A REVIEW PAPER ON MATHEMATICAL MODELLING AND SIMULATION OF FLUDIZED BED DRYING SYSTEM

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ABSTRACT: This is the study on MATHEMATICAL MODELLING AND SIMULATION OF ELECTRON FIRED FLUDIZED BED DRYING SYSTEM, in term of electric arc heating, resistance heating and static electrical energy. FLUDIZED BED DRYING System has been used since long time for drying grains and other types of solid. Drying process is commonly found in agriculture, chemical, mineral, ceramic industries etc. To remove moisture content from materialsfluidized drying system is commonly used. This motivation for FLUDIZED BED was driven by earlier studies that,it consumes a large portion of overall energy consumption and its operating cost is also large.In this study both experimental and theoretical approaches are used in simulation of electron and mathematical modelling. In this study introduced new dimension for mathematical formulation to represent the work of electrons. The inlet air temperature affects on the drying rate of the grains. By this study decrease per unit energy cost as well as drying rate of grains will increase.

Keywords: Fluidised, Electron fire, optimisation, modelling.

[1] Introduction

In many industries like pulp and paper industry, textile industry etc, drying of material and different type of solids has been done. It consumes a large amount of total energy used in different type of processes. For a single dryer the cost of energy is more than half of overall cost. In this process latent heat of vaporization requires to evaporate moisture from materials. If we consider the cost per unit, it is also important to keep eyes on the rate of energy consumption in any drying process.

After these earlier studies and investigation drying is still very complex process to be understood. In this study, it is difficult to get accurate mathematical description of the phenomenon. Study with the help of mathematical modelling and numerical simulation is very helpful in solving drying physics.Further drying technology should be cost effective and efficient for this introduced new method, strategies and optimization of system as well.

[2] Motivation and Problem statement

Research on fluidized bed dryers has focused primarily on the use of pressure fluctuation analysis, namely the S-statistic, as a tool for monitoring the drying process.

However, limited attention has been given to understanding the hydrodynamics associated with fluidized bed dryers, namely the influence of moisture on the fluidization behaviour. To complement basic understanding, as well as to get a better overall understanding of fluidized bed drying hydrodynamics, design features of fluidized beds are also important to consider. Other than operating parameters such as bed loading and superficial gas velocity, distributor design as well as vessel geometry have an impact on the hydrodynamics of drying. With this wide variety of hydrodynamic studies regarding fluidized bed drying, monitoring of drying processes using the S-statistic, or any other techniques, will become more meaningful.

[3] Survey of earlier work

The history of fluidization began in 1922 with Winkler's patent of a fluidized bed process for coal gasification which was used for the production of synthesis gasScattered study to early observations of what is known today is fluidization can be found in published literature as far back on 1878.

In **1940s** the fluidized solid process was commercialized on a massive scale in the petroleum industry to effect intimate contact between the catalyst and hot vapours in the cracking of heavy hydrocarbons to fuel oil.

The concept of fluidized solids actually arose in the field of catalytic cracking process. The standard oil development company has a lot of contribution in the field of fluidization then **Prof. W.K Lewis and E.R Gilliland** carried out independent research on flow properties of powdered solids suspended in gases and developed the concept of fluid bed**.** The first commercial plant using the fluid solids technique principle was put into operation in the year **1930** for no pharmaceutical application but the process was first used for pharmaceutical application in the year 1960 by **Wurster .** The coating of tablets by spraying the coating solution into a bed of tablets suspended in a stream of warm air was invented by **Dale Wurster** whose first patent for the method was filed in **1953.** Granulation of powder in a fluidized bed carried out in **1960** by **Wurster** . Then the **1980s** have seen an **explosion in the research, application and commercialization of fluid bed process**.

In 1996 **'Vanecek'**worked in design procedure for fluidized bed dryers:

They proposed a design procedure for fluidised bed dryer based on heat and mass balance of the whole apparatus. Actually the fluidized bed has been treated as a homogenous system, without considering bubbles, and its nitration with bed .

In 1980 **'Hoebink and Rietema'** development a model for fluidized bed drying:They developed a model for fluidised bed drying and described heat and mass transfer between the dense phase, the cloud, and the bubbles with the assumption of no diffusion limitation inside the solids. They described the moisture transport between particles and gas with single and constant and overall mass transfer coefficient which is useful for constant rate drying. This was first model and second model, **Hoebink and Rietema** , extended the first model to include a more general case where due to a several diffusion limitation of the particles, the concept of a constant mass transfer coefficient was no longer adequate to describe the moisture transport of solids.

Olazer observedfive flow regimes: fixed bed, partially fluidized bed, spouted bed, transition regimefrom spouted bed to jet spouted bed and jet spouted bed. The hydrodynamiccharacteristics for these five regimes are presented by empirical correlations

Thedifficulty in predicting the hydrodynamics of fluidization from the theory of **Pengand Fan** possibly lies in the fact that the inlet diameter for the conical spouted bed isless than that of the bed bottom. The same approach by Peng and Fan has beenadopted by **Gelperin and Nishi** for the incipient fluidization of gas–solidconical beds.The model developed by Shiis based on Ergun's equation andneglects friction between the particles and the wall. **Biswal**developed theoretical models, for minimum fluidization velocity and pressure dropin a packed bed of spherical particles for gas–solid systems in conical vessels.Due to the angled walls, random and unrestricted particle movement occursin a tapered bed with reduced back mixing.

Olazer compared their experimental results with that calculated using the models developed by Gelperin and Gorshtein and Mukhlenov for maximum pressure drop and found thatthe predictions were not very accurate. They therefore proposed a modifiedequation for calculation of maximum pressure drop.

Later, **Peng and Fan** madean in-depth study of the hydrodynamic characteristics of solid–liquid fluidization ina tapered bed and derived theoretical models for the prediction of minimumfluidization velocity and maximum pressure drop, based on the dynamic balance offorces exerted on the particle. The experiments were however carried out forspherical particles only.

Jing and Shan developed models forgas–solid conical fluidized beds for spherical coarse and fine particles based onthe **Peng and Fan** models but neglected the pressure drop due to the kinetic changein the bed.

Depypere have carried out studies in a tapered fluidizedbed reactor and proposed empirical models for determination of expanded bedheight by using static pressure and wall surface temperature measurements.

Levey 1960 have successfully used tapered beds in chemicalreactions.

Peng and Fan [1997] have mentioned that the beds could be used forbiochemical reactions and roasting of sulfide ores.

Kumar [1981] andYogesh Chandra and JagannathRao [1981] have investigated the hydro dynamics of gas solid fluidization in tapered vessels using single size particles.Tapered fluidized beds have many attractive features, among whichare their capabilities for handling particles with different sizes and properties

(Scott and Hancher, 1976; Ishii 1977) and for achieving extensive particlemixing (Babu 1973), These beds have been widely applied in variousprocesses including biological treatment of wastewater, immobilized biofilm
reaction, incineration of waste materials, coating nuclear fuel particles, crystallization, coal gasification and liquefaction, and roasting sulfide ores.
Interestingly, industrial fluidized beds are, more often than not, fabricated withtapered sections at the bottom.Nevertheless, fundamental understanding of the behavior of taperedfluidized beds appears to lag far behind their applications. Some of the previousinvestigations include studies on pressure drop of fixed and fluidized beds intapered vessels (Koloini and Farkas, 1973; Biswal 1984), flow regimes,incipient condition of fluidization, voidage distribution and bed expansion (Hsu,1978), and particle mixing (Ridgway, 1965 Maruyama and Sato, (199l). Afluidized bed is formed when the particles in the bed are in dynamic equilibrium;the fluid drag force and the buoyancy force are exerted in the upward directionagainst the gravitational force, which pulls the particles downward (Wilhelm andKwauk, 1948; Davidson and Harrison, 1971). This drag force is constant at anyposition of a columnar bed of uniform particles; however, it decreases in the
upward direction in a tapered bed accompanied by the reduction in the superficialvelocity of the fluid.Thus, the particles at the lower part of the bed will first be fluidized uponan increase in the flow rate: in contrast, those at the upper part of the bed remainstatic. This phenomenon of partial fluidization is peculiar to the tapered fluidizedbed. Relatively little has appeared in the open literature on hydrodynamiccharacteristics of tapered fluidized beds; the majority of what has been publisheddeals with flow regimes and incipient condition of fluidization.
Toyohara andKawamura (1989) have reported the flow regime of partial fluidization in a gas solidtapered bed. Descriptions have been given in Kwauk's monograph (1993) on thechange of the flow regime in a gas-solid tapered bed.The incipient condition of fluidization in a tapered bed can be predictedbased on the dynamic balance of forces exerted on the particle bed. Thisapproach was adopted by Gelperin et al. (1960) and Nishi (1979) for gas-solidtapered beds, and Shi et al. (1984) for liquid-solid tapered beds. Nevertheless, noneof these works took into account the phenomenon of partial fluidization inpredicting the incipient condition of fluidization and the concomitant, maximumpressure drop.

Fluidization in tapered beds have found wide applicability in manyindustrial processes such as, waste water treatment **(Scott and Hancher,1976),** coating of nuclear fuel particles, crystallization, coal gasification andliquification and roasting of sulfide ores (Peng and Fan, 1997), coating of foodpowder particles (Depypere et al., 2005), etc. Tapered fluidized beds are useful forfluidization of materials with wide particle size distribution and also forexothermic reactions. It can be operated smoothly without any instability i.e. withless pressure fluctuations (Ridgway, 1965) and also for extensive particle mixing(Babu et al. 1973, Maruyama and Sato, 1991). Various techniques includingintroduction of baffles, operation in multistage unit and imparting vibrationshave been advocated from time to time to tackle slugging problem inconventional bed. Introduction of tapered bed instead of a conventionalcylindrical one is an alternative technique in gas-solid fluidization to tackle suchproblem. Better solid fluid mixing and improved quality of fluidization can beachieved in a tapered bed.The gradual decrease in superficial fluid mass velocity due to increasein the cross-sectional area in the upward direction necessitates the use ofcontinuously decreasing size particles for smooth and stable operation of such afluidizer. Due to angled wall, random and unrestricted particle movementoccurs in tapered bed thereby reducing back mixing (Singh et al, 1992).Although some information for liquid-solid system in tapered bed is available, verylittle work related to gas-solid fluidization in tapered bed is available. In spite ofits advantages and usefulness not much work has been reported in literature forunderstanding certain important characteristics, especially fluctuation ratio of thebed. Some of the previous investigations include fixed bed pressure dropcalculations (Koloini and Farkas, 1973), flow regimes, incipient conditionof fluidization, voidage distribution and bed expansion calculations (Hsu et al, 1978).

Maruyama and Koyanagi (1993) have proposed analytical methods to predict the bed expansion and pressure drop in tapered fluidizedbed. Depypere et al (2005) have carried out studies in a tapered fluidized bedreactor and proposed a model for expanded bed height by the use of static pressureand wall surface temperature measurement.

'Yashwant Kumar and Seema. A. Belorkar' studied fluidized bed system for drying of Fruits and Vegetables, this paper reviewsthe various fruits and vegetables dried in the fluidized bed dryer and their retention ofsensory attributes in the dried products. This review states that fluidized bed drying indeedhas proved better compare to conventional drying (i.e. tray/cabinet drying) in respect todrying time of fruits and vegetables.

'**Doyce Tesoro-Martinez, Tomas U. GanironJr and Harold S.' Studied Fluidized Bed System in Solid Waste Management,** this has stimulated the development of advanced combustion, gasification, drying and or cooling of solid particles utilizing the fluidize bed technology The ability of fluidized bed to burn a wide variety of fuels, while meeting strict emission-control regulations, makes them an ideal choice for burning such fuels as high-sulphur coal, lignite, peat, oil, sludge, petroleum coke, gas and wastes. The fluidized bed technology is presented to inform the public about the important applications which can be utilized in dealing with our solid waste disposal problems under environmental restrictions and possible integration of this topic in the power plant design course.

'Christopher Tremblay and Dongmei Zhou' studied Efficient drying Parameters for Bed Dryers. The main aim for this present work is to prove that higher efficiencies can be achieved when the allotted drying time is considered as a parameter of the drying cycle. The paper investigates how to theoretically calculate the most efficient drying parameters for wheat based on the ambient conditions and allotted drying time. Drying in the constant and falling rates is discussed through mathematical models developed for each drying period. Drying air temperatures between 290 and 370 Kelvin, and drying air velocities between 0.3 and 5.3 meters per second are explored. The wheat is dried from a moisture content of 0.22 kilograms of water per kilograms of dry basis to a moisture ratio of 0.05. Energy and energy efficiencies are utilized as a determining factor for most efficient drying parameters. The results prove that the dryer is most efficient when the dryer runs at 370 Kelvin and 0.3 meters per second when the allotted drying time is less than 21.7 hours. An allotted drying time between 21.7 and 25.4 hours would require a drying air temperature between 290 and 293 Kelvin, and a drying air velocity of 0.3 meters per second. If the allotted drying time is greater than 25.4 hours, the ambient drying air temperature is most efficient due to no energy input. Results from mathematical models are compared to experimental results and it shows a good correlation with an average percent error of 5.9 percent.

'Oluleye, A. E., Ogungbemi, A .A. and Anyaeche' worked on Design and Fabrication of a low cost Fluidised Bed Reactor, this work therefore is an attempt to develop a simple low cost drying bed that can lead to reduced dryingtime. The fluidized bed designed and fabricated in this work consists of the drying column, fluidized plate,the inlet and outlet unit, the heating unit and the fan. The evaluation considered the drying time andtemperature in achieving quality. The drying efficiency and the amount of moisture reduced per time andwere investigated using rice and wheat with moisture contents of 23% and 33% respectively. The dryer hasshorter drying times and efficiencies of 89% and 90% for rice and wheat respectively.

'Edward K. Levy, Hugo S. Caram, Zheng Yao, Zhang Wei and NenadSarunac' studied Kinetics of coal drying in bubbling fluidized beds, this paper describes laboratory experiments, to determine the kinetics of coal drying in abubbling fluidized bed, and a simple theoretical model of coal drying. The experiments wereperformed with coal which had been crushed to minus 6 mm and fluidized with air withtemperatures ranging up to 66°C and with velocities of 0.9 to 1.7 m/s. In-bed electrical heaters,used to simulate an in-bed tube bundle, provided additional thermal energy for drying. Theexperiments determined the effects of superficial air velocity, drying temperature and inlet airhumidity level on rate of drying.A theoretical model of the drying process was developed in which the air and coalparticles are assumed to be at the same temperature and the air–water vapour mixture leaving thebed at the free surface is in equilibrium with the local values of particle moisture. This model isin good agreement with laboratory data, showing that for this application, the drying rates do notdepend on fluidized bed bubble behaviour or on particle- gas contact, but are controlled by in-bedheat transfer, flow rate, moisture content and temperature of the feed air, and the equilibriummoisture content of the coal.

'BabitaSoren' studied on drying kinetics using fluidized bed dryer, Some physical characteristics of different vegetables were determined as a function of moisture content. Parameters like time of drying, temperature of air, flow velocity of air and material to be dried were varied and the drying rates were determined. The effects of different parameters like temperature, time and velocity on drying kinetics were determined. Critical moisture content was also determined. The drying kinetics of vegetables was thus obtained from these data by considering the different experimental conditions. Effect of diffusivity also observed.

'Okoronkwoc.a, nwufo, o.c, nwaigwek.n, ogueken.v, and anyanwue.e' have done Experimental Evaluation of A Fluidized Bed Dryer Performance, the drying experiments were carried out according to the following parameters: initial moisture content of the material (High and Low), drying time and various optimum temperatures. The results obtained show that it took a total of 150minutes with an optimum temperature of 60oC to reduce the moisture content of the cassava and yam from 75.4%(w.b) to the equilibrium moisture content of 11% which is suitable for storage and preservation while maintaining the external conditions. While the optimum temperature that gives faster drying time for maize was 400C. Similarly, a preliminary sun drying experiment was carried out to ascertain the drying time of the cassava and yam chips. It was observed that in the case of sun drying of cassava, it takes a total of 72hrs with an average ambient temperature of 30oC to reduce the moisture content from 75.4 % (w.b) to the equilibrium moisture content of 11 % (w.b). Similarly, the effect of temperature at 300C on the drying curves for the maize shows that the value of the constant rate period of the experiment was smaller than the value obtained at the temperatures of 350C and 400C respectively. The drying rate of products below their optimal temperature was affected by the lower rate of moisture removal and the equilibrium moisture content by mass was high. While drying at temperatures above the optimum temperature, ultimately may cause the thermal degradation of the products been dried. This could be in form of physical defects, such as, decoration, cracking, shrinking and non-uniform drying. From the drying kinetic curves and visual observations during the experiments, it could be concluded that the fluidized bed dryer is an alternative for the processing of cohesive solids that preserve the final quality of the dry solids.

'A. Karbassi, Z. Mehdizadeh' studied Drying Rough Rice in a Fluidized Bed Dryer. The objective of this study was to examine the effects of the fluidized-bed drying methodon the final quality of two varieties of Iranian rice, medium- and long grain. The resultswere compared to that of paddy drying using a traditional method. Rough rice wastreated in the fluidized bed drier at 140ºC for 2 minutes. Similar samples were dried for8-10 hrs by the traditional method. Dried samples were dehisced and polished. Qualityfactors, including trade quality (head rice yield percent and whiteness), cooking quality(amylose content, gelatinization temperature, gel consistency, aroma and flavor) and nutritionalquality (thiamine and lysine contents), were then measured for each sample. Finally,the data was analyzed. Results show that paddy drying in a fluidized bed dryerwould reduce the quality factors except for rice whiteness for which conventional dryingis more acceptable. Therefore modification of fluidized-bed drying technique is recommended**.**

'Zeljko B. Grbavcic, ZoranaLj. Arsenijevic and Radmila V. Garic-Grulovic' studied Drying of suspension and pastes in fluidized bed ofinert particles. Afluid bed dryer with inert particles was used for the drying of suspensions andpastes. The effects of the operating conditions on the dryer throughput and on the productquality were investigated. Experiments were performed in a cylindrical column 215mm in diameter and 1200 mm in height with 0.925 mm diameter glass spheres as thefluidizing media. Cineb fungicide, copper hydroxide and pure water were used as thefeed material. With respect to the main efficiency criteria, i.e., specific water evaporationrate, specific heat consumption and specific air consumption, a fluid bed dryer withinert particles represents a very attractive alternative to other drying technologies. Ahigh drying efficiency results from the large contact area and from the large temperaturedifference between the inlet and outlet air. A rapid mixing of the particles, due toaggregative fluidization and mechanical agitation, leads to nearly isothermal conditionsthroughout the bed. In our experiments, suspensions and very dense pastes were successfullytreated. Suspension and product hold-up in the bed varies between 6 and 8 %by mass and a product with the same particle size as the raw material is obtained.

Jaehyeon Park_ Dowon Shun, Dal-HeeBae, Sihyun Lee, JeongHakSeoyJae HyeokParkzstudied the effect of gas temperature and velocity on coal drying in fluidised bed dryer. The objective of this research work is to develop fluidized bed coal dryer toovercome the disadvantages of low rank coal with high moisture such as lowcalorific values, costly transportation, high emissions of pollutants, and operationalproblem. In this paper, laboratory scale bubbling fluidized bed was used to dry highmoisture, low-rank Indonesian coal to produce low moisture, high-rank coal. Theeffects of temperature, gas velocity and bed height to diameter ratio (L/D) on dryingrate were studied to obtain information relating to optimum operating conditions.

Coal characterizations (proximate analysis, ultimate analysis, ThermogravimetricAnalysis (TGA), BET, Higher Heating Value (HHV), Lower Heating Value (LHV))were performed to identify the effect of the change of moisture content. Thisinvestigation aims to study the drying process under moderated heating conditions.

As a result of the experiments the conclusion is that the thermal fluidized bedprocess can be successfully applied to reducing moisture in Indonesian coal.Results also indicate that about 80~90% of total moisture could be reduced,including some of the inherent moisture, yielding high heating value product. Thedrying rate of coal in a fluidized bed is increased by increasing the temperature andvelocity of the drying gas. However gas temperature had limitations causing fromthe spontaneous combustion and gas velocity has to be decided considering energyefficiency.

'Yashwant Kumar1, Mohammad Ali Khan and Krishna Kumar Patel' studied Effect of Microwave on Fluidized Bed Drying of Beetroot. In the present work, an attempt has been made to study the effect of inlet air temperature and velocity on the drying characteristics of beetroot's (Beta vulgaris L.) pieces in microwave assisted fluidized bed drying (MAFBD) system. The results were compared with samples of beetroot dried in a fluidized bed dryer (FBD) at the same combination of temperatures and air velocities. The selected inlet air temperatures and inlet air velocities were 60°C, 67.50°C and 75°C and 9 m/s, 10.50 m/s and 12 m/s, respectively. Moisture content and outlet air humidity was measured at 5 minutes interval. The MAFBD method offered two to three times reduction in drying time as compared to the FBD method. It was also observed that the beetroot samples obtained from the MAFBD system had lower final moisture content than those obtained from the FBD system.

Scope of work:

After studying different thesis proposed by different Authors as well as my further studies on Fluidized Bed System, I conclude that we can compare models and experimental results for wheat and corns particles, effect of hydrodynamic modelling on drying characteristic, method for increasing thermal efficiency of fluidized bed, recycling of exhaust gas, intermittency and easily understand the gas flow pattern in fluidized bed, conditioning of grains, moisture content determination of grains, determine the properties of wheat and corns, understand the procedure of drying run of fluidized bed, able to understand the principles of electric arc heating, resistance heating, static electric energy, parting arc, electric fire bed system and drying.

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