A Reduced Order Model of Two-Phase Flow, Heat Transfer and Combustion in Circulating Fluidized-Beds

ANNUAL REPORT

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Introduction

This report presents the research activity completed during the first year of the project. The report describes the tasks assigned for the reviewing period, the accomplishments and challenges of this period, as well as the results obtained so far. The next section briefly presents the research objectives of the first year of the project. The following sections describe how these tasks were accomplished. These sections also present a sample of the results obtained. There were no changes in the approach originally proposed to complete the research program.

Research Objectives for the Reporting Period

The following three tasks have been planned for the first year period:

	Program deliverables	Begin date	End date	Status
1.	Generate database using MFIX code	10/02/00	12/31/00	Completed
2.	Develop and implement algorithm to calculate POD basis functions	01/01/01	09/30/01	Completed
3.	Develop visualization tools for reconstructing simulated data	04/01/01	12/31/01	In progress

Task 1

As part of this task, the MFIX code has been implemented on Intel and DEC-Alpha computers running Linux. The makefile of the MFIX code has been modified to run on the Linux Alpha. Two cases have been simulated in order to verify that the MFIX code has been properly installed. The input data for these cases has been provided by NETL. Case I, consists of the flow in a fluidized bed with a jet, as described in [1], p. 156. Case I has been run to simulate the flow for 5 seconds. The results of Case I have been validated using the animation provided by NETL. Figures 1 and 2 show two representative examples of the simulations. In particular, Figs. 1 illustrates the variations in void fraction, while 2 illustrates the variations in the y -component of gas velocity.

Case II consists of the flow in the bubbling fluidized bed as described in the ORNL experiments. Case II included two sub-cases, corresponding to two different values of y -component of the gas velocity, V_g . In case II.1 the velocity was $V_g=12.6$ while in case II.2 the velocity was $V_g=16.8$. Thus, in case II.1, the simulations are near the bifurcation point where the bubbles appear. Case II.2 is far away from the bifurcation point so that the bubble dynamics is more disorganized. As a result, a more coherent behavior is observed in case II.1 than in case II.2. The snapshots of the packed bed void fraction, EP_g , and the velocity V_g are shown in Figs. 3 and 4.

Figure 1: Case I. Snapshots of EP_g .

Figure 2: Case I. Snapshots of V_g .

Task 2

As part of the second task, an algorithm for calculating the POD basis functions has been implemented. This algorithm has been tested for case I presented in the previous section. Figures 5-8 show the POD analysis of the void fraction variable, EP_g . The zeroth POD mode, which is also the time average of the simulations, reflects the left-to-right symmetry of the fluidized bed. The remaining modes describe principal coherent structures in the evolution of the flow. The times series and phase-space projections of the corresponding amplitude coefficients further illustrate the periodic nature of the flow. Similarly, Figs. 9-12 describe the results of the POD analysis of the y -component of the gas velocity, V_g . For both variables, EP_g and V_g , the POD energy spectrum provides an estimate for the dimensionality of the problem and consequently, the number of equations that might be required in the reduction from a partial differential equations model to a reduced model based on ordinary differential equations.

Figure 3: Snapshots of EP_g .

Figure 4: Case II. Snapshots of V_g .

Figure 5: Case I. POD modes of EP_g

Figure 6: Case I. POD energy spectrum of EP_g .

Figure 7: Case I. POD time series of EP_g .

Figure 8: Case I. POD phase-space projections of EP_g .

Figure 9: Case I. POD modes of V_g

Figure 10: Case I. POD energy spectrum of V_g .

Figure 11: Case I. POD time series of V_g .

Figure 12: Case I. POD phase-space projections of V_g .

Results of the POD analysis for case II are shown in Figs. 13-20. Parametric studies have been completed by varying the packed bed void fraction (EP_g) between 0.395 to 0.445 with an increment of 0.01. The database generated as part of task 1 will be used to calculate the POD modes that will be used to project the partial differential equations onto the POD modes and produce ordinary differential equations as part of task 4 that started on 10/01/01.

Figure 13: Case II. POD modes of EP_g

Figure 14: Case II. POD energy spectrum of EP_g .

Figure 15: Case II. POD time series of EP_g .

Figure 16: Case II. POD phase-space projections of EP_g .

Figure 17: Case II. POD modes of V_g

Figure 18: Case II. POD energy spectrum of V_g .

Figure 19: Case II. POD time series of V_g .

Figure 20: Case II. POD phase-space projections of V_g .

In addition, the algorithm for performing the POD decomposition has been tested on a complex flow with large unsteadiness, such as the flow in turbomachinery cascades. A detailed analysis had been done in this case to evaluate the influence of the energy cut-off value on the solution reconstruction. The influence of the number of POD modes on the solution reconstruction is shown in Fig. 21.

Task 3

The last task of this reporting period consists of developing visualization tools for reconstructing the simulated data. This task is in progress and it is scheduled to be completed on 12/31/01. Some of the accomplishments of this task are illustrated by the figures presented in this report.

Figure 21: Energy variation on the stator as function of the number of POD modes at $t = 0$.

Bibliography

- [1] D. Gidaspow. *Multiphase Flow and Fluidization*. Academic Press, Boston, 1994.