THEORY AND SIMULATION OF THE INCIPIENT GAS-SOLID FLUIDIZED BED

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THEORY AND SIMULATION OF THE INCIPIENT GAS-SOLID FLUIDIZED BED

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The incipient instability in gas fluidized bed has not been fully understood despite extensive studies were conducted. A new transient theory was proposed by adopting the principles advanced by Tan and Thorpe (1992 and 1996) and Tan *et al.* (2003), and this was verified by computational fluid dynamic (CFD) simulations. The theory of instability in porous media has two functions. One involved the molecular diffusion of a microscopic mass flux in the gas phase with potential adverse density gradient, buoyancy convection in gas will occur, but the solid particles will stationary. If the solid particles were subjected to very high mass fluxes which is characterized by its high gas velocity such as those exceeding the minimum velocity of fluidization, then the buoyancy force of the particles will be overcome and the solids will be moved and fluidized almost instantaneously.

2D time dependent simulations were conducted using a CFD package - FLUENT for gas diffusion in porous media to observe buoyancy convection and also the incipient

instability in fluidized bed, using various gas pairs, mass fluxes and particles sizes. As a prelude to these studies, transient convection induced by gas diffusion in another gas was conducted, so as to understand fully the instability induced by mass diffusion. The simulated critical Rayleigh number were found to be 531 and 707 for top-down and bottom-up gas-gas diffusion respectively, which were very close to the theoretical value of 669 and 817. For transient buoyancy instability induced by gas diffusion in porous media, the average simulated critical Rayleigh number was found to be 26.7, which agreed very well with the theoretical value of 27.1. The simulated onset time of buoyancy convection were also found to be in good agreement with the predicted value. Very often gas velocity is used in designing a fluidized bed, despite that the instability of the bed is actually induced by the mass fluxes of the gas which provide the required velocity. Incipient instability in fluidized bed is caused by fluid velocity higher than the minimum fluidization velocity, U_{mf}. The simulations of incipient instability showed that the bed behavior was dependent on the fluid velocity and the particle size and porosity. The incipient instability was preceded by the gas or pressure saturation of the interstices, induced a high momentum force due to the high mass flux which mobilized and lifted the particles once the critical Rayleigh number was exceeded. The simulated critical Rayleigh number was found to be 30.4, which agreed with the theoretical value of 27.1 for buoyancy instability in porous media. The simulated critical times of the incipient instability in fluidized bed were in good agreement with the predicted values and reported experiments in literature. The bed pressure drop, expansion ratio and void fraction after the fluidization were successfully simulated and were found to be in good agreement with experiments and theoretical values.

THEORI DAN SIMULASI UNTUK KETAKSTABILAN INCIPIEN TURUS TERBENDALIR GAS-PEPEJAL

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Ketakstabilan incipien dalam turus terbendalir gas masih belum difahami sepenuhnya walaupun banyak pengajian telah dijalankan. Satu theori transient baru dicadangkan dengan merujuk kepada dasar-dasar yang dimajukan oleh Tan dan Thorpe (1992 dan 1996) dan Tan *et al.* (2003), dan ini telah pun dikenal-pasti dengan simulasi komputasi bendalir dinamik (CFD). Theori ketakstabilan dalam poros media ini ada dua fungsi. Satu melibatkan resapan molekular yang disebabkan oleh flux jisim mikroskopik dalam fasa gas dengan kecerunan ketumpatan lawanan potensi, perolakan pengapungan akan berlaku dalam gas, tetapi butiran pepejal tetap tidak bergerak. Jikalau butiran pepajal itu dikenalkan kepada flux jisim yang sangat tinggi yang disifatkan oleh kelajuan gasnya yang tinggi seperti yang mana melebihi kelajuan pengbendaliran minimum, maka kuasa pengapungan butiran itu akan diatasi dan pepejal pun digerakkan dan dibendalirkan pada masa yang sangat singkat.

Simulasi 2D ketakmantapan telah dilakukan dengan menggunakan CFD- FLUENT untuk resapan gas dalam poros media untuk memperhatikan perolakan pengapungan

dan juga untuk ketakstabilan insipien dalam turus terbendalir gas, dengan menggunakan bermacam-macam pasangan gas, flux jisim dan siaz butiran pepejal. Sebagai permulaan untuk pengajian ini, perolakan transien yang disebabkan oleh diffusi gas ke dalam gas lain telah dikaji, untuk memahami ketakstabilan yang disebabkan oleh diffusi gas dengan lebih jelas. Nombor Rayleigh kritikal daripada simulasi didapati bernilai 531 dan 707 masing-masing untuk bawah-keatas dan atas-kebawah resapan gas-gas, dimana ia adalah sangat dekat dengan nilai theori 669 dan 817 masing-masing. Untuk ketakstabilan pengapungan transien yang disebabkan oleh diffusi gas dalam poros media, purata nombor Rayleigh kritikal yang disimulasikan bernilai 26.7, dimana ia bersetuju dengan nilai theori 27.1. Masa permulaan perolakan pengapungan juga didapati bersetuju dengan nilai theori. Ketakstabilan incipien dalam turus terbendalir gas disebabkan oleh kelajuan bendalir yang lebih tinggi daripada kelajuan terbendalir minima, U_{mf}. Simulasi ketakstabilan insipien menunjukkan bahawa sifat turus itu adalah bergantung dengan kelajuan bendalir dan siaz butiran dan keruangan. Ketakstabilan insipien ini didahului oleh pengepuan ruang-ruang kosong dalam bed oleh gas, menyediakan satu kuasa momentum tinggi disebabkan oleh flux jisim besar dimana butiran pepejal itu akan digerakkan apabila nombor Rayleigh kritikal telah dilebihi. Nombor Rayleigh kritikal didapati bernilai 30.4, dimana bersetuju dengan nilai theori 27.1 dalam ketakstabian pengapungan dalam poros media. Masa simulasi kritikal untuk permulaan ketakstabilan adalah persetuju dengan nilai ramalan dan yang dilaporkan dalam gajian lain. Kejatuhan tekaan bed, kadar perkembangan dan pecahan kekosongan selepas pengbenaliran disimulasikan dengan sempurna dan didapati bersetuju dengan nilai theori dan esperiment.

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I certify that an Examination Committee met on **date of viva** to conduct the final examination of TAN YEE WAN on his Master of Science thesis entitled "Theory and Simulation of Incipient Gas-solid Fluidized Bed " in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

TAN YEE WAN

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