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Influence of particle size, density, particle concentration on bend erosive wear in pneumatic conveyors

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ABSTRACT

Particle concentration is a principal factor that affects erosion rate of solid surfaces under particle impact, such as pipe bends in pneumatic conveyors; it is well known that a reduction in the specific erosion rate occurs under high particle concentrations, a phenomenon referred to as the "shielding effect". The cause of shielding is believed to be increased likelihood of inter-particulate collisions, the high collision probability between incoming and rebounding particles reducing the frequency and the severity of particle impacts on the target surface. In this study, the effects of particle concentration on erosion of a mild steel bend surface have been investigated in detail using three different particulate materials on an industrial scale pneumatic conveying test rig. The materials were studied so that two had the same particle density but very different particle size, whereas two had very similar particle size but very different particle density. Experimental results confirm the shielding effect due to high particle concentration and show that the particle density has a far more significant influence than the particle size, on the magnitude of the shielding effect.

A new method of correcting for change in erosiveness of the particles in repeated handling, to take this factor out of the data, has been established, and appears to be successful. Moreover, a novel empirical model of the shielding effects has been used, in term of erosion resistance which appears to decrease linearly when the particle concentration decreases. With the model it is possible to find the specific erosion rate when the particle concentration tends to zero, and conversely predict how the specific erosion rate changes at finite values of particle concentration; this is critical to enable component life to be predicted from erosion tester results, as the variation of the shielding effect with concentration is different in these two scenarios.

In addition a previously unreported phenomenon has been recorded, of a particulate material whose erosiveness has steadily increased during repeated impacts.

1. Introduction

Since the 1970s, erosive wear problems in pneumatic conveying systems have been discussed in depth and many studies have been undertaken [for example 1–4]. These studies have shown that there is a substantial reduction in specific erosion rate (*i.e.* the mass of material removed from a solid surface per unit mass of solid particles impacting) as particle concentration in the flow increases. The consensus, which although unproven appears entirely reasonable, is that at a high level of particle flux the conditions are more favorable for increased frequency of inter-particulate collisions between rebounding and incoming particles near the surface. These collisions must act as a defensive barrier, impeding the progress of particles traveling towards the surface, and causing the observed reduction in the specific erosion rate. This phenomenon is also called the "shielding effect". Uuemois and Kleis [2] did some tests on a centrifugal rig, a vacuum rig and a sand-blast rig to understand the influence of particle concentrations on erosion. It was found that for metals, alloys and ceramics an increase of the particle concentrations led to a decrease of erosion rate. Anand et al. [3] measured the erosion rate as a function of erodent particle flux by using an airstream system. A significant decrease in erosion rate was observed with the flux increasing; the erosion rate varied approximately as an exponential decay with the particle flux, and the effect was more pronounced for small particles and low particle velocities. A model was then developed based on first-order particle collision statistics but the model was too simple to describe the particle collisions in pneumatic conveyor bends. The complexity of the inter-particle collisions makes it very hard to simulate and

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evaluate the very large number of particles in the relevant volume near the eroding surface, given the random, 3-D interactions among the particles advancing toward and rebounding from a surface to cause erosive damage. The presence of a poly-disperse distribution of both sizes and shapes amongst the many particles greatly amplifies the difficulty of modeling this process in a representative way.

Mills [5,6] did extensive studies on bend erosion in pneumatic conveying systems, including testing the effects of particle concentration. In his studies a term of particle "suspension density" (mass of particles per unit volume of gas flow) was used in the erosion measurements. The results obtained showed that the total mass lost from an entire bend, after conveying a fixed quantity of material, decreased when the suspension density of particles in the bend was increased, similarly to the other studies cited. He also explained this as being due to the likelihood of inter-particulate collisions increasing as the suspension density was increased. During the collisions particles would lose a part of their kinetic energy and thus have less energy available in the impact with the surface, thus reducing the erosion because particle velocity is the leading variable in erosion (widely established by many studies).

Deng et al. [1] investigated the effect of particle concentrations on erosion rate on an industrial scale pneumatic conveyor. The results showed that the weight loss rate of bends closely followed an exponential decay model against particle concentration (again characterized by suspension density). For very low particle concentrations, the weight loss rate of the bends was maximum and quickly dropped down as the particle concentration increased. Also it was found that the thickness loss rate reduced for a high particle concentration. Again the cause was thought to be reduced frequency and severity of impacts with the surface, due to increased inter-particulate collisions.

Nevertheless the particle concentration is not the only factor on bend erosive wear in pneumatic conveyors, many factors are also known to be important to the bend wear such as particle velocity, particle physical properties (size, shape and density) and bend material properties, etc. In the practical applications of pneumatic conveyors, the situation is further complicated in that for a given throughput, the particle concentration at the point of impact is also a function of air (and hence particle) velocity, particle size, particle density, bend geometry and chosen pipe size.

A method has been published by Hanson et al. [7] to use results from a rotary erosion tester [8] to predict bend wear rates in real conveyor bends. This is important industrially, because a rotary erosion test is very cheap and quick to undertake, also it is highly repeatable and uses a small quantity of material which can be characterized accurately; by comparison, a trial on a full size conveyor is extremely costly, usually requiring many cubic metres of particulates. An incorrect choice of erosion-resistant material for a bend can result in large warranty claims against the system supplier if the bends wear out too quickly, or excessive expenses in construction if an unnecessarily high grade of wear resistant material is specified. However, a shortfall in the prediction method is that the different magnitude of shielding between the erosion tester and the bend (for a given particle concentration), was not fully accounted for in Hanson's model. In fact the level of shielding in the erosion tester is low and in case can be established quickly and cheaply in the test, so the erosion rate as concentration tends to zero can be determined conveniently from the erosion tester. The challenge then lies in having a reliable model to scale this erosion rate under low concentration, to an accurate erosion rate at the adequate concentration in the industrial conveyor design. Whilst the published studies have shown the trend, all have used only fine sand as the erodent, so the dependence of the shielding on the particle properties needs to be explored more thoroughly to see whether the same rate of decay holds.

Hence the study reported here set out to investigate experimentally on an industrial scale pneumatic conveyor, the effect of using different particulate materials, with particular reference to the influences of particle size and particle density.

2. Experimental investigation

2.1. Experimental apparatus

The prime mover utilized for this investigation was a 1.5 m^3 capacity blow tank test rig constructed to serve a high-pressure test loop, the main components being a storage/receiving hopper mounted on load cells above a blow tank as illustrated in Fig. 1. Isolation of the storage hopper and control of material flow to the blow tank was achieved through the use of two motorized shut off valves; whilst a variable speed screw feeder controlled metering of erodent material out of the blow tank into the air stream. Pressure in the pipeline and the blow tank were kept balanced at all times so that the screw feeder did not operate across a pressure difference. This enabled an accurate and repeatable set-up of conveying rate from run to run.

A horizontal pipe loop was used (see Fig. 2), which provided for a total conveying distance of about 130 m. Construction of the loop was from 100 mm nominal bore schedule 40 mild steel tube (102 mm bore). The test bend was made of mild steel, placed at the end of a long straight section (24 m approximately) to ensure fully accelerated flow of the particles. All pipeline joints were connected using "Eurac" type external clamp couplings to ensure accurate concentricity and alignment of pipe ends (thus avoiding any internal "edges" to disturb the particle flow) and the loop was supported by a stiff steel racking system to ensure straightness of all the sections.

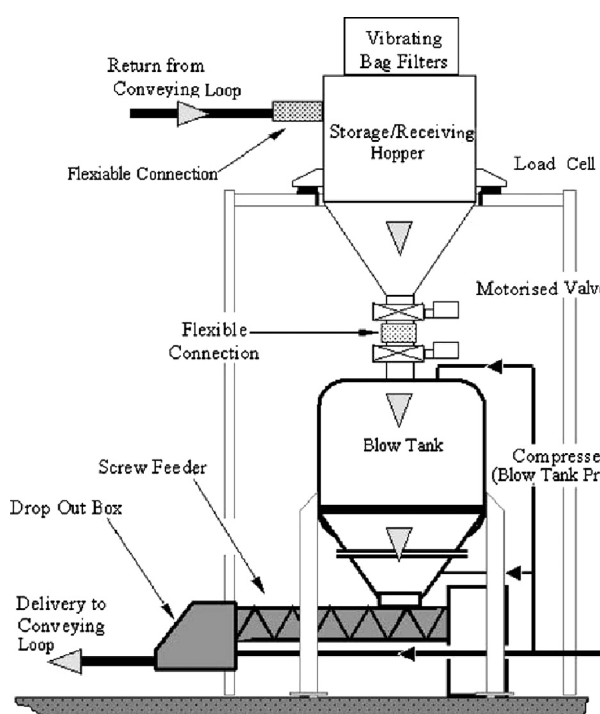

Fig. 1. Schematic arrangement of blow tank test rig.