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# Laboratory modelling of erosion damage by vortices in slurry flow

L.J.W. Graham [a,*], J. Wu [a], G. Short [a], C.B. Solnordal [a], C.Y. Wong [a], G. Brown [b], O. Celliers [b], D. Whyte [b]

[a] CSIRO Mineral Resources, Melbourne, VIC, Australia
[b] Technology Delivery Group, Alcoa Refining, WA, Australia

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ABSTRACT

Erosion damage caused by suspended particles in slurries leads to production loss and on-going maintenance costs. Such damage is common in flow equipment used in slurry transport, including processing equipment in alumina refineries.

CSIRO has been conducting research under AMIRA P931 "Multiphase Flow Erosion" projects from 2006 to 2013, under sponsorship funding support from Alcoa, BHP Billiton, Rio Tinto Alcan, Vale and Pentair Valves (Tyco Flow). CSIRO has a continuing focus on building knowledge and methods to improve prediction of the service life of flow equipment under erosion conditions, and to develop strategies to reduce erosion through altered flow design.

Interestingly, none of the case studies requested by the industry partners involved simple impingement erosion or sliding bed erosion. The emphasis has been on solving erosion problems using the principles of the underlying multiphase fluid dynamics, which called for an in-depth treatment of non-uniform flows. Consequently the current study was very different from the usual treatment of erosion (which focuses on direct impingement simply because it is easier to model and measure) and instead addressed the much more common industrial problem of localised erosion.

By using fluid dynamics modelling, experimental visualisation and quantitative measurements of erosion scars, several fluid dynamic mechanisms have previously been identified as causing severe erosion attacks. These included erosion by vortices, by flashing and by various non-uniform flows. Observations of accelerated wear have shown that vortex erosion is present in many flow geometries critically important in sponsors' plants, e.g. pipe work around a valve, protrusions in a pipe and many conventional engineering designs. This paper focuses on vortex erosion in a variety of flow situations and examines the fluid dynamics and consequent erosion.



## 1. Introduction

Severe erosion attack can occur in mineral process plants where complex fluid dynamics occurs. Reducing the maintenance costs associated with erosion damage is of significant interest to the minerals industry. Hence, CSIRO has been conducting fluid dynamics based erosion research under AMIRA P931 "Multiphase Flow Erosion" projects from 2006 to 2013, under sponsorship funding support from Alcoa, BHP Billiton, Rio Tinto Alcan, Vale and Pentair Valves (Tyco Flow) as well as continuing research activity in this area.

Vortex flows are one example of this and have been discussed in the literature by Brown (2002) in the context of a blanked tee in pipe work and Graham et al. (2010) who examined the flow around obstacles and the consequent erosion. A good summary of the fundamentals of vortex flows caused by obstacles is given by Simpson (2001).

As far as erosion due to vortex action around obstacles is concerned, there are several recent literature examples, particularly from the practical case of erosion of the base of bridge piers where the erosion action due to vortices generated from obstacles is significant. There is also interest in the vortex erosion phenomena in the areas of heat transfer where the obstacle (or "dimple") is used in heat exchangers to promote turbulence.

Escauriaza and Sotiropoulos (2011) used a detached eddy simulation approach to model the flow around a surface mounted pier. A new model was developed to examine the erosion of the surface around the pier. Their model was found to qualitatively reproduce the erosion effects observed, however the computed rate of erosion was found to be less than from observations.

Another recent example from the literature is Kirkil and Constantinescu (2015) who used experimental and numerical methods to examine the classic case of a cylindrical obstacle in a channel. Their numerical approach is interesting as a Direct Numerical Simulation was used for the low Reynolds number case (16,000) whereas a detached eddy simulation was used for the higher Reynolds number of

* Corresponding author.
*E-mail address:* Lachlan.Graham@csiro.au (L.J.W. Graham).

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50,000. The numerical results agreed very well with the PIV measurements. No erosion modelling was attempted.

Zhao et al. (2014) used numerical methods to examine the heat transfer and erosion behaviour of tubes used in heat exchangers which were fitted with dimples to enhance heat transfer. It was found that it was possible to optimise the tube design and vortex generators to get a good compromise between heat transfer and erosion performance.

The preceding examples demonstrate that the study of erosion due to vortices generated by obstacles is a topic of considerable interest. Vortices are also generated in other flow situations where the flow is required to change direction as demonstrated below.

A tee section is commonly encountered in mineral processing plants where the flow is required to be sent into one of two possible directions where the unused flow path could, for example, be closed by a knife gate valve. Blanking plates are also used for more long term blockage of the unused leg. Under some circumstances it is known that a vortex can develop in the tee which leads to significant erosion on the blanking plate or valve blade (Brown, 1999; Brown, 2002). The generic flow geometry is shown in Fig. 1.

This flow has previously been the subject of a Computational Fluid Dynamics (CFD) study by Brown (1999) and Brown (2002). The CFD results in these papers showed that a vortex was present at the position of the maximum erosion on the blanked end provided some swirl was present in the inlet flow. A photograph of a full scale eroded blanking plate is shown in Fig. 2(a). No erosion modelling was presented in these papers, although paint was used to visualise the erosion pattern in a separate investigation in the laboratory at CSIRO (Fig. 2(b)).

This paper presents examples of the erosion due to vortex action around obstacles and that caused by a blanked tee. Three examples are presented: erosion on a pipe wall caused by a cylinder protruding from the wall; erosion on a cylinder in cross-flow caused by a protrusion on the cylinder, and erosion in and around a blanked tee-junction. Quantitative measurements of the surface erosion are made and CFD analyses of the erosion around the obstacles are presented.

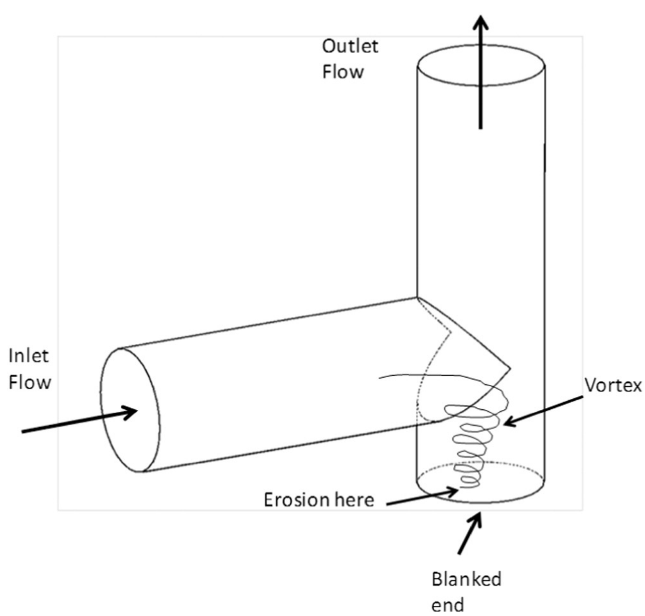


**Fig. 1.** Generic blanked tee geometry. The blanked end may be due to a valve being closed for example.

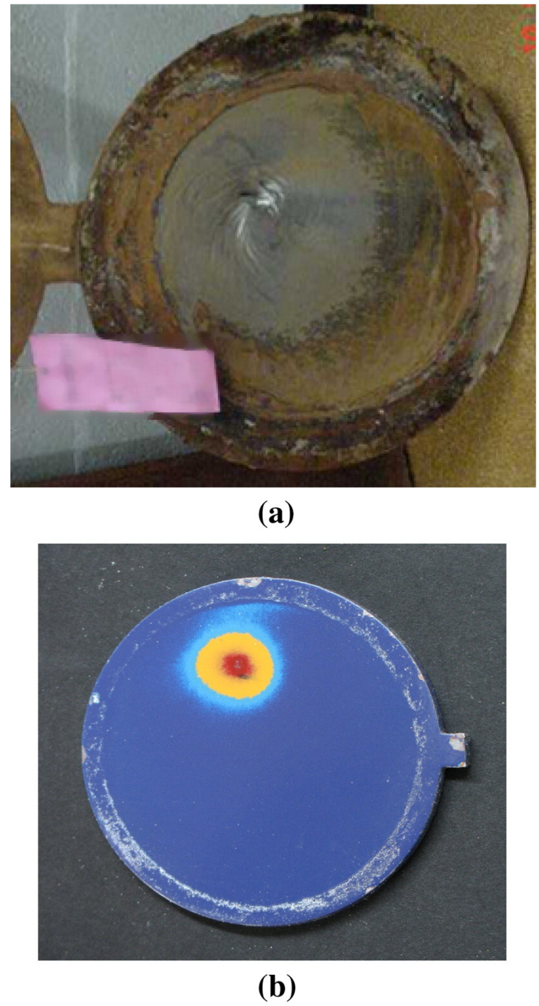


**Fig. 2.** (a) Full scale example of erosion in tee blank, (b) paint erosion model using the paint modelling technique from Wu et al. (2011).

## 2. Experimental and CFD methods

### 2.1. Slurry flow loop for erosion tests

The erosion tests were conducted in a slurry flow loop, schematically represented in Fig. 3. The flow loop consists of a 3000 L agitated tank, a Warman 4 × 3 AH slurry pump, a magnetic flowmeter and appropriate connecting pipe work in NB 50 mm pipe. The sample under investigation was arranged in a straight, vertical length of pipe. Normally a straight length of pipe of at least 20 diameters was provided before the sample, and the rig could be configured for up to four samples simultaneously if required. Cylindrical samples of the same material as the sample under investigation were tested at the same time (Fig. 3(a)). In this way they acted as a control sample undergoing direct impact erosion, for comparison with the sample under investigation.

### 2.2. Erosion measurement

All erosion measurements were made using a Sheffield Discovery II coordinate measurement machine (CMM) as shown in Fig. 4. The repeatability of measurements made using the CMM was of the order of ± 3 μm. The sample under consideration was placed in the CMM both before and after exposure to slurry, and a map of the erosion extent was created by determining the difference between the two profiles. More detail of the procedure has been published elsewhere (Wong et al., 2015).

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