Mansoura Engineering Journal, Vol. 19, No. 4, Dec. 1994

ANALYSES OF HYDRO-AND PNEUMOTRANSPORT OF HOMOGENEOUS FLOW FOR SOLID PARTICLES

تحليل للنقل باستخدام الماء والهواء للسريان المتجانس للأجسام الصلبة

A. M. TOLBA
Mechanical Power Engineering Department
Faculty of Engineering. - Mansoura University, Egypt

خلاصة :

إن عملية نقل الأجسام الصلبة باستخدام الماء والهواء كوسط حامل لها، عملية فى غاية الأهمية، وتستخدم فى العديد من عمليات الصناعة التى تعمل فى هذا المجال. وفى هذا البحث تم عمل تحليل ودراسة نظرية لعملية نقل الأجسام الصلبة والتى لم تعالج بمثل هذه الطريقة من قبل من حيث السهولة والبساطة، وتم استنباط معادلتين هامتين هما معادلة الفقد فى الضغط و معادلة السرعة الحرجة لخليط من سريان المائع والصلب فى صورة متجانسة فى أنبوبة لأى زوايا ميل (أفقى - مائل - راسى). وقد استخدمت طريقة التحليل الرياضى التى تناسب عملية التجاس للسريان وتتماشى مع موضوع الدراسة، هذه المعادلات هى معادلات عامة صالحة للأستخدام فى عمليات نقل الاجسام فى أنبوب فى وسط مائعى. ولكى يمكن اثبات وتاييد النظرية المقترحة للإستخدام العام، تم مقارنة الفقد فى الضغط المستبط فى هذا البحث بالنتائج العملية المتاحة للعديد من الباحثين السابقين وقد اعطت نتائج جيدة

Abstract

Transportation of solid particles through pipe line using air or water as a carrier fluid are widely used in the various types of industry. In this study, theoretical study is directed to develop general mathematical relations that could be utilized to predict the pressure drop and critical velocity for fluid-solid mixture flow through the pipe of any inclination. A general equation has been developed for solid transportation using fluid media in pipe, equation of head loss predicts quite accurately the flow of solids, of any shape, size and specific in pipe of and sizes and orientation (horizontal, inclined and vertical), . These equation have been compared with a various existing experimental results by other investigators and were given an accurate agreement.

1- INTRODUCTION

The conveyance of solid particles through pipeline using a carrier fluid is an old technique, finding its application in various fields of engineering such as mechanical, chemical, petroleum, mining and nuclear ...ect. Pipeline transportation of solids may be achieved either as an homogeneous or heterogeneous flow of the mixture, a homogeneous flow is one in which the particles are uniformly distributed across the pipe. Solids are transported through pipeline as air suspension in pneumotransport and as water suspension in hydrotransport.

In spite of research background in this field since beginning of this century, the design methodologies of hydro- and pneumotransport are still an empirical art. however the concerned literature shows that the majority of investigation on hydro- and pneumotransport have been directed mostly towards the determination of correlation for pressure drop and minimum transport velocity. The important investigation are summarized in the following paragraph :

In 1924 Cramp and Priestlegy [1] have been started studying the phenomenon of hydro--pneumotransport in pipe at different operating condition of horizontal, inclined and vertical pipelines. Wilson [2] carried out an experimental study as well as Hariu & Molstad [3] and Clark [4] at different solid flow rate through horizontal pipe. An experimental work of numerous investigators [5, 6, 7, 8] have been carried out work to get a relation of head loss and critical velocity through horizontal, inclined and vertical pipelines at different operating conditions. Rickarddson and Meleman (9) have been studied the pneumatic conveying (solid velocity and pressure gradient) in a one-inch horizontal pipe, they found that the pressure gradient increase with fluid velocity and sand flow rate. A number of investigators (10.11,12) carried out an experimental study of hydro-pneumotransport in pipe at different operating (solid grain size, flow rate and fluid velocity) conditions of horizontal, inclined and vertical pipelines, most of results on head loss. Konno and Saito [13] carried out study on pneumatic conveying of solids through straight pipe whereas, Konchesky et al. [14] have been studied experimental air and power requirement for the pneumatic transport of crushed coal in horizontal pipe and vertical pipe. Recently, Doron et al. [15] made experimental and modeling study for the slurry flow in horizontal pipes and developed theoretical models which found to be limited in use.

2- THEORETICAL ANALYSES

In the present study general mathematical relations for pressure drop (head loss) and critical velocity are driven for a fully accelerated fluid-solid mixture flow through pipe.

2 .1 Pressure Drop

when the solid particles flow through horizontal pipe under fully suspended condition, the total loss of energy is mainly due to the fluid-pipe friction and due to the drag of particles. In case of inclined and vertical pipeline flow mixture, additional energy, as compared with horizontal pipeline, is required to overcome the effects of gravity and buoyancy of the particles, which acts in the opposite to the fluid flow, when the mixture flow up the gradient.

Let us consider that a solid particle of weight w_p be flowing through an inclined pipe, the force balance of the particle is shown in Fig. 1, with a fluid of density ρ_f , may be obtained as :

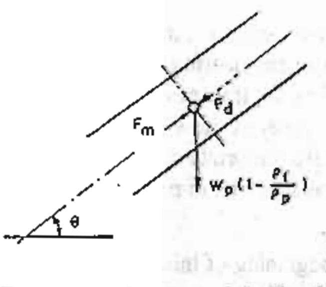


Fig. 1 Force Balance of the Particle

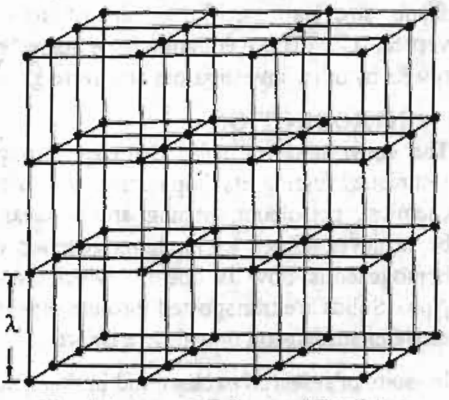


Fig. 2 Proposed Scheme of Particle Distributed in Pipe

$$F_m = F_d + w_p(1-\rho_f/\rho_p)\sin\theta \qquad (1)$$

Thus, equation 1 is valid for horizontal, inclined and vertical pipe flow of fluid solid mixture. The drag force F_d may be obtained by using the standard drag formula

$$F_d = \frac{1}{2}C_d\rho_f(V_f - V_s)^2 A_p \qquad (2)$$

If the total number N of solid particles at a pipe cross section be know for a certain solid flow rate, the total motive force F required by the particles at the pipe cross section will be given as :

$$F = F_m \cdot N \qquad (3)$$

substituting the value of F_m from the equation 1 and equation 2

$$F = \left[\frac{1}{2}C_d\rho_f(V_f - V_s)^2 A_p + w_p\left(1-\rho_f/\rho_p\right)\sin\theta\right]\cdot N \qquad (4)$$

The quantity and total number of solid particles remain constant in the unit length of pipe for particular rate of solid flow in fluid media. in order to estimate pressure drop and critical velocity a regular distribution of particles in the pipe is assumed and it is divided into a large number of hypothetical cubes of side λ as shown in Fig .2. The value of λ depends on the volumetric concentration of solid in the mixture.

$$n\lambda^3 = AV_s \quad \text{or} \quad \lambda = [A\cdot V_s/n]^{1/3} \qquad (5)$$

Substituting the value of ($n = W_s/w_p$) in the above equation

$$\lambda = \left[A\cdot V_s\cdot w_p/W_s\right]^{1/3} \qquad (6)$$

As one particle requires λ^2 area of pipe cross section, N particle require $n\lambda^2$ area of pipe cross section, Therefore,

$$A = N\lambda^2 \ldots\ldots \text{or..} N = A/\lambda^2 \qquad (7)$$

Substituting the value of λ from equation 6 in equation 7

$$N = (A)^{1/3}.\left[W_s/V_s\, w_p\right]^{2/3} \qquad (8)$$

Now, Substituting the value of N from equation 8 in equation 4

$$F = \left[0.5C_d.\rho_f(V_f - V_s)^2.A_p + w_p(1-\rho_f/\rho_p \,\mathrm{Sin}\Theta\right].A^{1/3} \\ .\left[W_s/(V_s.w_p)\right]^{2/3} \qquad (9)$$

2.1.1 Moving Power of Particles

The power P_c required for getting the particles of one such cross section of pipe moved will be obtained as :

$$P_c = F.V_s \qquad (10)$$

Substituting the value of F from equation 9 in equation 10

$$P_c = \left[\theta.5C_d.\rho_f(V_f - V_s)^2.A_p + w_p(1-\rho_f/\rho_p \,\mathrm{Sin}\theta\right].A^{1/3}.V_s \\ .\left[W_s/(V_s.w_p)\right]^{2/3} \qquad (11)$$

Now, power required for transporting the particles of unit length of pipe may be obtained as :

$P = P_c$ x number of such cross section in unit length of pipe where solid particles are present as assumed scheme of distribution

$$\text{or } P = (1/\lambda).P_c \qquad (12)$$

Substituting the value of λ and P_c from equation 6 in equation 10 with the help of equation 9, respectively in equation 12

$$P=\left[0.5C_d.\rho_f(V_f-V_s)^2.A_p+w_p(1-\rho_f/\rho_p)\mathrm{Sin}\theta\right]\left(W_s/w_p\right) \tag{13}$$

2.1.2 Head loss :

The additional head loss h_s due to presence of solid particles in fluid may be obtained from equation 13 in terms of fluid head by using the relation that the power is equals to the product of head loss and weight flow rate of fluid W_f, as :

$$h_s=\left[0.5C_d.\rho_f(V_f-V_s)^2.A_p+w_p(1-\rho_f/\rho_p)\mathrm{Sin}\theta\right]\left(W_s/w_p\right).1/W_f \tag{14}$$

If the average velocity V_s of solid particle is known, the head loss of the mixture (Two phase flow) may be calculated by using equation 14

2.1.3- Settling Velocity:

It was assumed that relative velocity of fluid particles , V_f-V_s , is approximately equal to the terminal settling velocity V_T of particle in the fluid. This assumptions based on conclusion of Cramp and Prieestley [2] and konno and Saito [13] for pneumotransport and that of Welson [2] and Durand [5] for hydrotransport. The terminal settling velocity V_T affected by size , density and surface roughness of the particles and hydraulic effects of shape as reported by Worster [6]. The head loss may be rewritten after substituting V_T in stead of V_f-V_s as :

$$h_s=\left[0.5C_d.\rho_f.A_p.V_T{}^2+w_p\ .\ (1-\rho_f/\rho_p)\mathrm{Sin}\theta\right]\left(W_s/w_p\right).1/W_f \tag{15}$$

Also V_T can be obtained by equating the gravitational force to the drag force for the free falling particle, as given below :

$$V_T=\sqrt{4.g.d(\rho_p-\rho_f)/(3C_d.\rho_f)} \tag{16}$$

where C_d depends on the particle Reynolds numbers Re_p which is define as:

$$Re_p=\quad V_T.d/\gamma_f \tag{17}$$

$$C_d=18.5\ Re_p{}^{-0.6},\qquad \text{for}\ 0.1\langle Re_p\langle 500 \tag{18}$$

$$C_d=0.44\,Re_p{}^{-0.6},\qquad \text{for}\ 500\langle Re_p\langle 2x10^5 \tag{19}$$

In the absence of actual terminal settling velocity , iterative method may be used to calculate the values of V_T and C_d from equation 16, 19 .

As we know the head loss h_f per unit length due friction between fluid and pipe surface, under the identical condition of flow to that of the solid-mixture, may be obtained by using the Darcey-Weisbach equation :

$$h_f=f\ \ V_f{}^2/2.g.D \tag{20}$$

Under fully suspended condition of solid particles, the losses due to friction between it and pipe surface

$$h_t\ =h_f\ +\ h_s \tag{21}$$

Substituting the value of h_s and h_f from equation 16, 20 respectively in equation 21

$$h_t = \left[0.5 C_d . \rho_f . A_p . V_T^2 + w_p (1 - \rho_f / \rho_p) \mathrm{Sin}\theta\right]\left(W_s / w_p\right).1 / W_f + f . V_f^2 / 2gD \tag{22}$$

This equation in a general relation of head loss per unit length of pipe and that can be written in two separate equation for horizontal and vertical pipeline by simply substituting zero and one for $\sin\theta$ in the above equation

$$h_t = 0.5\ C_d . \rho_f . A_p . (V_T^2 / w_f).(W_s / w_p) + f . V_f^2 / 2gD \tag{23}$$

for horizontal pipe, and

$$h_t = \left[0.5 C_d . \rho_f . A_p . V_T^2 + w_p (1 - \rho_f / \rho_p)\right](W_s / w_p).1 W_f + f . V_f^2 / 2gD \tag{24}$$

for and vertical pipe

2.2 Critical Velocity:

Equation 22 contained two part, the first part represents the additional head h_s due to presence of solids particle in fluid, which decreases as the fluid velocity increases. Whereas the second part, which in due to fluid-pipe friction, which increases with the increase of fluid velocity.

Hence, the plot of head loss h_t against fluid velocity V_f for certain solid flow rate will result a minimum head loss for a particular fluid velocity. Using equation 22, to make a separate plots for h_f, h_s and h_t against V_f for a weight (11.12 N/sec) and flow rate of lead shot in a horizontal pipe of 0.032m inner diameter with water, as shown in the opposite figure 3. the fluid velocity at which the head loss h_t is minimum is defined as critical velocity.

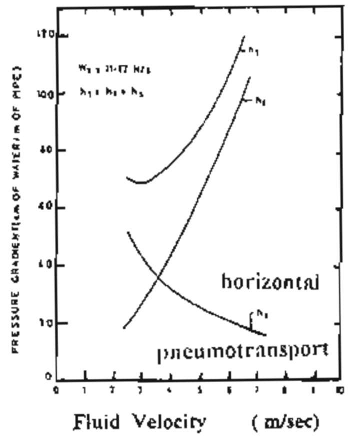


Fig. 3 Separate Plots for h_f, h_s and h_t against V_f

A relation for critical velocity V_c of fluid may be obtained by differentiating equation 22 with respect to fluid velocity V_f and equating with zero. Now, equation 22 after arranging my be written as :

$$h_t = (C_1 + C_2) C_3 / V_f + C_4 . V_f^{2-c} \tag{25}$$

$$\text{where, } C_1 = 0.5 C_d . \rho_f . V_T^2 . A_p$$
$$C_2 = w_p (1 - \rho_f / \rho_p) \mathrm{Sin}\theta \tag{26}$$
$$C_3 = W_s / (w_p A . \rho_f . g)$$
$$C_4 = K . v_f^c / (2gD^{c+1})$$

K and **C** are constant and can be determined from the plots of **f** against **Re** of the fluid flow in pipe , which results such relation as :

$$\mathbf{f = k / Re^c} \tag{27}$$

Now, equation 25 may further be simplified to

$$h_t = C_5 / V_f + C_4 \ V_f^{\,2-c} \qquad (28)$$

where, $C_5 = (C_1 + C_2).C_3$ **(29)**

Differentiating equation 28 with respect to fluid velocity $\mathbf{V_f}$ and equation to zero, the critical velocity $\mathbf{V_c}$ is obtained as :

$$V_c = \left[C_5 / C_4 (2 - C)\right]^{1/(3-c)} \qquad (30)$$

After Substituting the values of constants $C_1, \ldots\ldots, C_5$ in equation 30 the critical velocity $\mathbf{V_c}$ is given by :

$$V_c = \left\{\left[0.5\, C_d.\rho_f.V_T^{\,2}.A_p + w_p(1 - \rho_f / \rho_p)\right] \mathrm{Sin}\theta \cdot \left[2W_s.D^{c+1} / (w_p.K\, v_f^{\,c}(2 - C).A.\rho_f)\right]\right\}^{1/3-c} \qquad (31)$$

The critical velocity of fluid can be calculated for any flow rate of solid through horizontal, inclined and vertical pipes using the equation 31 with the knowledge of independent variables, The critical velocity for horizontal pipe flow simplified to :($\sin\theta=0$)

$$V_c = \left[C_d.V_T^{\,2}.d^2 W_s D^{c-1} / (2 - c).K.w_p \gamma_f^{\,c}\right]^{1/3-c} \qquad (32)$$

Similarly, equation 31 may be converted for choking velocity in case of vertical pipe by Substituting ($\sin\theta=1$)

3- RESULTS AN DISCUSSION

An equation 22 for head loss estimation for fluid-solid mixture flow through an inclined pipe was obtained as well as equation 31 for critical velocity. Equation 22 mat be used to calculate pressure gradient for the flow of mixture of any granular solid with liquid or gas through horizontal, inclined or vertical pipes. In order to corroborate the proposed theory for general use , the theoretical predictions of head loss are compared with the present established experimental results of others investigators for both pneumo- and hydrotrasport in this section.

3. 1 Comparison with Pneumotransport Experimental

The properties of air and solids, as reported by investigators and used for the computation of pressure gradients, along with the calculated values of C_d and V_T are compiled in Table 3.1.

Table 3.1. Properties of air and solids for computation and values of C_d & V_T.

S. No.	Reference	f	Solid used	d_px 10^3m	δ_g	ρ_f Kg/m^3	υ_fx10^5 m^2/sec	D m	V_T Cal m^2/sec	C_d
1	Clark. R. H. et al [4]	0.0931 $Re^{0.1342}$	Cress seek	1.105	1.17	1.200	1.51	0,0254	5.18	0.525
2	Rose, H. E. & Barnacle. H. E [7]	Blaius relation	Must - rd seek	2.00	1.152	1.200	1.51	0.0325	7.55	0.440
3	Rose,H. E.& Duckwourth, R. H. [12]	do	do	2.00	1.152	1.200	1.51	0.0325	7.55	0.440
4	Heriu. D. H. and Molstad, M. C [3]	do	solid c solid d	0.275 0.213	2.640 0.704	1.200 1.200	1.50 1.50	0.0135 0.0135	1.89 1.44	2.211 3.025

3.1.1 Horizontal pneumotransport

The experimental result of Clark et al. [4], Rose and Barnacle [7] and Rose & and Duckwourth [12] for horizontal pneumotransport have been used for the comparison purpose. the experimental result of Hitckcock and Jones [8], Rickardson [9]] and Konchesky et al. [14] could not be utilized for comparison of head loss as they lacked sufficient information required for theoretical computations. Clark et al.[4] used cress seek in their experiments, whereas mustard seek was used by Rose and Barnacle [7] and Rose & and Duckworth [12] in their experimental investigations. The comparison of these experimental results with the theoretically predicted experimental of pressure gradient are shown in Figures 4-7 .These curves provide a very good match of theoretical predictions with experimental values pressure gradient for all fluid velocities and solid flow rate

3.1.2 Inclined pneumotransport

Figures 8 shows that the comparison of experimental result of Rose and Barnacle [7] with theoretical predictions, though an inclined pipe with $\theta = 45^\circ$ with horizontal , It was found very close to the respective experimental values for all solid flow rate and all fluid velocities.

3.1.2 Vertical pneumotransport

The comparison of experimental result of Rose and Barnacle [7] support the theoretical predictions very well as shown as Figure 9. The experimental results of Hariu and Molstad [5] for pressure drop in the pneumatic conveying of sea sand of two different sizes (d=0.274mm & d=0.213mm) through vertical riser of 0.0135 m diameter have been plotted against solid flow rate for constant velocities in Figures 10. When pressure gradient plotted against solid flow rate for constant velocities result into straight line and give close agreement

3.2 Comparison with Hydrotransport Experimental

The properties of water and solids, given by investigators and used for the computation of head loss , along with the calculated values of C_d and V_T are compiled in Table 3.2

Table 3.2. Properties of water and solids for computation and values of C_d & V_T

S. No.	Reference	f	Solid used	d_px 10^3m	δ_g	ρ_f Kg/m^3	υ_fx10^6 m^2/sec	D m	V_T Cal m^2/sec	C_d
1	Newitt, D. M. et al [10]	Blaius relation	Sand D Gral. E	0.762 3.810	2.64 2.55	1000 1000	0.88 0.88	0,0254 0.0254	0,113 0.326	1.183 0.44
2	Rose,H. E.& Duckwourth , R. H. [12]	Blaius relation	Lead shot	2.00	11,12	1000	0.88	0.0320	0.850	0.44
3	Shih [11]	0.430 $Re^{0.259}$	Wooden balls	12.70	1.16	1000	0.88	0.0763	0.246	0.44
4	Newitt, D. M. et al [10]	Blaius relation	Pebble solid d	3.810 0.711	2.59 2.59	1000 1000	0.804 0.894	0.0135 0.0135	0.323 0.110	0.44 1.187

3.2.1 Horizontal hydrotransport

In figures 11 a 12 comparison of experimental result of Newitt et al. [10] with theoretical prediction of head loss for two different solid concentration have been presented for sand D and gravel E. For both types the theoretical values compare favouably with experimental results as shown by these figures. Rose and Duckwourth [12] used lead shot in their experiments. The experimental values of pressure gradient are very closed to the theoretical predictions as shown in Figure 13 for all solid flow and fluid velocities. whenever Shih [11] used identical wooden balls of $\delta_g > 1$ for horizontal hydrotransport and compare favorably as in Figure 14 with the theoretical value.

3.2.2 Inclined hydrotransport

Figures 15a and 16 clearly show that theoretical predictions are very closed to the experimental result of Shih [11] with angle of inclination $\theta = 8.73^{\circ}, 17.71^{\circ}$ degrees using wooden balls as a solid particle.

3.2.3 Vertical hydrotransport

The hydraulic gradients observed experimentally vertical hydrotransport of pebbled and sand c by Newitt et al. [10] are plotted against fluid velocity in Figures 17 and 18 respectively, the theoretical predictions of hydraulic gradients are very closed to the experimental result of both solid as shown by figures 17 and 18.

3.3 Critical Velocity

It is evident from figure 3 as well as from the various characteristic curves of head loss plotted against fluid velocity for certain solid flow rate of This figure will result a minimum head loss for a particular fluid velocity. Using equation 22, to make a separate plots for h_f, h_s and h_t against V_f for a weight (11.12 N/sec) and flow rate of lead shot in a horizontal pipe of 0.032m inner diameter with water, as shown in the Figure 3. the fluid velocity at which the head loss h_t is minimum is defined as critical velocity. It can be observed from there curves as well as from equation 31 that the critical velocity of fluid increase with the solid flow rate, if the other parameter are constant.

REFERENCES

1) Cramp, W., and Priestlegy, A., " Pneumatic grain conveyors" The Engineer , 134,34, 64, pp. 98-112, 1924.

2) Wilson, W.E., " Mechanics of flow with non-colloidal inert solids ", Trans, ASCE, Vol. 107,1942.

3) Heriu, D. H. and Molstad, M. C. " Pressure drop in vertical tubes in transport of solids by gases ", India, Eng. Chem. ,Vol. 41, pp. 1148-1160, 1949.

4) Clark., R. H. et al., " pneumatic conveying " pert I : The pressure drop during horizontal conveyance ", Trans. Inst. Chem. Engineering. Vol. 30, pp. 209-224, 1952.

5) Durand, R. " Basic relationships of the transportation of solids in pipe- experimental research ", Proc. int. association for hydraulic research ,Minneapolis, Minn. 1953.

6) Worster, R. C., and Denny, D.F., " Hydraulic transport of solid material in pipes ", Inst. Mech. Eggs., Vol. 169, pp. 563-586, 1955.

7) Rose, H. E. and Barnacle. H. E., " Flow of suspension of non-cohesive spherical particles in pipe ", The engineer, pp. 898-901, 939-941, 1957.

8) Hitckcock J. A. and Jones, C., " The pneumatic conveying of spheres through straight pipes ", Br. J. of App. Phys.,Vol. 9, pp.218-222, 1958.

9) Rickardson, J. F. ,and Meleman, M. , " Pneumatic conveying part II -solid velocity and pressure gradient in a one-inch horizontal pipe ", Trans. Inst. Chem. Eng. , vol. 38, 1960.

10) Newitt, D. M., et al. " Hydraulic conveying of solid in vertical pipe.", Trans. Inst. Chem. Eng. , Vol. 39, pp. 93-100, 1961

11) Shih, C. S., " Hydraulic transport of solids in a sloped pipe.", J. of Pipeline Div., Proc. of the ASCE. No. PL2 pp.1-14, 1964.

12) Rose, H. E. and Duckwourth, R.H., " Transportation of solids particles in liquid and gases ", The Engineer ,march14,21.28, pp. 392-396, 430-433, 478-483., 1969.

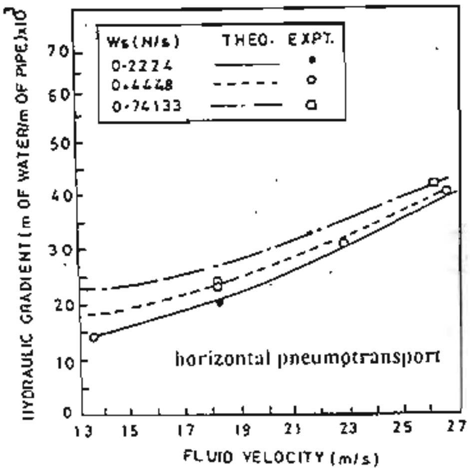
13) Konno, H., and Saito, S. , "Pneumatic conveying of solids through straight pipe ", J. of Chem. Eng. , Japan ,Vol. 2 pp.211-217, 1969

14) Konchesky, J. L. , et al. ," Air and power requirement for the pneumatic transport of crushed coal in horizontal pipe and vertical pipe. ", Trans, of ASME, J. Eng. for industry,pp. 94-100 and 100-106, 1975

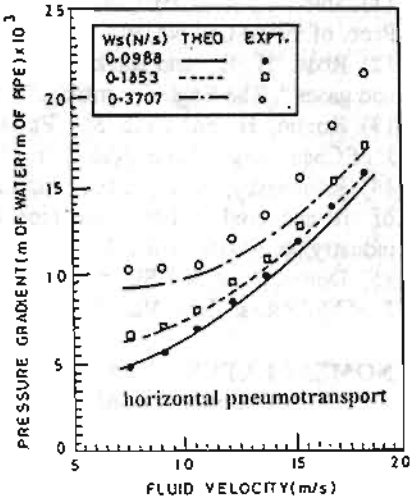
15) Doron, P. ,et al. " Slurry flow in horizontal pipes experimental and modeling ", Int. J. of Multiphase flow, Vol. 13, pp.535-547, 1987.

NOMENCLATURE

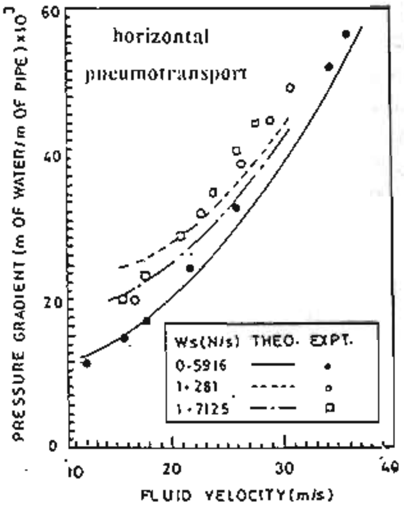
A	Cross section area of pipe (m^2)
A_p	Projected area of particle (m^2)
C, C_1, C_2, C_3, C_4, K	Constant defined by certain equations
C_d	Drag coefficient of particle
C_v	Volumetric concentration of solid in mixture
d	Mean equivalent spherical particle diameter (m)
D	Pipe inner diameter (m)
f	Friction factor for pipe surface
F	Total motive force required at a pipe cross section (N)
F_d	Drag force due to velocity difference of particle and fluid phase (N)
F_m	Motive force for moving single particle with constant velocity (N)
g	Gravity acceleration (m/sec^2)
h_f	Head loss due to friction (m/unit length m)
h_s	Head loss due to presence of solid particle in fluid (m/unit length m)
h_t	Total head loss due to friction and presence of solid particle (m/unit length m)
n	Total number of solids particles transferred per unit time
N	Total number of particles at a pipe cross section
P	Power required in transferring the particles of unit pipe length(w/unit length m)
P_c	Power required in transferring the particles in pipe cross section . (w)
Re_p	particles Reynolds numbers
V_c	Critical velocity of fluid (m/sec)
V_f	Average velocity of fluid (m/sec)
V_s	Average velocity of particle (m/sec)
V_T	Terminal settling velocity of particle (m/sec)
W_f	Weight flow rate of fluid (N/sec)
w_p	Weight of particle (N)
W_s	Weight flow rate of solid particles (N/sec)
θ	Pipe inclination with horizontal (^{o})
λ	Side of the hypothetical cube (m)
ν_f	kinamatic viscosity of fluid (m/sec2)
ρ_p	Density of particle (Kg/m^3)
ρ_f	Density of fluid (Kg/m3)
δ_g	Specific gravity



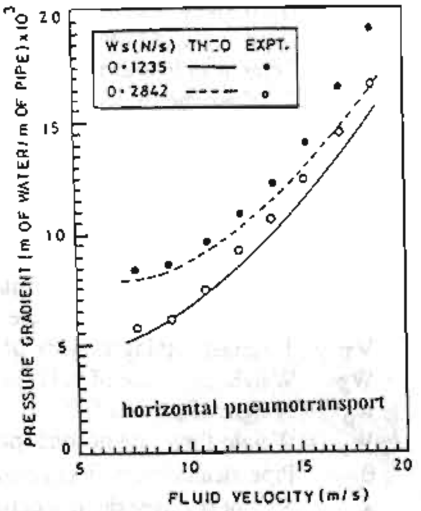
Fig, 4 Comparison of theoretical prediction with the experimental results [4] of cress seek.



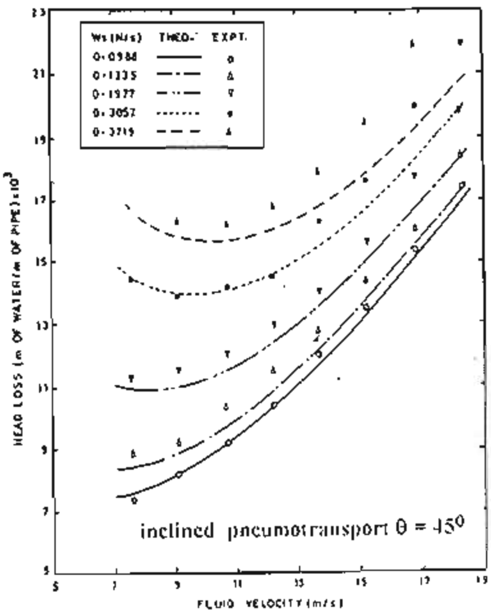
Fig, 5 Comparison of theoretical prediction with the experimental results [7] of mustard seek



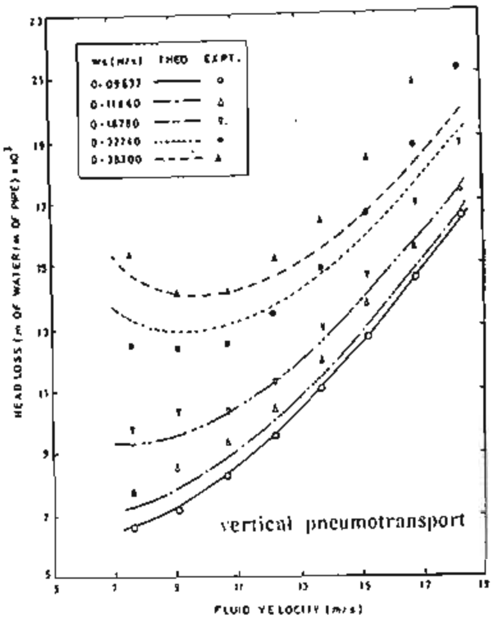
Fig, 6 Comparison of theoretical prediction with the experimental results [7] of mustard seek



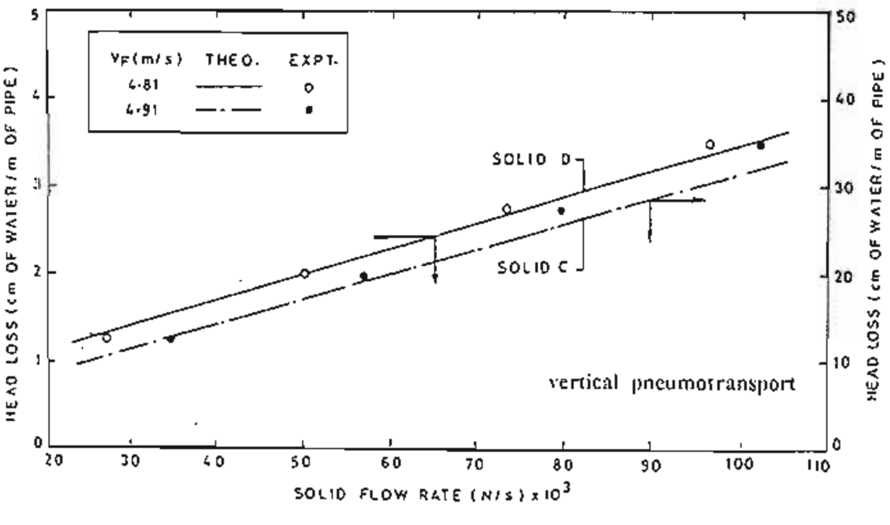
Fig, 7 Comparison of theoretical prediction with the experimental results [7] of mustard seek



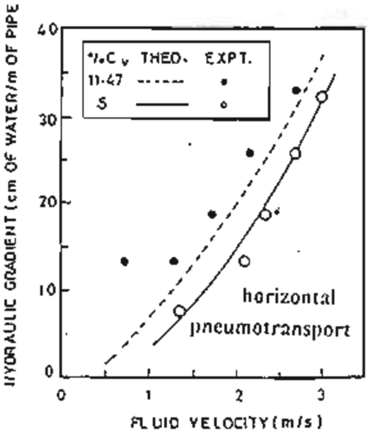
Fig, 8 Comparison of theoretical prediction with the experimental results | 7 | of mustard seek



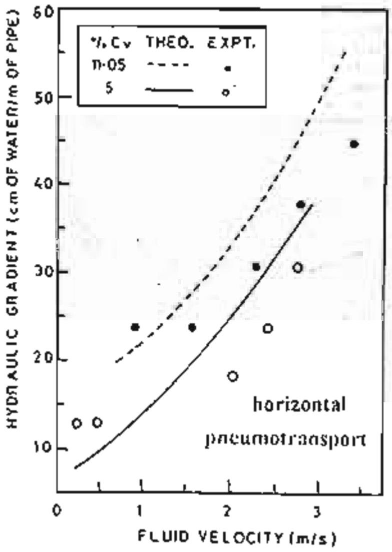
Fig, 9 Comparison of theoretical prediction with the experimental results ['7.] of mustard seek



Fig, 10 Comparison of theoretical prediction with the experimental results [3] of two sea sand of different type.



Fig, 11 Comparison of theoretical prediction with the experimental results [10] of sand C



Fig, 12 Comparison of theoretical prediction with the experimental results [10] of gravel E

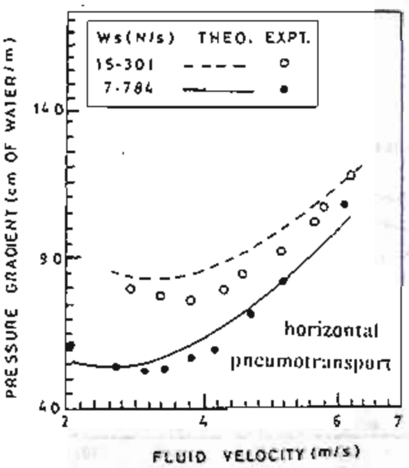


Fig. (13) Comparison of theoretical prediction wih with experimentat results of [12] of lead shot

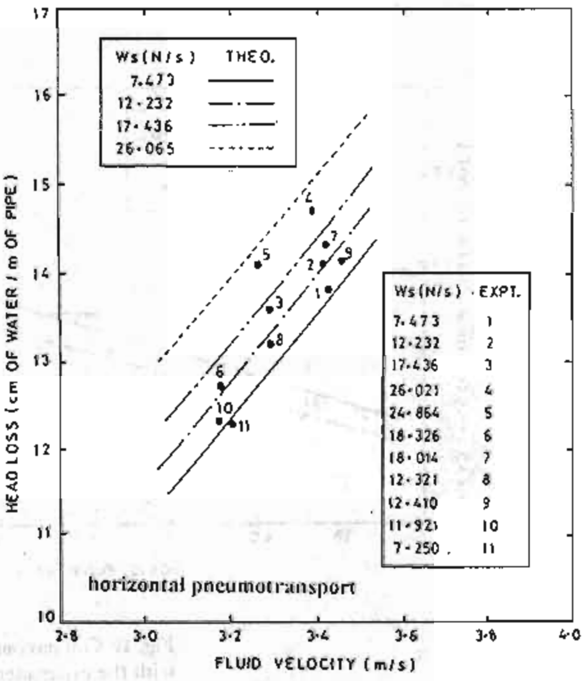


Fig. (14) Comparison of theoretical prediction wih with experimentat results of [11] of wooden balls.

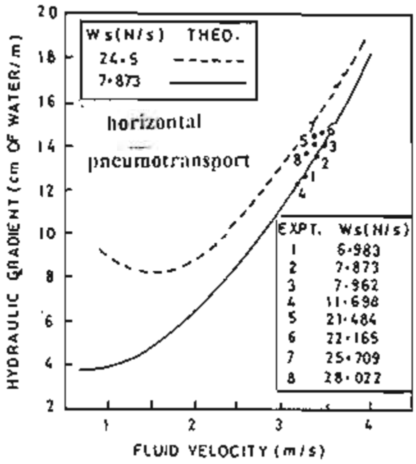


Fig. 16 Comparison of theoretical prediction with the experimental results [12] of wooden balls.

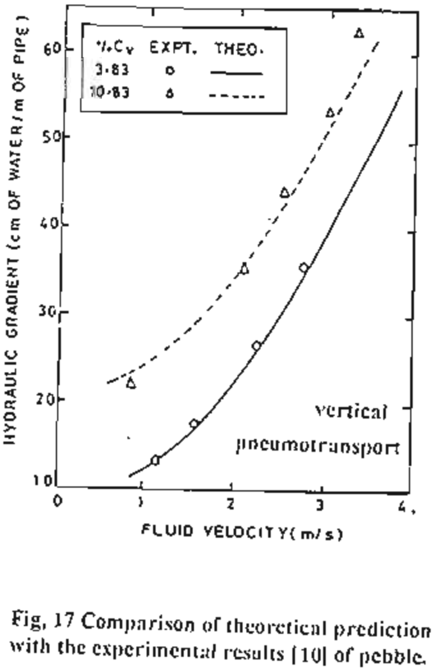


Fig. 17 Comparison of theoretical prediction with the experimental results [10] of pebble.

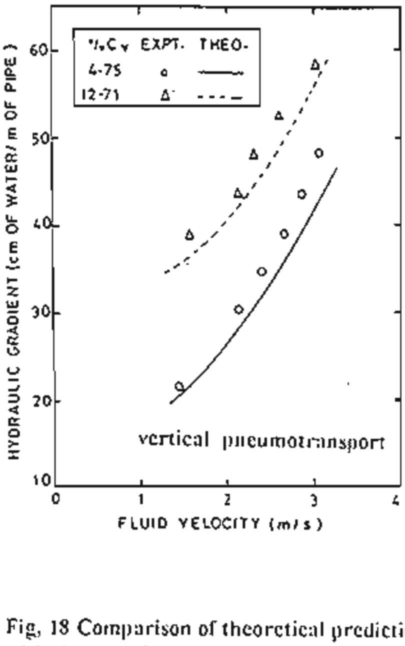


Fig. 18 Comparison of theoretical prediction with the experimental results [10] of sand C.