied on the large industrial scale in relatively few cases, e.g. drying of azoic dye, combustion of spent liquor from a sulfite pulp mill, drying of manganese sulfate, and the fluid cooking process. In this process, when the liquid feed rate is high enough, the coated particles may collide before the solution completely dry and causing the particles agglomerates. At the lower coating flow rates and higher fluidizing velocities; the particles may undergo an "onion ring" growth [12]. Additional factors that affect the transition from layered growth to agglomeration are the feed solution make up, the excess fluidizing air velocity and the particle size [13]. The high velocity air atomizing causes particle attrition, which is used to control the bed particle size. If no means of controlling the particle size were available, the particle would grow until they become too large to be fluidized and the fluidized bed would become in operable [14].

**Fluidized Bed Bioreactor**

Fluidized Bed technology in biological treatment process can be regarded as combination between the biological filtration process and of activated sludge process. Fluidized bed bioreactors are also commonly applied in the treatment of wastewater containing organic pollutants, especially for the use in petrochemical industries. While bio-film reactors are also implemented in various biotechnological process (e.g. fermentation, production of enzymes, production of primary and secondary metabolites, production of antibiotics and bioconversion [15-16]. However, with the exception of wastewater treatment processes, the application of bio-film reactors at full industrial scale is scarce [16]. Biomass is grown on the particle surface for the growth of attached microorganism. The bed of particles instead of being fixed is kept in fluidization state in the vessel by the injection of air or oxygen. The degree of expansion is dependent on the type of biological reaction. This is due to the fact that biomass grown on the media and this decreasing the overall density of the particles. As a result, higher yielding system would have higher degree of expansion. The biomass concentrations are relatively high, thus reducing the size of plant required to treat a given amount of waste. The other advantages of fluidized particulate bioreactors are: high terminal settling velocity of solids, leading to possible elimination of external clarification stages, high reactor concentration, high bio-film surface area, high biomass concentration and mass transfer area result in high conversion capacities, compact reactor with small area requirement and high biomass age and minimization of excess sludge production [17-18]. Whereas the disadvantages of this technique are: the difficulties in controlling bio-film thickness, bio-film formation on carriers poses problems, overgrowth of bio-film tends to elutriate of particles, liquid distributors for fluidized system are costly for large scale reactors and pose problems with respect to clogging and uniform fluidization [19].

**Fluidized Bed Roaster and Fluidized Bed Carburizing**

Fluidized Bed roaster is generally used in metal and mineral industries. Roasting processes are all characterized by not too exothermic oxidation reaction. Thus, the process needs energy supply. A very good gas-solid mixing is strongly needed in this process. Fluidized bed operation has shown its capability to ensure good gas-solid mixing. However, the optimization of energy utilization in mineral roasting has been forgotten in many years due to the abundant source of energy in the world. Direct reduction of fined iron ore concentrate suited to our energy structure, particularly direct use of solid reductants without addition of intermediate gas will be the simpler process over the conventional one. Corrosion and pollution problems associated with roasting with halogen, especially in the development of new equipment and materials of construction. Magnetizing of roasting of low-grade iron ores is very competitive with high intensity magnetic dressing. Roasting of alunite for simultaneous utilization of potassium, aluminium and sulfur, especially with direct injection of fuel into the fluidized solid is one of good improvement in fluidized bed roaster application [2].

The carburizing process can be performed in atmosphere furnaces, vacuum furnaces, plasma furnaces, fluidized bed and salt baths. As the plasma and vacuum carburizing are costly, while salt baths carburizing is not good in ecological aspect, therefore the development of the fluidized bed carburizing has represented as new goal for the heat treatment shops. Generally, the discussions on the carbon transfer in fluidized bed have to consider the following: the carburizing reactions and the equilibrium between gaseous atmosphere and steel surface and in the inside of gaseous atmosphere, the deviation from the equilibrium conditions due to the carburizing kinetics, the carbons transfer mechanism from the gaseous atmosphere at the steel surface and the carburized layer increasing through the carbon diffusion. To explain the carbon transfer mechanism from the gaseous atmosphere to the steel surface in the fluidized bed carburizing, it is necessary to take into account the main reactions involved in this process as follows:

$$CH_4 = C + 2H_2 \quad (1)$$

$$CO + H_2 = C + H_2O \quad (2)$$

$$2CO = C + CO_2 \quad (3)$$

Carbon transfer coefficient is generally twice than the carbon transfer coefficient obtained in conventional carburizing for the same atmosphere due to high chemical reaction rates and the specific carbon transfer mechanism. The fluidized bed atmosphere can be achieved insitu in the furnace or can be supplied from generator [20]. In the first stage of carburizing, the boost phase, the carbon potential is held over the soot limit and in the second stage, the diffusion phase, which takes place in nitrogen, the required surface carbon level and the case depth are obtained. The switching between the two stages of the fluidized bed carburizing can be easily achieved due to the specific motion of the carburizing media, which allows the rapid changing of the carbon potential [21]. Also, for these reasons, the carburizing rates in fluidized bed furnace is 30% faster than in conventional atmosphere carburizing in the range of 950-975°C.The advantages of the fluidized bed carburizing process are: no environmental pollution, clean work piece surface, short carburizing time, possibility to control the atmosphere, good temperature uniformity and low operating costs.

## DISCUSSION

The fundamental feature of any chemical reactors with gas-solid system is almost always determined by selecting both contacting mode and the mode of supplying thermal energy [1]. Then, the study to enhance the fluidized bed reactors performance will comprise the fundamental research to study about physical and chemical changes in the reactor system, selection the contacting mode between gas and solid to supply thermal energy, flow pattern of both gas and solid for scale up and mathematical simulation as guide lines for scale up problems. The two factors that determine the specific features of a gas–solid reactor system are the reaction condition for getting the desirable products such as temperature, pressure and contact times for both gas and solid stream and the contacting mode between gas and solid phases. The second term is important in connection with the energy and environmental problems. The method to supply the energy to the reaction zone also determines the heat transfer efficiency. Indirect heating using furnace firing of conventional fuels, utilization the heat released from exothermic reactions, heat carriers and electric heating are the choices of heating methods [1]. Nevertheless, generate electric energy by burning petroleum or coal to supply the energy for large-scale system to be uneconomical for the near future. The combination of contacting mode and the method for heat supply gives a specific feature of gas-solid reactor system and should be used in suitable reactions.

Calcinations process requires a great amount of energy [11]. It means that the heat required for this process is always supplied by direct heat transfer from flue gas at a high temperature, and then the process corresponds to the gaseous heat carrier system. Because of this reason, the main feature of such any process can be specialized by the contacting mode between the solid material and the stream of flue gas. For reduction of fuel consumption in the calcinations process, heat should be recovered from both the flue gas and the calcined material. The previous calcinations systems were carried out in the fixed bed reactors. However, it was found theoretically, that combustion zone could hardly have reached the central portion of the bed when the flue gas was flown in to the bed horizontally from the sidewall, resulting incomplete calcinations of the portion. Based on the Kunii [1] suggestion, depending on the size of the material, some contacting mode are better used in the effort of heat recovery in the reactor system such as vertical moving bed, horizontal or inclined moving bed and pneumatic conveying bed, while fluidized bed is the best choice. The suggestion can be accepted due to its performance in handling of heat and mass transfer.

In the carburizing process, the carbon transfer involves the following steps [21]: reaction in the homogeneous phase, transfer of the molecules, which contain carbon through the carburizing atmosphere to the steel surface, diffusion of the molecules, which contain carbon through the Nernst layer, reaction in the steel surface through the gaseous molecules decomposition at the gaseous atmosphere/steel surface interface, the carbon atom adsorption in the steel surface and their dissolution and the carbon diffusion in the steel through the metallic matrix and around the grain boundaries inside the steel. Considering, the transport and diffusion of the gaseous elements, which transfer carbon to the steel surface are going rapidly, the reaction at the phase boundary-the molecule decomposition at the surface is the controlling stage for the carbon transfer rate in the steel surface. Taking into account that in fluidized bed, carburizing takes place in the fluidized bed media then the heat transfer between the bed media and the gas reactants become has a significant role to achieve good carburization. In addition, to get good heat transfer, good mixing between the two phases is needed.

Drying is a major operation to aid the conservation of products in the agro-food industries and other dry solid products [3]. The mechanisms, which occur in the course of drying, are complex to the extent that the transfer of heat and mass are closely intertwined. In addition, the wide variety of materials to be treated and the complexity of their nature are also determining the suitable drying method. Temperature is the most significant factor in drying process. In the drying process, increasing the temperature allows the rate of heat transfer to the product to be increased, but also favors the migration of water towards the periphery of the material by the biasing effect, which exerted on the parameter such as diffusivity and viscosity while water content is still quite high. While the airflow rate, air humidity and the particle size give less significant effect to the drying system. In the application of fluidized drying, it is different drying performance between batch and continuous operation. The difference in performance between the batch and continuous operation is due to the distribution in particle residence times. The combination between fluidized bed and microwave heating is carried out to achieve better performance of the drying process. The pressure distribution in the particle may have significant effect on the microwave-fluidized bed drying process, while the microwave power plays an important role in affecting the magnitude as well as the distribution of moisture, temperature, and pressure in the wet particle. The microwave power decreases in the drying process, and some microwave power absorbed by the particle s can be lost to the fluidizing gas [22]. Theoretically, when fixed microwave heating rate is maintained, there exists a critical loading to the fluidized bed, beyond which the drying time is constant. The particle temperature can be higher than the gas temperature; in this case high heat transfer coefficient of the fluidized bed becomes the disadvantages in the microwave-fluidized bed drying process. Finally, the heat will be absorbed by the fluidizing gas and moves out from the system.

The granulation process in fluidized bed is a complex process, because there are several parameters that can give significant effects. Therefore knowledge about the effects of those parameters to the granulation process is important to control the process. The parameters that can influence granule properties can be classified as apparatus, process, or product variables .The geometry of the equipment, distribution grid, filter mechanism, and nozzle spray characteristics are included in the apparatus parameters. While, the product parameters are related to the formulation used .The process parameters are related to the procedure used for the preparation of the granules, i.e. inlet air flow rate, inlet air temperature and humidity, spray rate of the binder solution, nozzle air pressure, spraying time interval, etc. [23]. Schaefer and Worts [24] have demonstrated that the granule size is affected by the droplet size of the binder solution and therefore by the nozzle air pressure. Geometrically, the larger diameter of the nozzle, the larger the droplet size, and thus larger granules will be obtained. The Nozzle air cap position also determines the angle in which the binder solution is sprayed on the fluidized powder bed by changing the airflow rate through the nozzle. Regard to the granulation mechanism, the apparatus and the process parameters become effective when one considers scaling-up the granulation process.

The fluidized bed incinerator and fluidized bed combustor are very similar. The serious problems of the two systems are difficulties in solid handling, which affects in the feeding system and the hazardous gas released from those systems. Hence, the recent researches are stressed to solve the two problems. Commonly, those researches are not only purposed to the environmental view, but also aimed to recover the energy contained in the material and use the energy to produce electricity. Diego, et al., reported that the NOx emission increased and the $N_2O$ emission decreased when the temperature increased [25-26]. In Addition, when the excess air factor in the combustion chamber increased from 5 to 30 % the NOx emission increased significantly and the $N_2O$ emission increased two times. This fact happened due to the high conversion of volatiles ($NH_3$ and specially HCN) to $N_2O$. The combustion rate (the proportion of carbon, which is emitted as CO and $CO_2$) decreases as linear function of the amount of the coal added in coal combustion. In the combustion of municipal solid waste, which contains large amount of chlorine several studies have shown that HCl formation can inhibit the CO oxidation [26]. Nowadays, limestone is added to the fluidized bed combustor to reduce SO2 concentration and to increase the free CaO in the combustor. As has been studied by Diego, et al., the increased presence of free CaO caused the NOx emission to increase and the $N_2O$ emission to decrease [25].

Microbial cell aggregates, such as flocs and bio-films, are great of interest in biotechnology [19]. They offer advantages, with respect to the suspended single cells in downing stream processing by facilitating cell-liquid separation by sedimentation or filtration. Due to the smaller size (typically between 10 and 150 μm) and higher porosity, diffusional transport is generally faster in flocs than in granules or bio-films. On the other hand, bio-films presents better settling properties than flocs and can be easily retained in bioreactors. When aerobic treatment is needed in the bio-film fluidized bed, and then the reactor is aerated by recirculating the liquid from the reactor to an oxygenator where air, or possible oxygen is bubbled [27]. To overcome problems related to the high recirculation rates, needed when there is a high oxygen demand in the reactor, then the reactor must be aerated directly as three phase bio-film fluidized bed reactor.

From the review above, it can be seen that beside the advantages of fluidized bed applications in industrial processes, fluidized beds still have several limitations. Hence, the researches related to the fluidized bed development are still widely opened.

## CONCLUSION

Refer to the explanation above it can be concluded that the challenges of fluidized bed applications in industrial sectors are very competitive. However, it is also important to improve fluidized bed performance in the proper applications to achieve higher productivity and reduce its disadvantages by doing many researches related to the processes. While, the conventional fluidized bed applications can be continued with the addition of precise modifications. Another challenge in fluidized bed application is how to create a new type of fluidized bed, which its concepts can be used in simplifying several conventional processes become a single system but covers the related simultaneous processes.

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