*13th Australasian Fluid Mechanics Conference*
*Monash University, Melbourne, Australia*
*13-18 December 1998*

# Parallel Processing in Lagrangian Treatment of Particulate phase in a Power Utility Boiler

**A. Eghlimi[1], C.A.J. Fletcher[1], J.A. Reizes[2]**

1. Centre for Advanced Numerical Computation in Engineering and Science (CANCES), Australian Technology Park, Eveleigh NSW 1430
2. University of Technology, Sydney

## ABSTRACT

The complexity of the flow generated in power utility boilers, (3D, turbulent and two-phase flow), has pushed designers to use empirical information to investigate the problems associated with erosion reduction, heat transfer enhancement and more efficient boiler heat exchangers. The annual cost of erosion is as high as several million dollars; this is too expensive procedure (Tu *et al.*, 1997). Hence, it is desirable to utilise CFD codes to predict the very detailed flow within power utility boilers under different operating conditions.

The present paper describes a general three-dimensional calculation procedure based on the Lagrangian approach to predict complex fly-ash flow in a power utility boiler. The RNG k-ε turbulence model (Orszag *et al.*, 1993) is used to characterise the time and length scales of the continuous phase turbulence. Models investigated are used to predict turbulent, fully developed gas-solid boiler configuration.

The architecture considered is a HP, 7200, or 4 processors system. In single-phase modelling the grid has been partitioned into multiple sub-domains such that the number of partitions is an integral multiple of the number of compute nodes available. Each partition is resident on a different computer node. This paper outlines the effect of partitioning on parallel processing and illustrates the rate of process and real time savings in going to more processors. The present study will show that as the number of computer nodes increases, the turnaround time for the solution will decrease. However, the parallel efficiency decreases as the ratio of communication to computation increases. The paper will address the important issues of achieving high parallel efficiency for interacting physical processes in complex geometric domains.

## INTRODUCTION

Recent improvements in CFD modelling led engineers to a significant progress in analysing, design and operating energy conversion systems. However, the computational time for modelling an average 3D boiler configuration is significant. The structured 3D grid for the power utility boiler studied is depicted in Figure 1. Dilute fly-ash particulate phase of monodisperse spherical particles with diameters of 5 to 80 μm have been traced in a Lagrangian approach as depicted in Figures 2 and 3. The flow operating conditions are taken to be as close as possible to the measurements obtained by Platfoot (1991). The gas density is taken to be 1.17 $kgm^{-3}$. Kinematic viscosity of the gas is 1.68 x $10^{-5}$ $m^2s^{-1}$, uniform vertical inlet velocity of both phases is 10 $ms^{-1}$, the gas turbulent intensity is 5% and particle loading ration is 0.1 $kgkg^{-1}$. It is found that the mean streamlines of both gas and particulate phases are very different between the sections away from and near the rear wall. The smaller fly-ash particles are more influenced by the gas flow, and with increasing particle size, the larger fly-ash particles are accelerated by the centrifugal force, and involve wall collisions. Tu *et al.*, 1997 analysed and validated the turbulent interactions of gas and particulate phase in an Eulerian approach. Eghlimi, 1998 outlined the turbulent interactions of the gas-particulate phase based on a Lagrangian approach. The present study will focus on the issues involved in parallel processing in a power utility boiler simulation and the performance and practical suggestions in parallel processing will be addressed.

## PARTITIONING PROCEDURE

The grid has been divided into partitions so that each partition is solved with one processor. The partitioning allows generating equal number of cells in each group. Appropriate partitioning should minimise the number of partition interfaces and minimise the number of partition neighbours. Equalising the number of cells in each partition is important because it ensures that each processor has an equal load and they will be ready to communicate at about the same time. A recursive bisection algorithm has been used to partition the grid and unlike the other partitioning methods the number of partitions does not have to be a factor of two.

### Bisection Methods

The grid can be partitioned using different bisection methods. In the present study four methods have been investigated. The first one is known as Principal Axes or moment-of-inertia partitioning, which is based on a coordinate frame aligned with the principal axes of the domain. Figure 4 illustrates how the Principal Axes method divides the boiler configuration into different partitions. To divide the grid into two partitions (for two processors modelling) the recursive bisection algorithm has been applied that bisects the entire boiler configuration into two child domains. To generate three partitions the solver bisects the boiler configuration into two partitions, one approximately two times as large as the other and then bisects the larger domain to create three partitions in total. The other methods employed are Strip X, Strip Y and Strip Z. These method use the coordinate bisection but restrict the bisection to be in the selected Cartesian directions (Figure 4).

**Optimisations**

It is recommended to bisect perpendicular to the direction of longest domain extend. However, it is not always the best choice for creating the smallest face boundary. A smoothing algorithm has been employed that minimise the number of interfaces by swapping cells between partitions and gives computational cells to the neighbouring partition if the interface boundary surface area is decreased.

## RESULTS AND DISCUSSION

As mentioned earlier, for investigating the Eulerian-Eulerian and Lagrangian-Eulerian dilute gas-particle modelling and the gas-particle turbulence interactions one is referred to the work done by Elghobashi, 1994, Eghlimi, 1998 and Tu *et al.*, 1997. It has been shown that in this boiler configuration, small particles (5 µm with the Stokes number of 0.004) follow the velocity streamline of the gas phase even in the presence of 180 degree bend in the boiler. Larger particles (80 µm corresponding to the Stokes number of 0.64) are more dominated by inertia and not strongly influenced by flow turbulence and respond slowly to the mean flow, therefore their motion is influenced by the centrifugal effect (Figures 2 and 3).

In the present study, the parallel version of the solver has been employed that simultaneously computes the solution using multiple compute nodes (processes). All the processors have the same clock speed. Table 1 summarises the total clock time for each partitioning method based on different number of nodes, whereas Table 2 outlines

| Partitioning Method | Total clock time | |
|---|---|---|
| | Two Processors | Three Processors |
| Principal Axes | 701.2 | 234 |
| Strip X | 267.3 | 225.7 |
| Strip Y | 298.8 | 249.6 |
| Strip Z | 313.9 | 292.9 |

**Table 1**: Total clock time based on different partitioning method

As it shows in Table 1, all models provide less clock time when the number of nodes increases. For two processors the Principal Axes method is more time consuming than the other ones and this can be related to the way the partitioning is done. For both two and three processors the Strip X method seems to be the most efficient parallel processing method. This can be related to number of cells allocated to each processor (node), the number of interfaces between each partition and the engagement of each processor to other task while doing this parallel processing study. Table 2 illustrates the number of cells allocated to each node and the number of interfaces generated based on different partitioning methods. As it shows, the Strip X method has the least number of interfaces compare to the other ones. It also has a more uniform distribution of the number of cells allocated to each processor and consequently providing a more efficient parallel processing result.

| Method | | Nodes | Cells | Inter-face Faces |
|---|---|---|---|---|
| Principal Axes | Two Nodes | 0 | 8531 | 1639 |
| | | 1 | 8541 | 1639 |
| | Three Nodes | 0 | 5696 | 1761 |
| | | 1 | 5686 | 2283 |
| | | 2 | 5690 | 1266 |
| Strip X | Two Nodes | 0 | 8529 | 202 |
| | | 1 | 8543 | 202 |
| | Three Nodes | 0 | 5684 | 678 |
| | | 1 | 5696 | 1265 |
| | | 2 | 5692 | 578 |
| Strip Y | Two Nodes | 0 | 8522 | 1209 |
| | | 1 | 8550 | 1209 |
| | Three Nodes | 0 | 847 | 1162 |
| | | 1 | 1474 | 1742 |
| | | 2 | 1122 | 1262 |
| Strip Z | Two Nodes | 0 | 8535 | 1622 |
| | | 1 | 8537 | 1622 |
| | Three Nodes | 0 | 5689 | 1655 |
| | | 1 | 5690 | 3402 |
| | | 2 | 5693 | 1747 |

**Table 2**: Cells and Inter-face distribution for each partitioning method

## CONCLUSION

Different partitioning methods have been investigated to illustrate the efficiency of parallel processing in complicated practical engineering application. It has been demonstrated that the appropriate method can influence the computational time significantly. Based on the number of cells allocated to each partition and the number of interfaces, the time requires for each calculation might vary significantly and each partitioning method will produce different efficiency for an individual problem.

## REFERENCES


EGHLIMI, A., "Dilute Gas-Particle Turbulent Interactions", *Ph.D. Thesis*, Department of Mechanical Engineering, University of New South Wales, 1998.

ELGHOBASHI, S., "On Predicting Particle-Laden Turbulent Flows", *Appl. Sci. Res.*, **52**, 309-329, 1994.

ORSZAG, S.A., YAKHOT, V. and FLANNERY, W.S., "Renormalisation Group Modelling and Turbulence Simulations", in SO, R.M.C., SPEZIALE, C.G. and LAUNDER, B.E. (eds), Near Wall Turbulent Flows, Elsevier, 1031-1046, 1993.

PLATFOOT, R.A., "Internal Flows in Coal Fired Boilers", *Ph.D. Thesis*, Department of Mechanical Engineering, University of Sydney, 1991.

TU, J. Y., FLETCHER, C. A. J. and. BEHNIA, M., "Numerical Modelling of Three-Dimensional Flyash Flow in Power Utility Boilers", *Int. J. for Numerical Methods in Fluids*, **24**, 787-807, 1997.

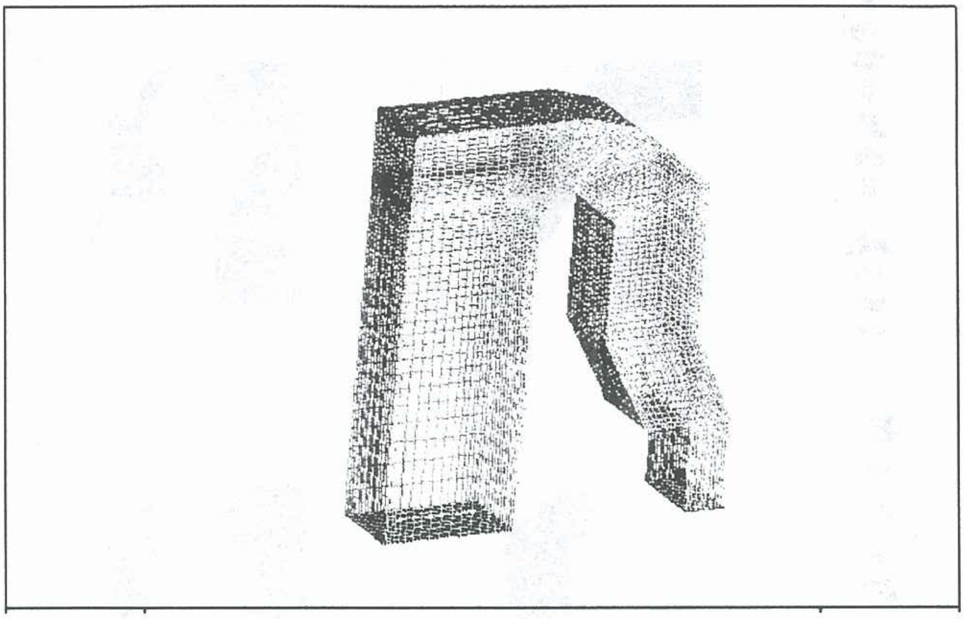

**Figure 1:** 3D Boiler Configuration- Physical Grid and Typical Mesh Size

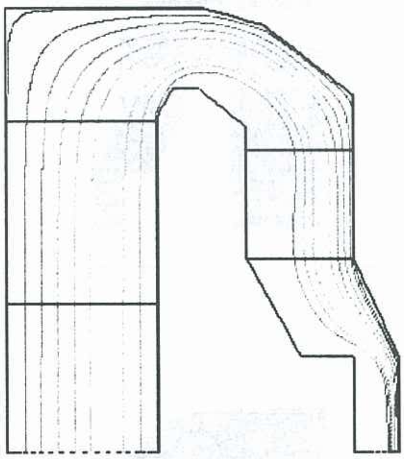

**Figure 2**: Fly-Ash Particle Trajectories (80 μm)

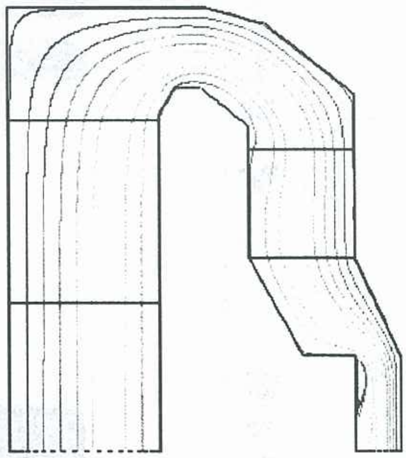

**Figure 3:** Fly-Ash Particle Trajectories (5 μm)

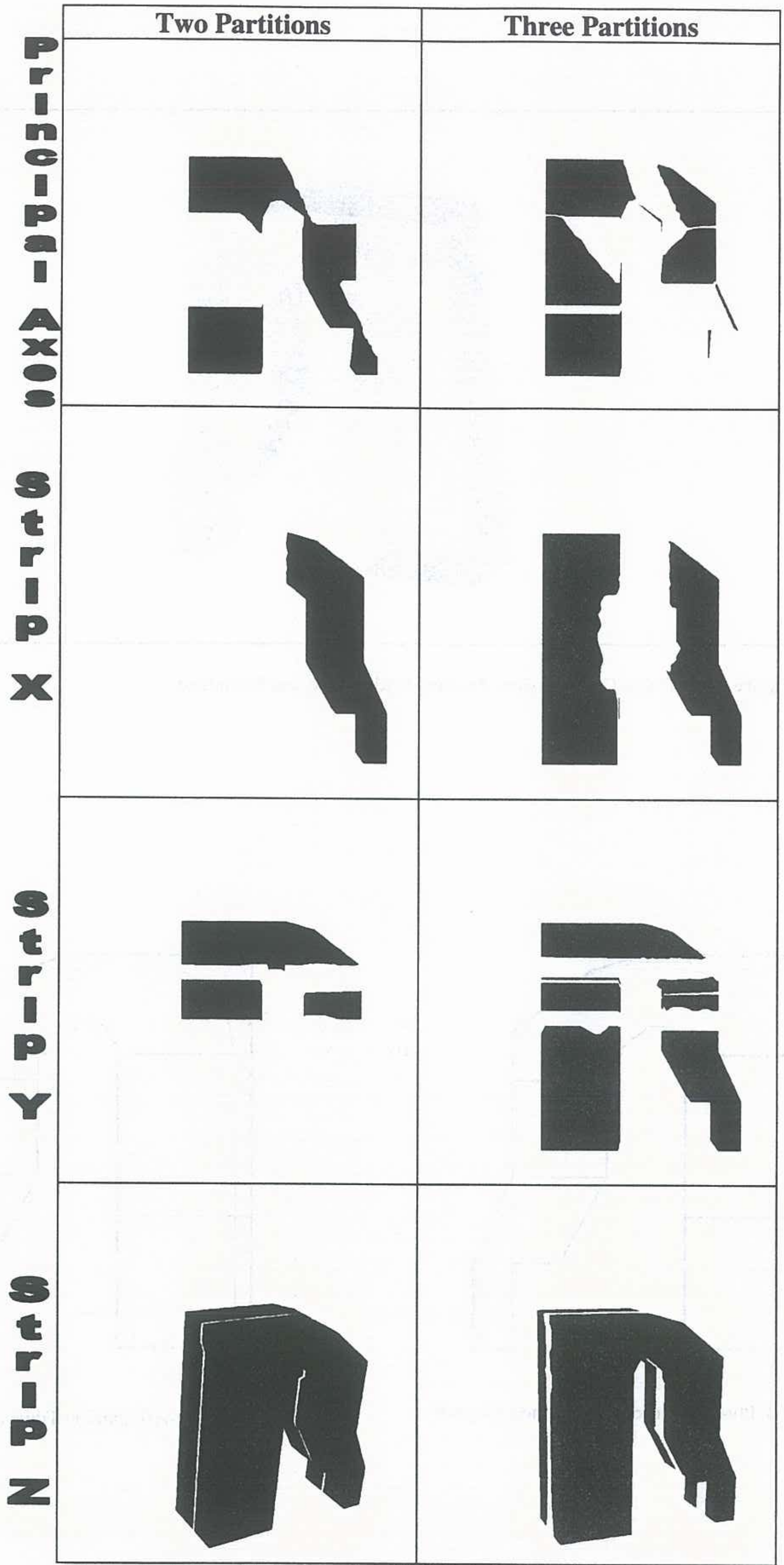


**Figure 4:** Grid partitioning based on different methods for parallel processing