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Bulk Solids Handling Research at the University of Wollongong

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Forschungsvorhaben an der University of Wollongong
Recherche sur la manutention des matériaux solides à l'Université de Wollongong
Investigación en torno a la manutención de materias sólidas a granel en la Universidad de Wollongong

ウロンゴン大学における粉体取扱いについての研究

沃龙贡大学对散装固料处理的研究

ابحاث مناولة المواد الصلبة السائبة بجامعة وولونجونج

1. Introduction

Research relating to the storage and handling of bulk solids has been undertaken at the University of Wollongong, Australia (and its predecessor institutions) for the past 25 years. The early work related to the performance characteristics of and damage due to grain conveyors and chutes [1—14] while the more recent work has concentrated on storage bin design, the measurement of flow properties, the flow of fine powders in converging channels and the pneumatic conveying of powders. It is aspects of this more recent research that will be highlighted in this paper.

The research has been contributed to significantly by graduate and undergraduate students undertaking research projects, and by the attracting of significant research grants and contracts from such sources as the National Energy Research Development and Demonstration Council (NERDDC), The Electrical Research Board (ERB), The Electricity Commission of New South Wales (ECNSW) and The University of Wollongong.

In a paper of this nature it is impossible to present any aspect in great detail, however, a full list of references is given. Anyone interested in particular aspects of the research is invited to consult the relevant references for more detail and/or make contact with the authors, who will be glad to provide further information.

2. Calculation of Parameters for Mass-Flow Hoppers

To enable analytical expression for such parameters as

— the flow factor for no-arching — *ff*
— the normal stress at the wall — $\sigma_w/\gamma B$
— the non-dimensional surcharge factor — q

in a converging mass-flow channel to be obtained, it is necessary to have an explicit expression for the stress function $s(\alpha)$.

The necessary explicit expression has been obtained from the Walters Theory [20] and from the Enstad Theory [22, 24]. The expressions for *ff*, $\sigma_w/\gamma B$ and q obtained from the Enstad Theory provide a useful alternative to the numerically derived values of Jenike, especially in the evaluation of hopper wall loads and feeder loads.

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3. Wall Loads in Mass-Flow Bins

The prediction of bin wall pressures continues to be an area of bin design which is the subject of considerable research and conjecture. While there are still widely varying approaches to the problem, one thing is clear — the loads exerted on the walls of a bin under operating conditions are directly related to the flow pattern which the stored bulk solid exhibits when flowing into and, more importantly, when flowing out of the bin. Suggested procedures for predicting wall stresses in mass-flow bins are:

For initial filling or static conditions:

a) cylinder — Janssen method with $K_j = 0.4$

b) hopper — Jenike method of reference [25] or Walker method with

$$K = \left[1 + \frac{\mu}{\tan\alpha}\right]^{-1},$$

or Walters/Clague method with $K_w = 0$ and $D_n = 1$.

For flow or dynamic conditions:

a) cylinder — Jenike minimum strain energy method with the modifications as suggested in reference [25]

b) hopper — Jenike method of reference [25] or Walters/Clague method.

Readers interested in the detail of any of these theories are referred to references [25—27]. To illustrate the variations in the predictions obtained with the suggested methods, Fig. 1 is given which shows the theories applied to one of the experimental bins used by Clague. Clague's experimental results are included for comparative purposes.

4. Wall Loads in Funnel-Flow Bins

Two of the most recent and comprehensive methods for predicting the wall loads in funnel-flow bins are due to Jenike et al [28] and the American Concrete Institute [29]. Both

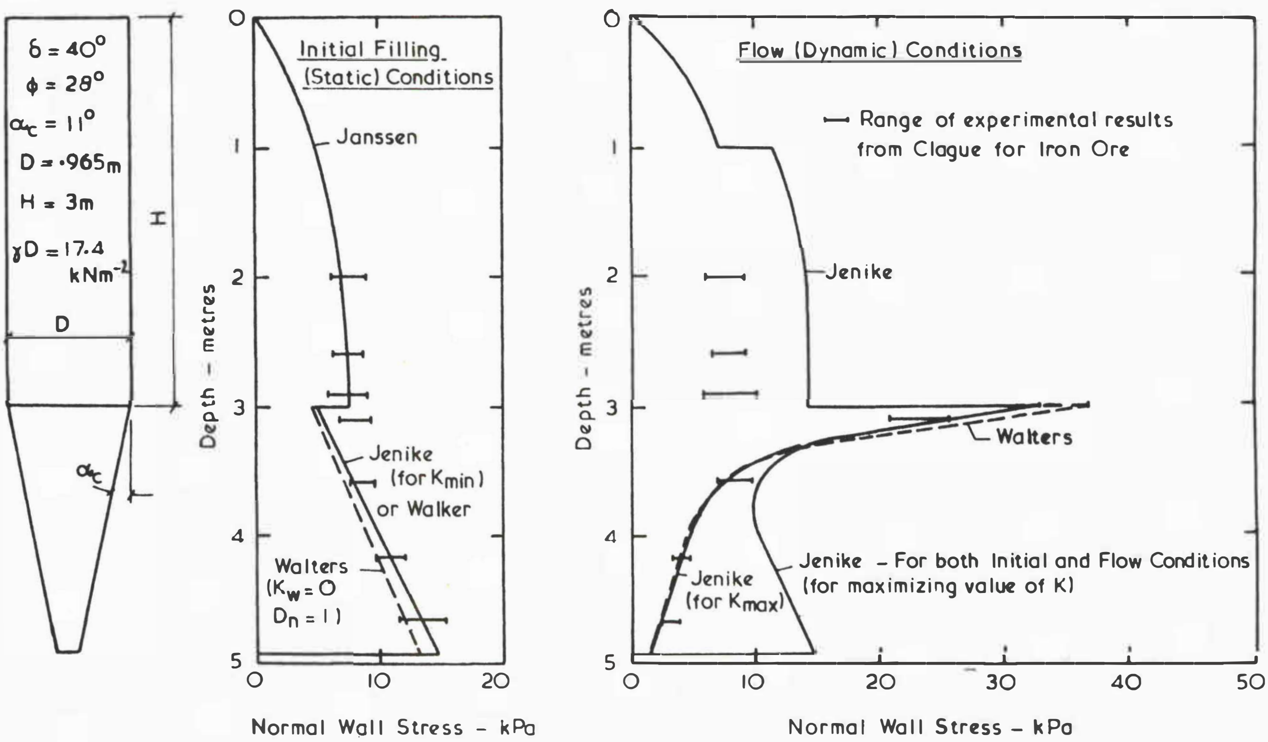

Fig. 1: Comparison of wall stress theories and Clague's experimental results

methods make use of the Janssen method (or the Reimbert method in the case of reference [29]) for predicting the static or initial filling loads on the vertical walls and apply overpressure factors to account for the increased wall loads under dynamic or flow conditions. Both theories assume a single symmetric outlet.

The authors have provided alternate methods for calculating the wall loads in the cylinder and hopper of funnel-flow bins, based on the Jenike approach. For details readers are referred to reference [27].

5. Measurement of Flow Properties of Bulk Solids

In recent months considerable work has been done on determining the flow properties of coal for storage bin design. This research is being sponsored by The National Energy Research Development and Demonstration Council [NERDDC], who have provided funds for the employment of a professional engineer and a technician. This project is still in its early stages and no definite research findings have been published. An indication of some preliminary trends can be found in reference [30]. The work being undertaken may be classified under three general headings

- development of standardized procedures for flow property testing,
- development of interactive computer programs to process flow property data and provide hopper geometry, bin capacity, flow rate and wall load information,
- collection of flow property data on individual coal samples. Particular attention is being paid to variations in the basic composition of the sample, its moisture content, particle size and particle size distribution.

Work has also been done on assessing the effect of vibration on the flow properties of bulk solids. In references [19, 23] it is shown that vibrations can have a significant effect on reducing wall friction, while in reference [31] it is shown that vibration of a filled shear cell for 1 hour can increase the strength of coal more than time consolidation at rest for 1 day. The vibrations used were aimed at simulating conditions existing in bulk rail waggons.

6. Prediction of Feeder Loads

In 1979 the authors published a method for predicting, theoretically, feeder loads for mass flow bins [32]. The initial loads predicted by this method, in general, are higher than those predicted from a more empirical standpoint. Subsequent experimental work has confirmed that the usual empirical multiplier of 4 to estimate initial loads from the calculated flow loads [33, 34] is inadequate; a more realistic multiplier would be 8 to 10. As a result of this work it seems that the flow loads on feeders are best predicted using the approach of Reisner [35] based on the major consolidation stress at the bin outlet, while initial pressures are best predicted by using the approach given in reference [32].

7. Flow of Fine Powders from Mass-Flow Bins

An important aspect of storage bin design is the determination of flow rate. In some situations adequate plant performance, or in other cases, maximum plant capacity may be governed by the discharge rate from a bin.

The prediction of the flow rate of bulk solids requires that certain properties of the flowing bulk solid be known. These properties include its cohesive and frictional characteristics, the variation of bulk density and ease with which interstitial fluid can permeate through the powder as a function of the extent of consolidation of the powder. The determination of the permeability of the bulk solid indicates whether the material can be regarded as a coarse bulk solid or one in which fluid-particle interaction effects will be significant. Such materials are referred to as fine bulk solids.

With the handling of finer powders in industry it became apparent that the flow rate of fine bulk solids could be orders of magnitude less than the flow rate predicted by formulae pertaining to the flow of coarse bulk solids. This discrepancy can be accounted for by the formation of adverse interstitial fluid pressure gradients which occur at the hopper outlet during flow, Fig. 2.

To prevent the formation of excessive negative void pressure developing in the vicinity of the hopper outlet, interstitial fluid may be injected into the hopper at selected locations, thereby obtaining an increased flow rate. The quantity and pressure of the injected fluid must be determined so that fluidisation and flooding of the bulk solid is avoided and the unfavourable pressure gradients due to the injected fluid have little effect, Fig. 2.

Research by the authors has enabled theories to be developed which both account for and predict the magnitude of the interstitial fluid pressure distribution during flow of a fine powder in a mass-flow bin [36—39, 41, 45—47]. Figs. 3 and 4 show a comparison between predicted values and observed values for the interstitial fluid pressure distribution and flow rate variation with outlet width in a plane flow type mass-flow experimental bin. At the present time the initial approximate model is being improved and extended to allow better predictions to be made and also to describe the flow of bulk solids from pressurised bin systems.

8. The Evaluation of the Contents of a Silo

In a recent paper [40] the authors have shown that the accurate prediction of the content of a silo in a static state of stress requires that the variation of bulk density with depth in the silo be known. Such a prediction is possible by accounting for the effects of compressibility in the evaluation of the variation of the vertical stress with depth in the silo. The effect of the compressibility of the bulk solid is described by an empirical equation, the constants for which are readily determined using simple laboratory measurements.

For tall bins a sufficiently accurate prediction of the contents may be obtained by utilizing the value of the bulk density which is attained at the base of the silo. Such a value may be predicted using an iterative procedure incorporating the familiar Janssen equation for the vertical stress and an empirical variation for the bulk density versus major principal stress. Alternatively, for the determination of the contents of a tall silo, use of the bulk density value obtained from a sample box situated at the base of the silo is suitable. However, measurement of the bulk density using this approach may be inconvenient.

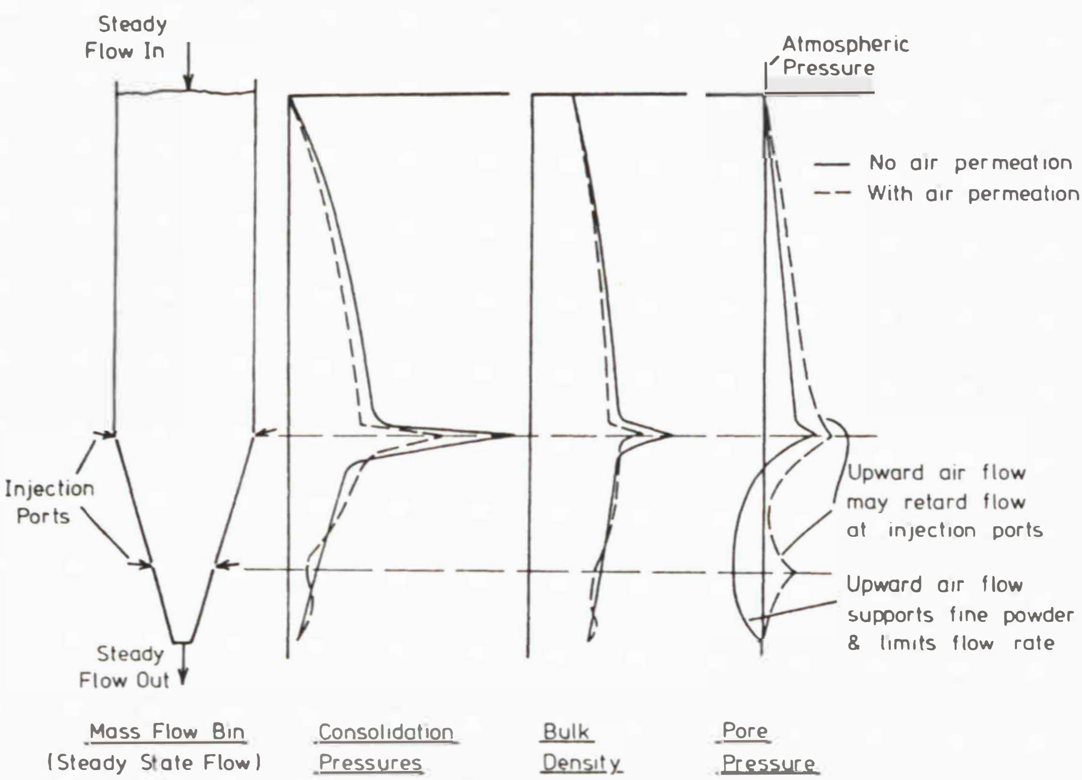

Fig. 2: Air permeation assists the flow of fine powders from mass flow bins

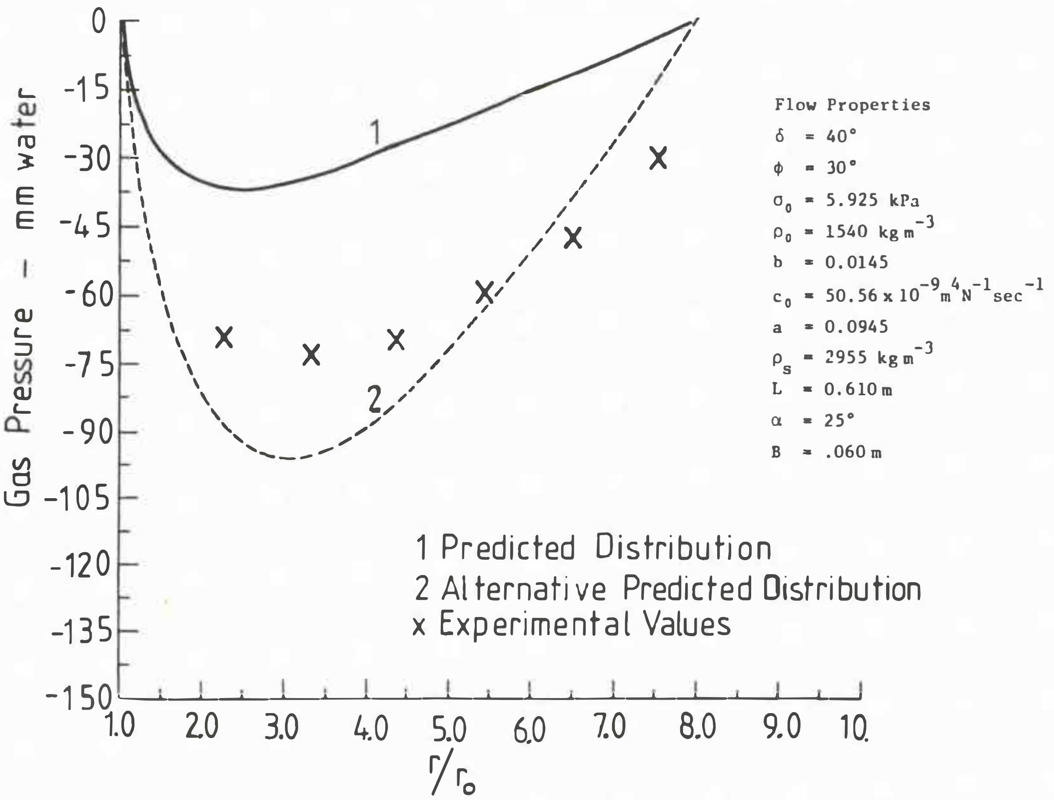

Fig. 3: Comparison of experimental and predicted gas pressure distributions in an experimental plane flow bin

9. Flow Properties and Handling of Precipitator Dust

The authors have been asked by the Electricity Commission of New South Wales to evaluate and advise on the methods being used in New South Wales power stations for the dry handling of precipitator dust.

The project is aiming to provide design parameters to enable the dust, collected in the hoppers of power station precipitators and bag filters, to be handled more effectively. The conventional flow properties, together with fluidisation characteristics are being examined. Theoretical models for deaeration times and hopper discharge under positive pressure, are being developed.

10. Dense-Phase Pneumatic Conveying of Pulverised Coal

Pulverised coal is becoming increasingly important as an industrial fuel and it is essential that techniques for efficiently handling the coal be developed. One handling technique with considerable merit is dense-phase pneumatic conveying.

In 1980 the Bulk Solids Handling Laboratory at Wollongong University purchased a Sturtevant Pulse Phase pneumatic conveying rig with funds donated by the Electricity Commission of New South Wales.

In 1981 research grants from the Electrical Research Board and from NERDDC have enabled a professional engineer and a technician to be employed on the project.

The research aims to establish

- conditions of the coal under which it will dense-phase convey in continuous rather than slug form
- the solids loading ratios possible
- the pressure drops which result
- conditions which will allow good control over the solids flow rate and techniques for varying the flow rate
- techniques for achieving continuous rather than batch conveying
- a mathematical model for dense-phase pneumatic conveyor design.

11. Industrial Consultancies

Over the past twelve years members of the research group have undertaken research and consultancies on behalf of industry. Assistance has been provided to more than 45 industrial concerns and several successful bulk solids storage installations have been built based on our recommendations.

12. Inclusion of Bulk Solids Handling in Engineering Degree Programs

An important aspect of our work on bulk solids handling has been the inclusion of electives on bulk solids handling in the third and fourth year of the Mechanical Engineering Undergraduate Degree Program and in the Coursework Masters Program.

Undergraduate students are now able to choose from three elective offerings relating to

- — storage bin design including the modelling of flow in bins, flow property measurements, hopper geometry determination, bin wall loads, flow rate prediction, feeder design
- — conveying of bulk solids including belt conveyors, screw conveyors, bucket elevators, pneumatic and hydraulic conveying.

These subjects provide a unique opportunity to give students subjects which combine, in one unit, the elements of

- — theoretical model development
- — experiment to obtain the model parameters, and
- — design, where the theory and experiments are used to produce designs of bulk solids handling plant.

In these courses we are able to present to students up-to-date information relating to bulk solids handling where we can combine the experience that is gained from research and industrial consultancy. The courses also enable us to realize the gaps and shortcomings that exist in the current information, thus providing the impetus for our on-going research program.

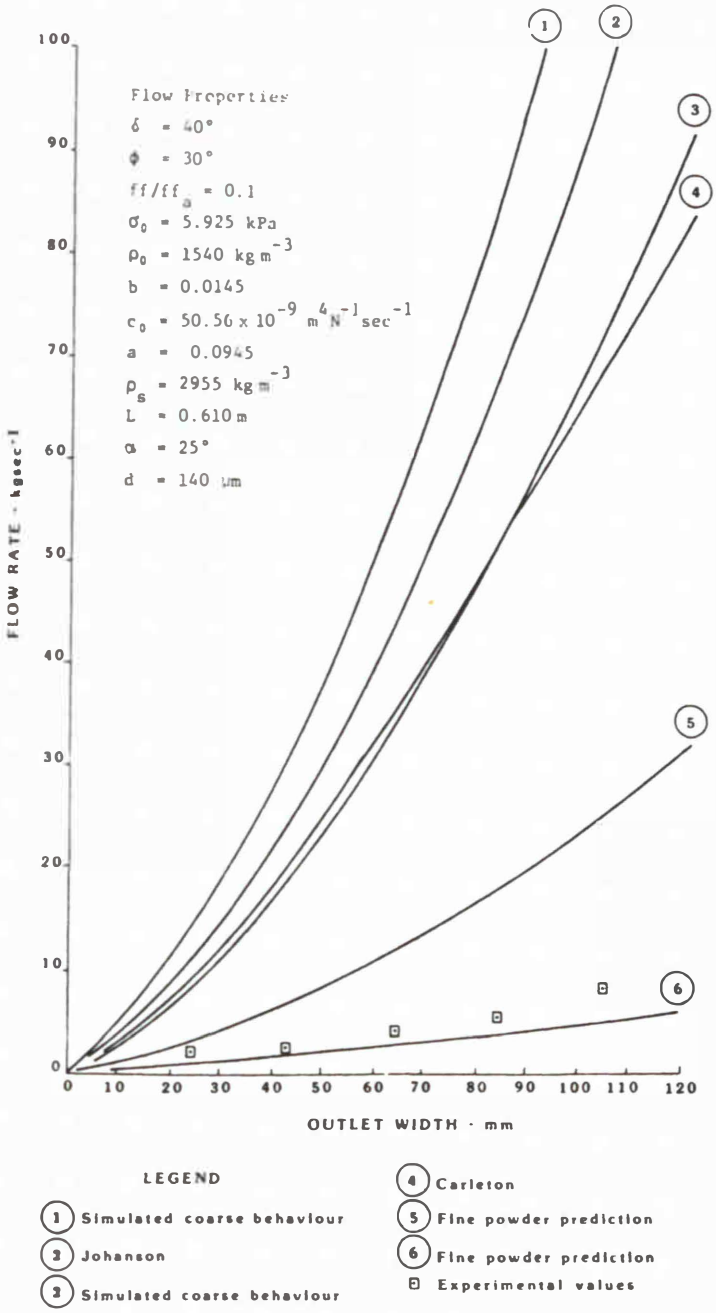

Fig. 4: Comparison of predicted flow rates to experimental values

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