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Introduction

The 8^{th} International Conference on Measurement and Control of Granular Materials (MCGM' 2009) will be held in Shenyang, China from August 27-29, 2009. The first MCGM conference was held in 1988 in Shenyang, China, with attendees from 18 countries. The International Federation of Measurement and Control of Granular Materials (IFMCGM) was established shortly after the conference. During the past twenty years, IFMCGM has successfully organized six MCGM conferences and become a global organization serving the fields of granular, powder, Particulate, solids and nano materials. All Councilors of IFMCGM have given their selfless great contributions and wisdoms to globalization of MCGM development. The Organizer has deeply cherished the memory of some late VIP founders of IFMCGM such as Prof. Koichi Iinoya (Japan), Prof. B. Scarlett (The Netherlands), Prof. Isa Addullayev (Azerbaijan) and Prof. D. F. Bagster (Australia) who all had passed away in a few years. Their spirits will impel younger members and Councilors of IFMCGM to develop the MCGM field unceasingly in the future! Nowadays, researchers and engineers are in cooperation with each other to solve technical and theoretical difficulties in MCGM field. MCGM field has become a worldwide important branch in academic, technical and industrial developments!

The preparation of MCGM2009 is done well by all authors from 10 countries. IFMCGM warmly invites and welcomes academic researchers and industrial experts to attend the MCGM' 2009. There will be oral and poster presentations as well as exhibitions of the latest products in the fields of MCGM. 130 papers will be presented during the Conference. It is a new milestone of great development for us to hold MCGM2009 Conference in MCGM field since 1988! Many excellent papers will be published in MCGM2009 Confernce. Scholars, researchers and engineers in MCGM field have done , are doing and will do persistent and hard research work both in academic and industrial applications. Many thaks to them to promote worlwiide eocmomic development with the MCGM techniques and newest products!

Shenyang, located at northeastern China with a population of seven million, is a modern industrialized city and has many historic sites and tourist attractions. There are some of the heaviest and lagest machine enterprises of China in Shenyang. Many New Development Zones have been set up which you will visit in siteseeings after Conference. Airlines and domestic railroads are very convenient means for traveling to and from Shenyang and everywhere in the world. You will be moved by the rapid economic growth in Shenyang during the Reforming Period of China. It will be a great opportunity for attendees to stay in Shenyang and have a great time, in addition to attending the conference. You will be the most honorable guests to the people of Shenyang and warmly welcome.

The Organzers sicerely hope that you can have a great time staying in Shenyang, Chna and see you again in 2011!

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The 8^{th} International Conference on MCGM 2009
Shenyang Association for Science and Technology, China

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Section 1

Measurement and Control of Particle and Solid Materials

Bulk Solids Research: Current Trends and Future Outlook

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Abstract: The efficient and reliable handling of bulk materials is vital to the resource and process industries all over the world. This paper outlines some of the major developments in Bulk Solids research in the areas of storage, handling and transportation. This will include hoppers, silos and stockpiles; pneumatic conveying (dilute and dense phase) and overland belt conveying. The presentation will also touch on feeding, feeder interfacing and transfer chutes.

The presentation will focus on current developments in research illustrated with industrial case studies taken from over 2500 industrial projects undertaken by TUNRA Bulk Solids at Newcastle for companies all over Australia and from around the world.

Keywords: Bulk Solids Handling, Silo Design, Stockpiles, Flow Properties, Belt Conveying, Pneumatic conveying

Introduction

The storage, handling and transport of bulk materials is a multi-billion dollar cost to the world's mining, minerals and process industries. Unfortunately, the storage, handling and transportation of bulk materials adds no value to the materials being handled and is often seen as a regrettable cost which detracts from the bottom line of a companies accounts. However, although the handling costs do not improve the value of the products, poor handling can very easily take value away through attrition and breakage of the material particles. In addition, poor handling can lead to excessive dust, mess and spillage which are becoming major environmental issues; and poor equipment design leads to excessive downtime and very significant costs for industry. However, these problems can be avoided if the approach to design is one which embraces and takes into account the individual behaviour of the given bulk solid to be handled.

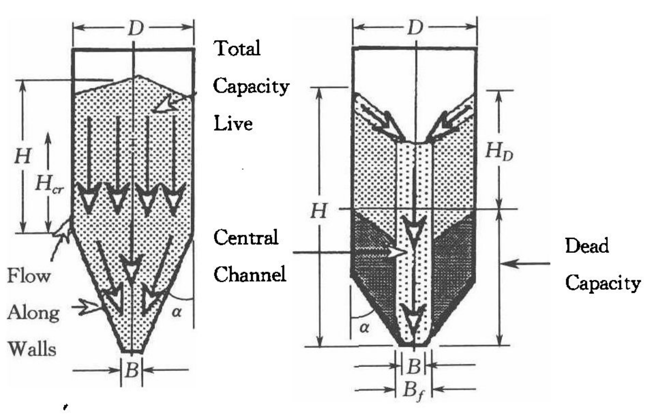

Fig.1 Bin Flow Patterns[1]

The fundamentals of powder flow were developed by Jenike[2] at the University of Utah in the late 1950s and early 1960s. This work led to an analytical approach to silo design based on the characteristics of the bulk material and the mode of flow prevailing in the storage vessel. This work was a major advance and provided a methodology which has been used extensively over the intervening years. The University of Newcastle Research Associates (TUNRA) formed a new division in 1975 called TUNRA Bulk Solids Handling Research Associates (TBS) which aimed to provide high level contract research and development for industry. TBS has been working in this field ever since and has now grown to be an internationally recognised leader in this field.

1. Developments in Storage and Flow

The fundamental work of Jansen (1895)[3] and Jenike et al (1958—1983)[2] has provided a strong underpinning foundation to the identifiable professional discipline of Bulk Solids Handling. This field is vital to the resource and process industries, and has developed to a point where many of the design principles and testing procedures are now very well accepted in industry, both in Australia and overseas. The acceptance of this technology by industry has had a very significant and far reaching impact on materials handling efficiency and productivity. However, the theoretical basis to this technology is extremely secure in some areas but quite empirical in others. There are two areas of theory in particular that require further development and which have far reaching implications in terms of overly conservative design. This leads to less safe procedures being adopted to overcome these shortcomings and an unnecessary and significant environmental impact through the generation of dust, mess, spillage and noise.

The first of these areas concerns the 'radial stress' theory used to determine the outlet dimension for Mass Flow hoppers. This is a critical part of the Mass Flow Bin Design method but it is known that the current approach is overly conservative leading to significantly larger outlet dimensions than are necessary. The current approach does not take into account surcharge loads arising from the volume of material stored above the converging section of the silo, neither does it take into account impact pressures due to rapid filling. Initial work by Roberts[4] has shown these effects to be significant and they need to be adequately accounted for in the fundamental theory.

The second area of concern is the theory used to determine "rathole" dimensions in funnel-flow applications particularly in relation to gravity reclaim stockpiles. The current approach extrapolates the two dimensional stress theory to situations involving three-dimensional stress states in cases where the third dimension is significant. This leads to a serious under-estimate of draw-down and "live" capacity. Roberts[5] has developed a hoop stress analysis which initial testing has shown to provide a more accurate approach for design. A schematic of the hoop stress approach is illustrated in Fig.2. This is an area of work that is currently being developed at Newcastle which will have very significant effects on large scale operations such as reclamation from stockpiles under gravity conditions.

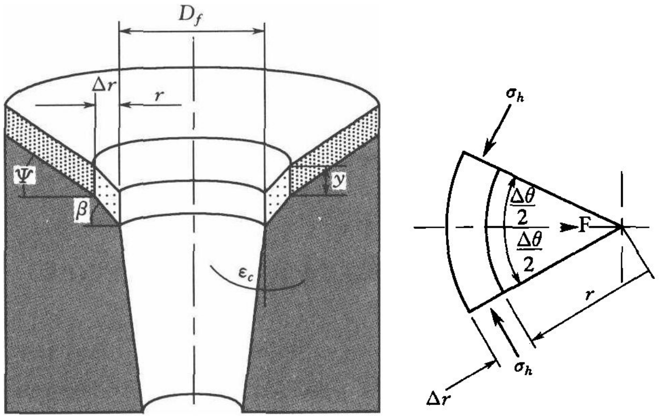

Fig.2 Funnel Flow Design - Hoop Stress Analysis[5]

2. Belt Conveyor Design

In recent years, there has been an increasing need to convey bulk materials over longer distances and at higher rates. Belt conveying is a very efficient means of transportation with low specific energy requirements. However, there is still pressure to reduce power requirements and produce even more efficient conveying systems. Recent research by Wheeler[6] has quantified indentation rolling resistance as a very significant factor in power consumption particularly for long overland belt conveyors. A significant research effort is being undertaken at Newcastle under the leadership of Craig Wheeler to investigate this effect and to develop comprehensive modelling techniques using finite element modelling to understand the loads and deformations that the belt experiences. Although a number of workers have considered the tensions in the belt, it is only recently that the interactions between the bulk solid on the belt and the belt material and geometry have been investigated.

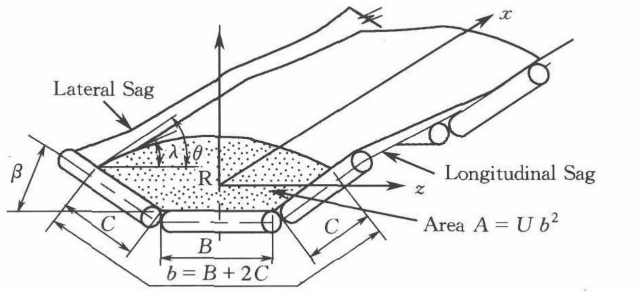

Fig.3 Throughput and Load Profile on a Belt[6]

Much of the work carried out at Newcastle has been verified using industrial scale test rigs. Fig.4 shows a close up view of an instrumented idler roller which is able to measure both the vertical and horizontal loads applied during the passage of the belt over the idler.

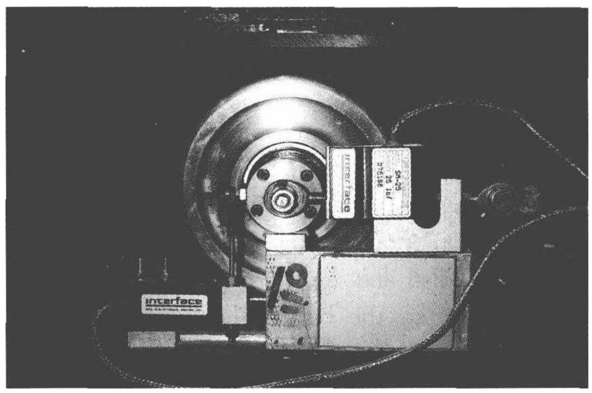

Fig.4 Indentation Rolling Resistance Measurement

3. Pneumatic Transport

3.1 Transient Modelling of Fluidised Dense Phase

Traditionally, the Centre at Newcastle has used a steady state approach to predict pressure drop in dense phase conveying, particularly for the fluidised dense phase mode of flow. The approach used for determining the frictional resistance of the particles utilises the two-phase fluid model method detailed by Weber[7], and as such, a global approach to the pressure drop is used. One phase relates the losses due to air alone, while the second phase accounts for the resistance of the bulk solid in the pipeline. Equation (1) and (2) details the basic form of this model, which has been used with success for predicting the total frictional pressure drop in dense phase systems.

$$\Delta P_{fa} = \lambda_a \frac{\rho_a v_a^2}{2}\frac{L}{D} \tag{1}$$

$$\Delta P_{fs} = m^* \lambda_s \frac{\rho_a v_a^2}{2}\frac{L}{D} \tag{2}$$

where ΔP_{fa} is the frictional pipeline pressure drop due to air,

ΔP_{fs} is the frictional pipeline pressure drop due to the solids, L is the length of the pipe, D is the pipe diameter and ρ_a and ν_a are the average conveying air density and velocity respectively. The solids loading ratio, m^*, represents the non-dimensional ratio between the mass flow of the solids (Ms) and the mass flow of the air (Ma).

To determine λ_s, a back calculation technique is used based on pilot trials data. By eliminating the pressure drop components due to the bends, potential energy and air friction , a solids friction relationship of the form in Equation (3) is obtained[8]:

$$\lambda_s = \frac{C}{m^{*a} Fr_a^b} \quad \text{and} \quad Fr_a = \frac{\nu_a}{(gD)^{0.5}} \qquad (3)$$

Where Fr_a is the average superficial air Froude number.

However, although this technique has been found to be useful practically, typical results of this approach produce predicted values being approximately ±15% of the actual (measured) values[8]. Further analysis has also shown that the sensitivity of the exponents in the model lead to excessive fluctuations in the predicted pressure drop. While searching for an explanation for this behaviour, it has become obvious that the nature of low velocity fluidised dense phase flow is not steady state with significant variation in the bulk density of the material occurring during flow. This has led to a significant research program of work investigating the transient nature of the dense phase flow of bulk solids in pipelines. Electrical Capacitance Tomography (ECT) has been used to analyse the internal concentration of the bulk material during flow. Fig.5 illustrates the approach with some of the results shown in Fig.6.

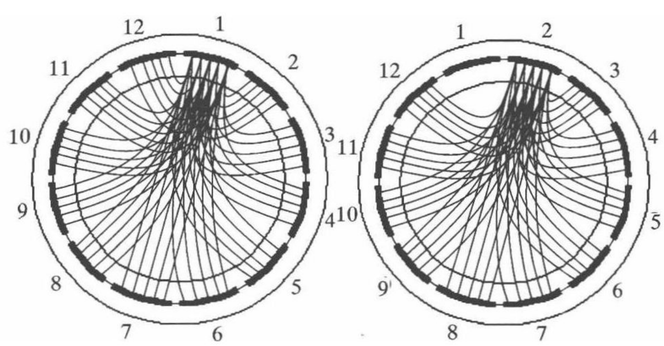

Fig.5 Two Cycles of a Dynamic Excitation Field of a 12 Electrode Sensor

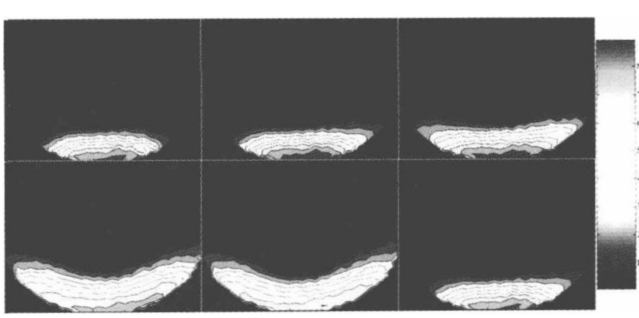

Fig.6 Six contour plots of bulk density variations from a series of images during a pulse of conveyed flyash. The colour bar shows the corresponding bulk density [kg/m³]

3.2 Transient Modelling of Slug Flow

In Slug flow, full bore material slugs are conveyed although the composition of the slugs varies along the length of the pipeline. Hence, this mode of flow lends itself to being modelled using the Janssen approach. In this case, an analysis of the forces acting on a slug or plug of material at the point of incipient motion in the horizontal plane is considered. Fig.3 shows a particle slug element which is subjected to air pressure and stresses in a horizontal pipe[9].

The balance of the forces acting on an element of the length dx can be written as follows:

$$\frac{d\sigma_x}{dx} + \frac{dp}{dx} + \frac{4\mu_w k_w}{D} \cdot \sigma_x + 2\mu_w \rho_b g = 0 \qquad (4)$$

This approach has been developed by various workers[10-11] however a new approach to the transient behaviour of the slugs in the pipeline has been developed at the Centre in Newcastle[12]. This involves an analysis of changes to the mass flow rate and pressure of the conveying gas upstream of the given slug and within the slug.

Example predictions of dynamic pressure, slug length, slug velocity and slug position are shown in Figs 7 and 8.

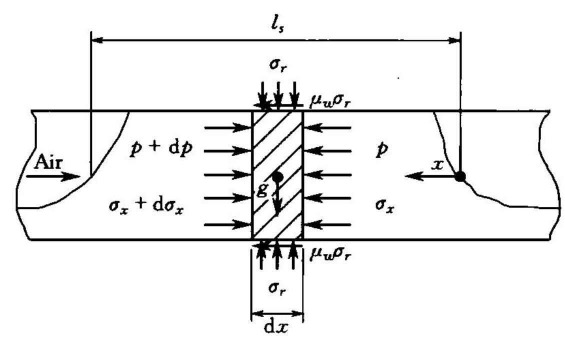

Fig.7 Air pressure and stresses acting on a horizontal particle slug[9]

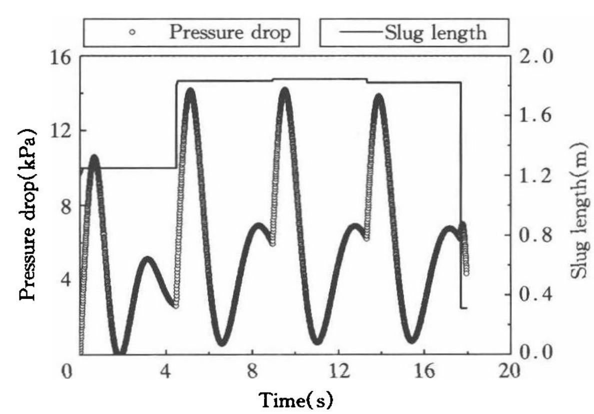

Fig.8 Dynamic Pressure and Slug Length Prediction

4. Concluding Remarks

The Centre for Bulk Solids and Particulate Technologies has had a long standing involvement in bulk materials handling research covering storage and flow, mechanical conveying, belt conveying, pneumatic conveying and associated in-