INTRODUCTION

In conveying of particulate materials, certain physical, chemical, and biological properties of the materials are of importance in the functioning of the handling system.

The properties may be divided into two categories:

I. Those which influence the flow mechanism and, through this, such items as the power requirement and system capacity. Since the properties of individual particles are fundamental to the behaviour of a mass of material, this category includes particle size, shape, density, surface roughness, and friction coefficients.

II. The second category includes properties which will not be discussed in this paper, such as the tendency of the conveyed material to cause damage or to be damaged through dynamic shock, temperature effects, chemical activity, and abrasiveness.

Research investigations have produced general equations intended to relate particle properties to such variables as power requirement, capacity, or critical design dimensions. However, there are many materials for which they cannot be properly used because the particle properties have not been thoroughly investigated. This is particularly true of agricultural grains.

CONVEYING METHODS

Three steps in moving a material are: putting it into motion, moving between locations, and stopping it at the desired point. Generally these processes are carried out with the aid of one or more of three types of agencies.

1. Those which employ a fluid carrier (gas or liquid), such as a blower, fluidizing conveyor, or air slide.

2. A mechanical device which contacts the material, such as a flight, screw, bucket, belt or vibrating veyer.


CONVEYING WITH A FLUID AGENT

In the case in which the particles being conveyed are intimately mixed with the fluid agent, the mixture behaves in many ways similarly to a real fluid. For example, the rate of flow of a mixture through a tube or duct is related to the observed fluid pressure drop (1) (2). Also, following from this, the rate of flow of solids can be evaluated approximately by measuring the pressure drop across a nozzle placed in the line (3) (4) (5).

Studies of the fluid properties of beds of fluidized particles have included measurements of viscosity (6), and formulation of relationships for temperature and viscosity equivalent properties (7). Despite the apparent similarities to real fluids, which suggest that the mixture behaves like a homogeneous material, it has been necessary to include terms to describe the individual particles in order to obtain general correlations of experimental data.

A particular case of fluid conveying is that in which particles are carried along or blown by an air stream, as in a grain blower. Characteristic of this mode of conveyance in a horizontal direction is the hopping motion, or saltation observed by Segler (8) in wheat conveying, and also observed with blowing dust particles. The sequence of events in each hop includes, upward motion due to aerodynamic lift or bouncing, horizontal motion due to air drag, and downward motion due to gravity force. (Fig. 1).

From considerations of this type Vogt and White (1) developed an equation for pressure drop for an air-solid particle mixture being conveyed in a pipe. This expression includes particle density, particle diameter and air-solids weight ratio.

In the case of vertical conveying, the particle is raised by the drag of the air flowing past it at a speed which is sufficient to overcome wall friction, gravity, and particle acceleration forces. If only gravity force is acting, the relative velocity of the air and the particle is called the terminal velocity.

Particle density, the drag of the air on the particle, and particle friction on the duct or other boundary surfaces are important in both horizontal and vertical conveying. Also high rates of spin have been observed (8) consequently though it is not usually included in equations of this type, particle moment of inertia may be of significant importance.

Particle Density

Particle density can generally be found by using a pycnometer.

Air-Particle Drag Forces

The force of air on a particle, due to a difference in velocity, is related to the drag coefficient (2) (9). For the case of a body falling freely the drag coefficient is dependent on object density and a characterizing dimension of the object. For spheres the latter variable is the diameter. However, for non-spherical particles the selection of a characterizing dimension is more difficult.

Cramp and Priestly (10) used mass/length in evaluating the forces on individual wheat grains in their investigation of the maximum efficiency possible in vertical conveying. Squires et al (11) encountered it in connection with sedimentation of discs.

It is possible that no easily found linear dimension will properly characterize such particles in fluid flow analyses. However, the topic was reviewed by Hawksley (12) and, within certain limits, the effect of being non-
spherical can be accounted for by introducing a sphericity term.

\[
SP = \frac{\text{area of a sphere of the same volume } V \text{ as the particle}}{\text{area of the particle}} = \frac{\pi d^2}{\pi da^2} = (1)
\]

\[d = \text{diameter of sphere having the same volume } V \text{ as the particle}
\]

\[d_s = \text{diameter of a sphere having the same area } A \text{ as the particle.}
\]

Further, the term \( V/A \) is sometimes used with reasonable success as a characterizing particle dimension in fluid flow work, where for a sphere

\[
V = \frac{1}{6} d
\]

\[V, A, d = \text{volume, surface area and diameter respectively.}
\]

The same term might be useful in terminal velocity equations (4) (13), particularly if the particles did not orient themselves systematically relative to the fluid flow. It might also be useful in the pressure drop equation of Vogt and White (1).

The use of this approach requires the measurement of the surface area of irregular particles. There are many different methods of finding surface areas (14) (15).

The measured surface area may vary with the technique used, even though both values are valid and accurate. The particular surface area obtained by application of a principle due to Cauchy (12), which states approximately that the surface area of an object is four times its projected area, would seem to have value in the case in question.

In addition to the conveying case, there are many problems in which the evaluation of a characterizing particle dimension is important. These include the formulation of a mathematical expression for pressure drop of air flowing through grain beds (16), also such knowledge would allow insertion of an appropriate value in fundamental grain drying equations (17) where rate of drying depends on the diffusion of moisture in kernels and therefore on the size of the kernels.

**Particle-duct friction**

In conveying studies, the fractional effect due to impingement of fluidborne particles on each other and on duct walls is often not evaluated specifically (8). However, it has been done by Hariu (5), Mehta (18), and Crane and Carleton (19) who carried the analogy to a fluid to the point of calculating a friction factor based on the use of the Fanning equation. The friction factor was evaluated from observed pressure drops but no attempt was made to relate it to the physical characteristics of the particles. Shortcomings of the use of the Fanning equation in this application are discussed by Pinkus (20). He demonstrates that since the effect of particle properties, including size, are not taken into account, it does not have general applicability.

**MECHANICAL CONVEYORS**

In transport involving flight, screw, belt, and bucket conveyors, the coefficient of friction and material density have an important effect on power requirement and capacity.

The coefficient of friction has many values depending on the situation. Firstly, the friction may be between contacting particles, alternatively it may be between particles and a bounding surface. In addition, these may be static, or dynamic values. Further, the dynamic values may vary with the type of handling. For example, a vibrating conveyor reduces friction between the particles and the conveyor, an air-slide also reduces frictional effects, on some belt conveyors the particles are dropped on to the moving belt and are accelerated to belt speed by contact with the belt by a force which could be evaluated in terms of a friction factor (21). A still further variation may arise from moisture content changes.

Coefficients of friction for static cases have been found (22) but apparently little work has been done in evaluating the other ones.

**GRAVITY FLOW**

In gravity flow of granular materials a major portion of the attention has been given to the difficulties associated with starting or maintaining flow in beds of material. In this connection a variety of factors are important. Studies indicate that the internal friction factor (between particles) and the friction between particles and containing walls are of primary importance since they contribute to bridging or doming and consequent prevention of flow. (Fig. 2).

The bridging effect was studied by Jenike (23) (24) who evaluated the minimum hopper opening required to insure flow, in relation to the properties of the material in question. Thus, he found that in order for flow to be unobstructed by doming, the width of hopper opening

\[
B > \frac{b v}{b h} \sin 2 \phi \cdot \frac{1}{w}
\]

where \( f_c \), called the flow factor, a property of the granular material, is of critical importance in determining whether or not flow will occur.

\[
f_c = \frac{f_c}{2 \tan (45 + \phi)}
\]

\[
\phi = \text{the angle of static internal friction}
\]

\[
\phi = \text{depends on the wall slope and the friction factor between the material and the containing wall.}
\]

The flow factor can be measured on a transverse shear testing machine over a range of applied pressures. Its value will, of course, vary with conditions such as the degree of packing and moisture content of the material.

In studies of coal flow, Legget (25) concluded that factors, including surface moisture and interlocking of particles, combined to give a cohesion which permitted the formation of steep, unstable slopes. When such a slope is broken down, it achieves an angle of repose which presumably is primarily dependent in the internal friction. A condition of this type is frequently observed with ground feeds.

Summary.

In the conveying of many agricultural products, physical properties of
mocouples were located flush with the concrete surface and two were located at the bottom of each slab. It was considered that the thermocouples at the surface would measure the temperature of the junction between the slab and a pig whenever a pig lay directly on one of the couples. The leads from the thermocouples were connected to a variable-span 12 point recorder.

Two series of tests were made, one recording surface and base temperatures of two slabs simultaneously, while for the other test surface temperatures of all three slabs were recorded simultaneously. Throughout the tests no bedding was used on the floor slabs and from three to five hogs, each approaching market weight, were kept in the pens. This number of hogs together with the limited size of the sleeping platforms, insured a reasonable incidence of contact between the hogs and the thermocouples.

Results

Figure 2 shows a curve of surface temperature obtained from the recorder when a pig laid down on a thermocouple located on the surface of the 1:1 vermiculite slab.

From this figure it is obvious that the surface temperature did not immediately assume the normal body temperature of the pig. The rise from the slab base temperature over a period of time indicates a heat flow condition where boundary layer is an important factor. The second state of transient flow must then apply: that with surface resistance controlling. Data from this temperature curve were combined with the physical characteristics of the slab, and the theoretical relationships plotted in Figure 1, to reveal the nature of heat flow from the pig into the sleeping floor. Referring to Figure 1 the value of X was obtained by combining time values from Figure 2 with the physical properties of the slab. The value of Y was obtained by combining the temperature data from Figure 2 with the normal body temperature of hogs. With values of X and Y available, intercepts on Figure 1 gave a value for m. From m in turn, a value for h the surface coefficient was derived. The appendix shows the calculations which were carried out to arrive at a numerical value for h. The value obtained was:

\[ h = 1.5 \text{ btu/ft}^2 \text{ hr °F} \]

Conclusions

The method developed here may serve to reduce the physiological phenomena associated with heat dissipation from animals to terms more readily handled by engineering methods.

Further investigation is required to determine the value of surface coefficients over a range of ambient temperatures, and to attempt to fix these values accurately in certain ambient temperature ranges. Having done this, a suitable standard for flooring materials could be established. A suitable standard would appear to be that heat loss to the flooring material per unit contacting area should not exceed heat loss to the surroundings from a standing animal under conditions of thermoneutrality.

APPENDIX

To obtain \( h \)

Vermiculite concrete, i:1 mix

\[ \begin{align*}
\text{rm} &= 1/4 \text{ ft} \\
k &= 0.167 \text{ btu/hr ft °F} \\
\text{cp} &= 0.20 \text{ btu/lb °Ft} \\
\rho &= 75 \text{ lb/ft}^3 \\
\end{align*} \]

Substituting for \( X \) in Figure 1

\[ X(\theta = \frac{1}{2}) = 0.167 \times \frac{1}{4} = 0.0417 \]

\[ X(\theta = \frac{1}{4}) = 0.045 \] \[ X(\theta = \frac{1}{8}) = 0.025 \]

From recorder chart, Figure 2

\[ \begin{align*}
Y(\theta = \frac{1}{2}) &= 101 - 82 \\
Y(\theta = \frac{1}{4}) &= 100 - 64 \\
Y(\theta = \frac{1}{8}) &= 53 \\
Y(\theta = \frac{1}{16}) &= 61 \\
Y(\theta = \frac{1}{32}) &= 75 \\
\end{align*} \]

From Figure 1, to there values of \( X \) and \( Y \)

\[ m = 0.45 \]

from which

\[ h = 1.5 \]

Using \( h = 1.5 \)

\[ m = 2.56 \]

\[ k = 1.0 \text{ btu/ft hr °F} \]

\[ \text{cp} = 0.20 \text{ btu/lb °Ft} \]

\[ \rho = 150 \text{ lb/ft}^3 \]

from which values of X may be obtained, and, from X and m, values of Y, solving:

\[ t_1 (\theta = 0) = 64 \text{ °F} \]

\[ t_2 (\theta = \frac{1}{8}) = 68.5 \text{ °F} \]

\[ t_3 (\theta = \frac{1}{4}) = 70.5 \text{ °F} \]

\[ t_4 (\theta = \frac{1}{2}) = 72.5 \text{ °F} \]

List of References


2. Hottel, H. C., from (1).
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APPENDIX C

Capital Cost
Auger bunk feeder $1,427.50
Unloading wagon system 583.00
Hand feed cart system 423.00

Operating Cost Per year
Auger bunk feeder 7.50
Unloading wagon 24.00
Feed Cart 0.00

1.) Pay-off period for auger vs. unloading wagon:
(1427.50 - 583.00) = 57.5 years
( 24.00 - 7.50) = 3.5 years

2.) Hand cart vs. unloading wagon
The hand cart system, having both a lower first cost and operating cost, is clearly indicated as the best selection.

APPENDIX D

Capital Cost
Self feeder

Yearly Feed Costs
Limited feeding system
Grain (Appendix B) 3,865.00
Roughage 112 Tons at $17.50/Ton 1,960.00

Self feeding system
Grain (Appendix B) 4,625.00
Roughage 82 Tons (1) at $17.50/Ton 1,435.00

Net feed cost favoring limited feeding 235.00

Pay-off period 123

= ½ year 235

For additional comparisons:

17. Jenike, A. W., Better Design for Bulk Handling Chemical Engineering, 61, p. 175, 1954.

LIST OF REFERENCES

3. Self Feeder for cattle, Alberta Department of Agriculture, Hlndon-
4. MTM Association for Standard and Research, 620 Penn. Ave., Pittsburgh, Penn., 1950

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Economic advantage of such a program. If the economics are not favor-
orable, then inducements must be added, possibly through construction
or financial aid. This is another portion of the program that will require
a great number of years to accomplish.

Research activities must keep abreast or ahead of watershed develop-
ment work. The development of techniques and methods and the compi-
lation and analysis of research information will need priority in an
adequate program of water use and conservation.

Experience has shown that there are two distinct phases to a water development program, the engineer-
ing and the agronomic which must be brought together. It is virtually im-
possible to deal with watershed development or with research in hydro-
logy solely in terms of one or the other. Close co-operation is required
to develop to the fullest the potential-
ties of any watershed. Satisfactorily
designed structures are but half the
job, compatible crops and cropping
practices are necessary to complete
the picture. It is only through such
co-operation that the project econ-
omics can become favorable.