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COMPUTATIONAL FLUID DYNAMICS AS A TOOL IN THE MINERALS PROCESSING AND METAL PRODUCTION INDUSTRIES

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ABSTRACT

The minerals industry is one which demands a high level of productivity and efficiency in the processing of raw materials. This demand is fuelled by the necessity to compete in an aggressive profit-driven market. In recent times, even greater pressure has been exerted on companies to achieve such profit growth in a safe, socially and environmentally acceptable manner.

In the strategy to produce products at the lowest possible cost, it is *essential* that mineral processing and metal production companies optimise, as far as possible, every element of their operation. Modern Computational Fluid Dynamics (CFD) is a powerful, perhaps imperative tool, which can be utilised by companies to significantly enhance their understanding of plant components.

Advances in CFD have been so immense that the simulation of industrial processes need no longer be confined to the elementary prediction of gas and liquid flow, or the trajectory of solids through vessels. Applications in the minerals industry include model complexities such as dynamic electromagnetic processes, chemically reactive and combustion systems, transient mechanically-stirred systems and coupled processes.

This paper will review CSIRO's experience in the application of CFD to process design and optimisation in the minerals processing and metal production industries. Technical challenges confronting process modelling researchers and anticipated future developments will also be discussed.

INTRODUCTION

The Commonwealth Scientific Industrial Research Organisation (CSIRO) is Australia's leading research agency, which conducts research and development across a broad range of industries. Extensive fluid dynamics capabilities have been progressively accumulated during the past thirty years in various divisions of CSIRO including building and construction, minerals and exploration, mathematical sciences and entomology research sections.

CSIRO has successfully used CFD in conjunction with physical experimentation to assist companies to steadily reduce capital and operating expenses (Schwarz, 1994b). The majority of this research and development has been conducted in close partnership with progressive companies who have identified inefficiencies, deleterious behaviour or the need to manage operational risk. The united outcome of this fluid dynamics research has delivered enormous benefit and savings to Australia.

In applications related to minerals and metal processing, mathematical modelling has progressed from a mediocre modelling technique (Batterham *et al.*, 1982) to use of CFD as an extremely powerful optimisation tool (Hardie *et al.*, 1992; Davis *et al.*, 1997). Extensive physical validation coupled with improved commercial modelling packages and increased computer performance has greatly increased confidence in the manner CFD can be utilised. Models combining multi-phase interactions, chemical reactions and combustion are commonly developed for industrial problems.

Fluid dynamics, and in particular CFD, will continue to strengthen and play a considerable role in the growth of mineral processing knowledge. Increased model complexity, accompanied by superior correlation with physical measurement, will make CFD even more essential for organisations in order to maintain competitiveness. To better meet these requirements however, it is important to comprehend the current nature of the minerals and metal processing environments, and gain a firm appreciation for the issues confronting companies.

THE ROLE OF RESEARCH IN MINERALS

Research plays an important function in mining and metal production sectors of the Australian economy. Resource companies have traditionally enjoyed elevated share evaluations due to exploration and deposit development programs, but a significant proportion of market capitalisation has been forfeited during the past ten years. This is primarily due to subdued world economic growth, unstable profits and competition for investment funds.

Decreased public confidence in resource companies has generally been met by cost reduction measures. Profits have been moderately dilated by a blend of labour market reform and incremental process improvement. Funding for highly speculative or innovative research has nonetheless been reduced however support for CFD has remained because of the cost-effective manner in which it can identify expense-saving alternatives.

Forces Driving Research

The necessity for fluid dynamics research is primarily driven by three incentives:

i. Process design and risk management,
ii. Problem interrogation and diagnosis,
iii. Process improvement and optimisation.

Process Design and Risk Management

Development of new industrial processes or significant modification to pre-existing plant elements customarily requires a certain level of verification and risk management. CFD fulfils this need admirably since it can be used in conjunction with physical experimentation to accurately predict likely behaviour of the proposed system. Fluid dynamicists can numerically simulate the process design and determine whether the desired performance will ensue or that deleterious behaviour may result, negating any positive gain.

Process scale-up is an important function of CFD (Hardie, 1992; Davis, 1997). Costly development of new smelting and refining processes is ordinarily conducted using a combination of laboratory testing, pilot plant evaluation and full scale development. These stages ensure that sufficient understanding is gained during the progress of the project and that practical operating issues are resolved and the process is economically profitable. CFD can be utilised as a scale-up tool for hydrodynamics and chemical reactions. This is a particularly powerful approach when the CFD model is validated at several stages of process development.

Problem Interrogation and Diagnosis

Difficulties frequently arise during operation of industrial equipment under highly demanding conditions. Accretions may form, dislodge and obstruct equipment; high velocity flows may severely erode parts; unknown changes may compromise performance; modified system properties or throughput rates may decrease efficiency; or the process simply does not perform as expected. These and other symptoms can provide the incentive to employ fluid dynamics research. CFD is normally required since high temperatures and chemical reactions cannot always be easily manipulated and investigated using physical experimentation.

Process Improvement and Optimisation

Incremental improvement and efficiency gains are aggressively sought in highly competitive industries and markets. Australian mining and metal production companies are not insulated from international companies since the resource sector is highly globalised. Globalisation requires that companies must meet or better mean reductions in unit costs in order to remain economically viable. This demand is normally met by reducing operating costs (decreased labour and resource utilisation) and exploiting economies of scale with minimal capital expansion.

CFD has frequently been used by CSIRO to achieve incremental improvement of company equipment and processes. The model is used in conjunction with physical measurement (perhaps previously performed or acquired from plant) to determine precise operation of the equipment. Once a firm understanding of the operation has been obtained, improvements in efficiency in the range 5% to 200% can often be achieved. These gains may be due to direct productivity increases, resource utilisation (lower operating costs) or reduced need for plant capital expansion. As a result of these possible benefits, fluid dynamics and in particular CFD is a powerful cost reduction tool.

APPLICATIONS IN MINING AND METAL PRODUCTION

CSIRO Australia has extensive experience in application of CFD to the mining and metal production industries. The following sections will review industrial situations in which CSIRO has utilised CFD to diagnose problems, assist design or for optimisation purposes. Future challenges confronting process modelling researchers and anticipated future developments will also be discussed.

Status of CFD Technology

CFD has been applied in the minerals industry for approximately twenty years. The present standing of CFD technology in resource related industries can be best illustrated by surveying examples where it is being successfully used. Relatively evolved areas of application include cyclones and separation devices, mixing vessels, fluidised beds, thickeners, smelting and combustion systems. Whilst a certain amount of physical validation still needs to be performed to gain adequate confidence in some of these areas (eg. combusting flows, fluidised beds and mixing vessels) application in other fields is comparatively advanced.

Cyclones and Separation Devices

Use of CFD in the design and optimisation of cyclones and other particle separation devices is relatively well established in the minerals industry.

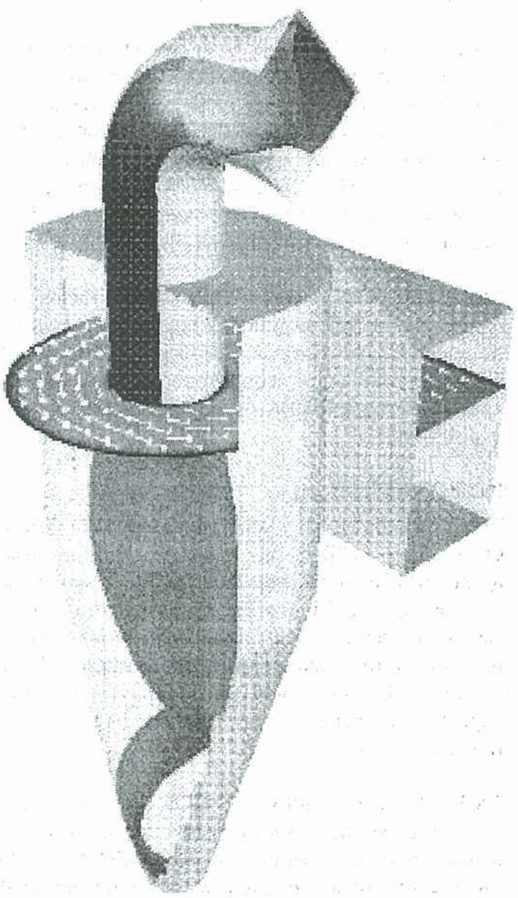

Figure 1 : CFD prediction of regions with positive vertical velocity in a swept inlet cyclone.

Models can be utilised to predict gas and particle flows in the cyclone inlet, vortex structure (Davidson, 1991; Mittoni *et al.*, 1998), non-uniform velocities, flow separation around the vortex finder, separation efficiency and to determine erosion prone regions (Zughbi *et al.*, 1991).

Figure 1 presents a plot of a cyclone isocontour representing the region where positive vertical velocity is predicted to occur. This data is useful for detecting gas flows which may re-entrain particles from the wall of the cyclone, therefore reducing separation efficiency. CFD models can be used as a tool to contrast various cyclone geometries, or to determine the likely effect of scale-up, heat transfer or sensitivity to operating conditions. For example certain cyclone aspect ratios can have poorly defined vortex structures which can be corrected prior to installation if numerical modelling is performed.

Mechanically Stirred and Gas Agitated Vessels

A relatively new area of CFD research involves prediction of velocity profiles in mechanically stirred systems. Two approaches, including blade element theory (Niclasen *et al.*, 1997) and full three dimensional simulation (Lane and Koh, 1997) have been used to simulate fluid flow throughout mixing vessels.

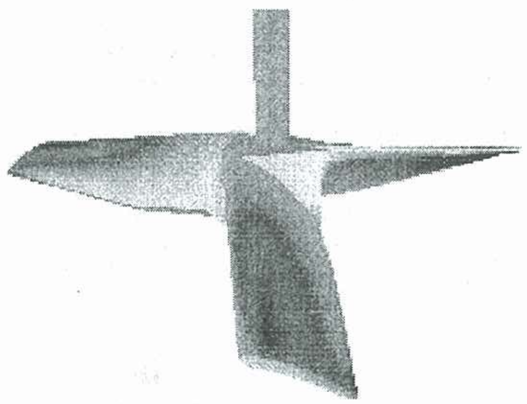

Figure 2 : Three-dimensional view of an A310 blade used in a full CFD simulation of a stirred vessel.

Mixing has been applied in many areas of minerals and chemical process industries. Gas agitated vessels and mixing systems have also been actively researched (Schwarz, 1994b; Dang and Schwarz, 1991a). CFD models in conjunction with physical validation may be used to predict fluid velocity profiles, solids settling and wall velocity. It is also simple to rearrange impeller combinations, blade positions, gas injection rates, and solid density / size distributions.

Fluidised Bed Design and Operation

Fluidised bed systems are complex systems to simulate using CFD due to the effects of particle-particle interactions at high solids loading (Bell *et al.*, 1997; Witt *et al.*, 1997). CSIRO has been involved in extensive modelling and physical validation of two and three-dimensional bubbling and circulating fluidised bed processes. Models can be utilised in the design of fluidisation tuyeres (White *et al.*, 1997) prior to commissioning, or to determine the probable flow patterns and identify inferior erosion tolerance or mixing efficiency.

A large number of tools are now available to assist in the validation stage of fluidised bed CFD models. This instrumentation includes fibre optic velocity probes, capacitance solids fraction probes, differential pressure transducers and capacitance tomographic imaging systems. Predicted solids volume fraction and velocity can be compared with those measured in a laboratory model or obtained from the full scale industrial process.

Thickener Feedwells

Thickener technology has progressed substantially with the exploitation of CFD technology. Fluid flow, relative proximity of feed, dilution and flocculant introduction significantly affect the efficiency of thickener vessels and feedwells (Johnston *et al.*, 1996).

CSIRO has been involved with a large number of research projects performed in partnership with industry. Design modifications such as feedwell geometry or shelf position greatly affect mixing and solids distribution in the remainder of the system. A recent project concerned CFD modelling of a thickener with various feedwell designs and flocculant sparge locations. The optimisation exercise led to a doubling in residue handling capacity, a sharp decrease in operating costs and substantially increased soda recovery (Kahane *et al.*, 1997). These gains can potentially save companies many millions of dollars through decreased capital expansion needs.

Smelting and Combustion Systems

CFD has been used extensively in the design and scale-up of smelting and combusting systems. These models have developed over several years to become relatively powerful prediction tools which can be used to gain detailed fluid flow information (Davis, 1997; Koh *et al.*, 1997).

Numerical models of smelting systems have generally been used to predict and overcome erosion, vibration and bath splash problems. Non-optimal fluid flow regions which inhibit efficient heat or mass transfer can also be identified and improved (Nguyen *et al.*, 1992). Model validation against the full scale process is often difficult, and is normally performed using a combination of cold flow modelling and limited plant measurements. For instance the research of Doblin and Nguyen (1997) coupled cold flow cobra probe measurements with a modified CFD model to validate swirled burner injection.

Future Applications of CFD

Advancement in CFD modelling has been rapid as computer power has increased and experience in solving complex problems has expanded. Further improvements in speed and CFD numerical approaches will result in further shifts in the variety of processes and systems which can be tackled.

Assuming computers continue to increase exponentially in processing speed, CFD will eventually be exploited as a powerful monitoring and control tool. Bath smelting furnace models could be coupled with control and measurement parameters such as feed material composition or desired product composition. Continuous on-line validation and advanced instrumentation will also enable plants to automatically maintain optimised operation. Processes could be run more efficiently, with a decrease in frequency of adverse situations which lead to plant down-time. On-line CFD models will also enable plants to adjust the control conditions in reactors to altered feed rates or properties. For example the location of flocculant sparging in thickener feedwells could be automatically adjusted in reaction to CFD model simulation results as feed density changes.

Further research and development in CFD will also result in greatly increased model confidence and complexity. Numerical models of entire systems will be developed which account for a wide range of physical interactions. For example highly turbulent swirled multi-phase flows including combustion, radiation, compressibility, heat transfer and mass transfer will be solved on moving computational grids using a transient solution strategy. Models will also resolve fine-scale flow behaviours such as turbulent eddies and regions of flow separation. Increased experience in these systems with such complexities will also deliver greater confidence in the simulation results CFD models will be able to provide.

CONCLUSIONS

The Australian minerals processing and metal production industry has evolved considerably during the past ten years within a highly competitive commercial environment. Research and development is necessary to constantly reduce processing costs and to remain economically viable. To achieve these benefits, CFD has been exploited as part of an overall strategy to manage: (i) process design and risk management, (ii) problem interrogation and diagnosis, and (iii) process improvement and optimisation.

CSIRO has accumulated extensive experience in the application of CFD to minerals and metal processing operations. Levels of knowledge, modelling capabilities and prediction confidence have gradually increased, and will continue to increase with the improvement in computer speed and numerical methods. The importance of CFD in industry will also continue to strengthen as models evolve to become very powerful analysis and simulation tools. Future ability of CFD and the problems it will be capable of tackling are emerging to be extremely exciting fields of research.

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