INJECTION OF COAL BY SCREW FEED

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SUMMARY

The use of the screw feeder for injecting solids through a 20 to 30 psi barrier is common practice in the cement making industry. An analytical extrapolation of that design, accounting for pressure holding characteristics of a column of solids, shows that coal can be fed to zones at several hundred psi with minimal or no loss of gas. A series of curves showing the calculated pressure gradient through a moving column of solids is presented. Mean particle size, solids velocity, and column length are parameters. Further study of this system to evaluate practicality is recommended.

INTRODUCTION

The screw feeder has long been in use as a handy device for moving granular solids through troughs or conduits from one point to another, usually against a distributed resistance in the form of a gradient in elevation or pressure. Desirable features of the system are the continuity and simplicity of operation and the minimal need to depend upon integrity of precisely formed parts. Such features are desirable in meeting the increasingly severe conditions under which solids are handled in the process industry and in the treatment of coal.

A practical example of the above is the use of the screw feeder to pump dry cement solids. The unit loads a system of conduits for the air-driven transport of cement to storage silos. The system is pressurized to perhaps three atmospheres (gauge) at the pump station. The dry solids are pumped into the system by the screw feeder against this pressure head. The rate of solids injection may be as much as 200 tons per hour.

The screw feeder has also been used to inject solids at high pressure, as in the extrusion molding of plastic products. The feeder is of a special configuration designed to develop pressure over a relatively short length of pump. Compression of the solids within a constricted channel and extrusion of this material in a plastic form from this section is the objective. The interplay of frictional forces at the leading edge of the screw and the surface

of the channel to produce forward motion is similar to that in the cement solids pump.

The foregoing practices suggest that the injection of ground solids into a pressurized zone should be practical. It is not desired to compact the solids but to move them through the screw channel in a lightly packed condition, utilizing the drag of this structure on gas to reduce or overcome the counterflow of gases.

An analysis of the pressure gradient likely to develop over the length of the solids pump was performed and is presented below. It is based simply on the calculation of gas pressure along the length of a uniformly moving column of solids. Several sets of operating conditions were studied. The results indicate that solids can be transferred continuously through a pressure barrier of several hundred psi with a modest velocity of flow, i.e., from 1 to 5 feet per second.

DISCUSSION

System Configuration

The screw feeder system considered reasonable for coal feeding is shown in Figure 1. It is very similar to the system used to feed ground cement except that the channel containing the screw is much longer, extending to perhaps thirty feet. It is fed from a hopper containing solids to a short section of the pump channel in which the pitch of the screw is considerably larger than in the remaining section, where the pitch is constant. The screw terminates at the high pressure end before a port through which the solids can discharge. The port is covered by a cap, which acts as a check valve against blowout.

The function of the screw section immediately below the feed hopper is to engage the ground solids and maintain a continuous column of lightly packed material flowing into the channel. The average density of the solids/gas mixture in this section is believed to be less than that downstream.

The pressures p_1, p_2, p_3, p_4, p_5 along the channel and p_T, the pressure in the vessel, are progressively higher. Gas movement along the channel can be from or toward the zone of high pressure or can be non-existent as in the results developed below.
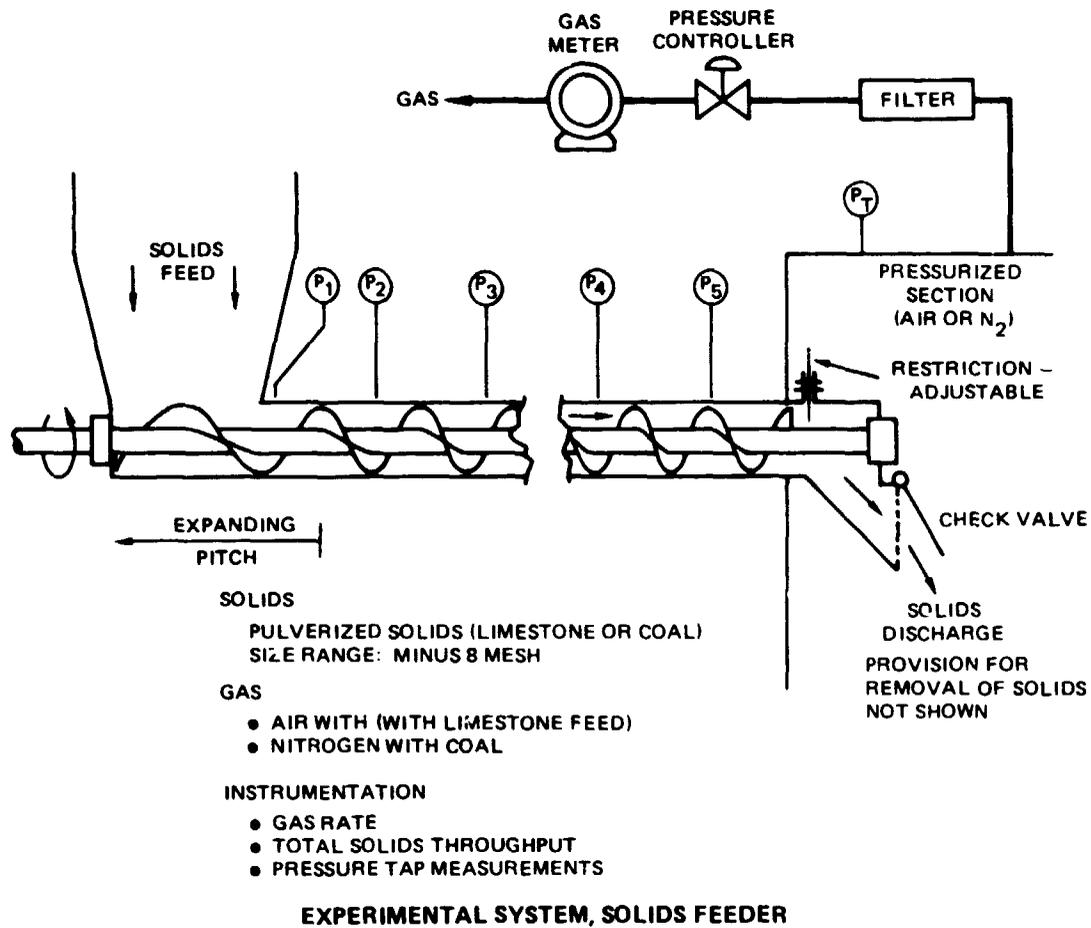
GAS

GAS METER

PRESSURE CONTROLLER

FILTER

SOLIDS FEED

PRESSURIZED SECTION
(AIR OR N$_2$)

RESTRICTION – ADJUSTABLE

EXPANDING
PITCH

CHECK VALVE

SOLIDS
DISCHARGE

PROVISION FOR REMOVAL OF SOLIDS NOT SHOWN

SOLIDS

PULVERIZED SOLIDS (LIMESTONE OR COAL)
SIZE RANGE: MINUS 8 MESH

GAS

• AIR WITH (WITH LIMESTONE FEED)
• NITROGEN WITH COAL

INSTRUMENTATION

• GAS RATE
• TOTAL SOLIDS THROUGHPUT
• PRESSURE TAP MEASUREMENTS

EXPERIMENTAL SYSTEM, SOLIDS FEEDER

Figure 1. EXPERIMENTAL SYSTEM, SOLIDS FEEDER

Model for Analysis

The physical model conceived for purposes of analysis is a straight circular conduit that is fully occupied by a column of moving solids (Figure 2). The column is homogeneous, representing a plug of solids, lightly packed, moving at a constant velocity. At any station along the pump channel, the conditions are at steady state. The relative movements of gas and solids at the station produce a gas pressure gradient, which is a function not only of the relative velocity but also of the shape and size characteristics of the solids.

For purposes of evaluating the pressure gradient the Ergun equation can be used (1). This relation gives the change in pressure with respect to distance in terms of the character of the solids structure and the velocity of the gas relative to a bed of stationary solids. The relation as applied to a thin transverse section is:

$$- \frac{dp}{dL} = \left[\frac{150}{144 g_c} \frac{(1-\epsilon)^2}{\epsilon^3} \right] \frac{\mu U_g}{(\phi_s d_p)^2} + \left[\frac{1.75}{144 g_c} \frac{(1-\epsilon)}{\epsilon^3} \right] \frac{\rho_g U_g^2}{\phi_s d_p} \qquad (1)$$

$$= C_1 (G_g/\rho_g) + C_2 \left[(G_g)^2/\rho_g \right]$$

where $G = \rho_g U_g = \rho \epsilon u_g$

The assumption is now made that the same relation can be used to derive the pressure gradient at a given station when the bed as a whole moves with a constant velocity u_s.

$$- \frac{dp}{dL} = C_1 G_g'/\rho_g + C_2 (G_g')^2/\rho_g \qquad (2)$$
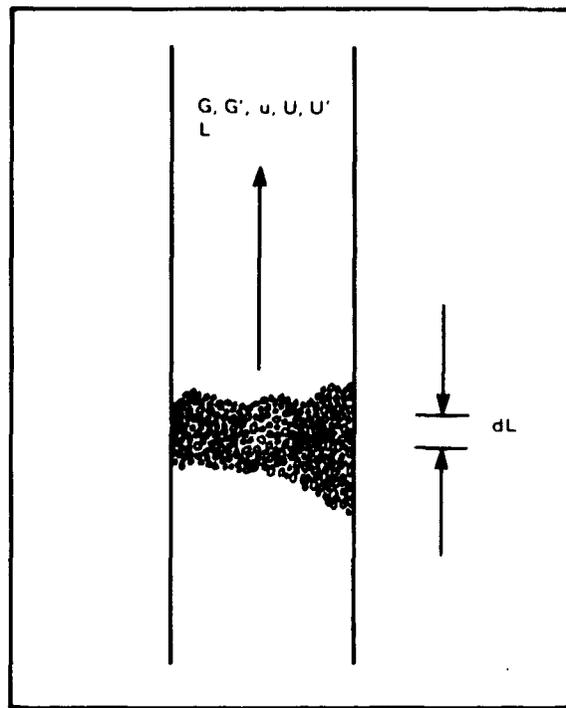
CHANNEL FOR TRANSPORT OF SOLIDS

Figure 2. CHANNEL FOR TRANSPORT OF SOLIDS

The term G' is the mass velocity of gas with respect to the solids, which are in motion with the velocity u_s.

$$G'_g = \rho_g \epsilon (u_g - u_s) = \rho_g U'_g \quad \text{See Note} \tag{3}$$

Thus

$$dp/dL = C_1 U'_g + C_2 (U'_g)^2 \rho_g \tag{4}$$

and

$$U' = \epsilon (u_g - u_s) \tag{5}$$

U' can be regarded as superficial velocity of gas referenced to the solids. If the gas velocity u_g becomes zero, then:

$$U'_g = -\epsilon u_s, \text{ a constant.} \tag{6}$$

For this special case the gradient

$$- dp/dL = C_4 + C_5 p \tag{7}$$

Integration leads to

$$L_2 - L_1 = (1/C_5) \ln \left[(p_1 + C_4/C_5)/(p_2 + C_4/C_5) \right], \tag{8}$$

the length of column necessary to sustain a pressure difference $p_2 - p_1$.

Note: $\quad G'_g = G_g - (\rho_g/\rho_s) \left[\epsilon/(1-\epsilon) \right] G_s$

RESULTS

Ranges of conditions for several variables were covered in calculating the performance of the model, the object being to find the length of column needed to establish a given pressure difference when pumping solids at practical velocity:

Particle diameter (mass mean):	0.625 to 2 mm or 250 to 9 mesh (Tyler screen)
Solids velocity:	1 to 5 fps
Void fraction:	0.35 to 0.60
Entrance pressure:	15 psia
Discharge pressure:	300 psia
Volumetric pumping efficiency:*	35%
Gas molecular weight:	25

The resulting performances are plotted as several families of curves in Figure 3, giving the pressure gradients throughout the pumping channel for the several conditions of mean particle size and voids fractions. Representative of a practical set of conditions for which the model performance may be of interest are the following:

Void fraction	0.45
Solids velocity	2 fps
Particle diameter, mass mean	115 mesh (opening)

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*Ratio of actual solids velocity to product of screw pitch and rotation rate.

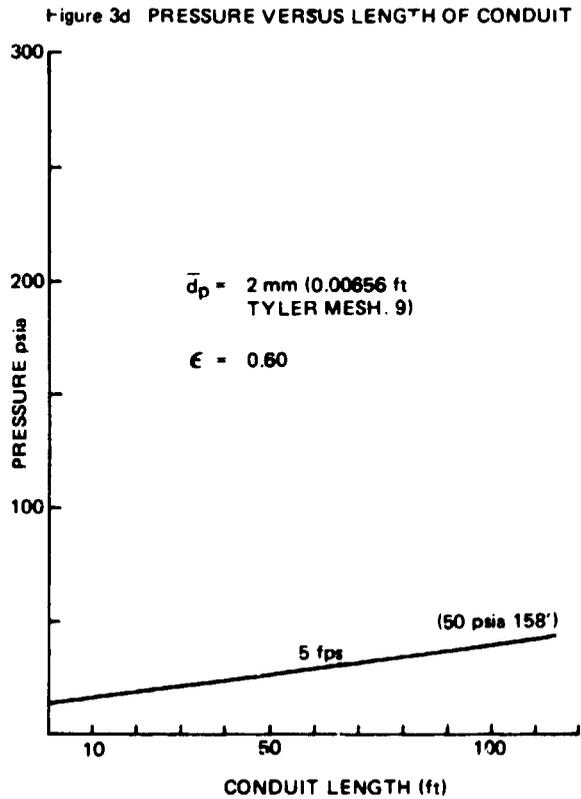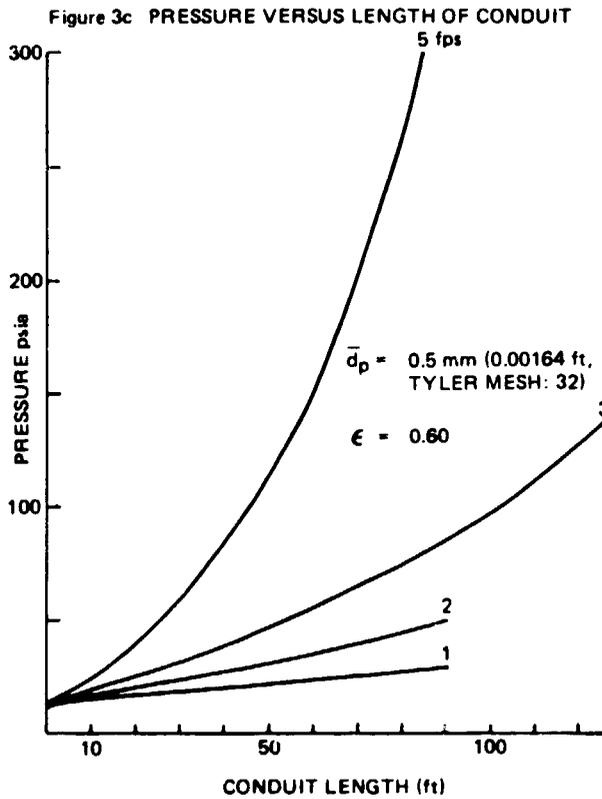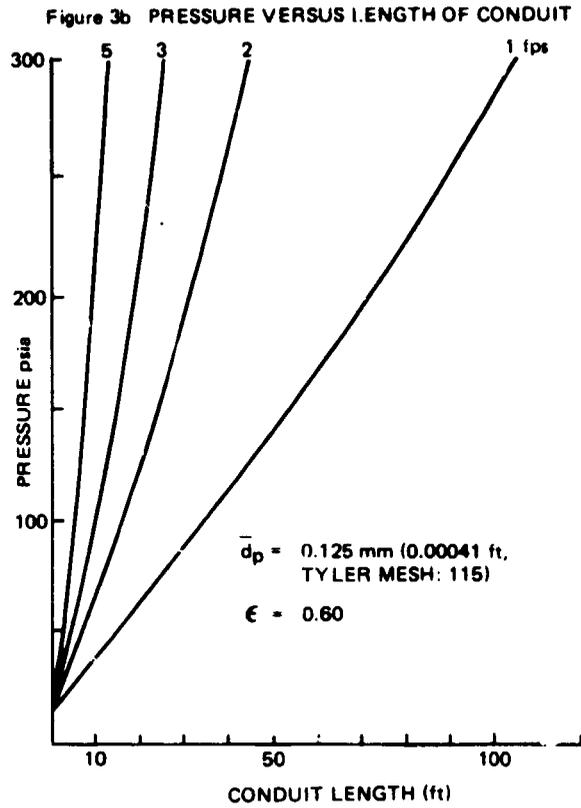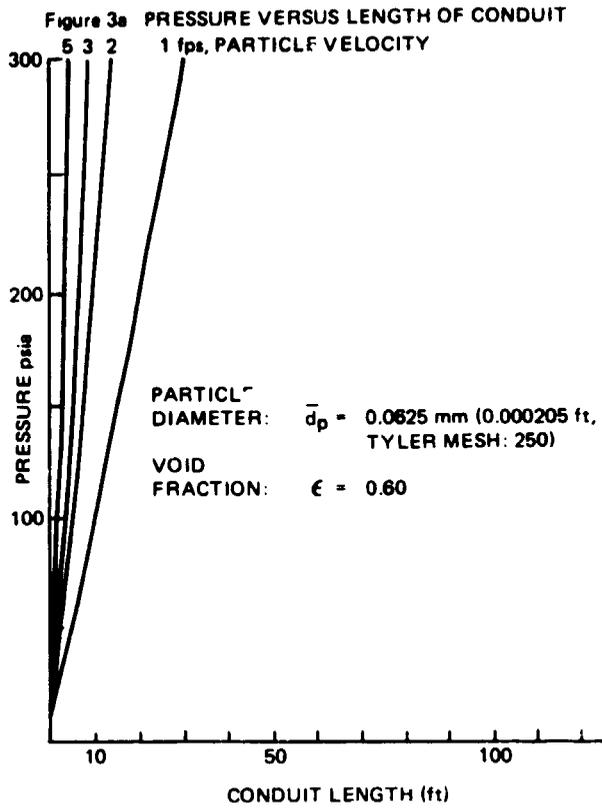**PERFORMANCE – PRESSURE VS. LENGTH, VOID FRACTION 0.60**

Figure 3a PRESSURE VERSUS LENGTH OF CONDUIT
1 fps, PARTICLE VELOCITY

PARTICLE
DIAMETER: $\bar{d}_p$ =   0.0625 mm (0.000205 ft,
                            TYLER MESH: 250)

VOID
FRACTION: ϵ =   0.60

PRESSURE psia vs *CONDUIT LENGTH (ft)*

Figure 3b PRESSURE VERSUS LENGTH OF CONDUIT

$\bar{d}_p$ =   0.125 mm (0.00041 ft,
                TYLER MESH: 115)

ϵ =   0.60

PRESSURE psia vs *CONDUIT LENGTH (ft)*

Figure 3c PRESSURE VERSUS LENGTH OF CONDUIT
5 fps

$\bar{d}_p$ =   0.5 mm (0.00164 ft,
                TYLER MESH: 32)

ϵ =   0.60

PRESSURE psia vs *CONDUIT LENGTH (ft)*

Figure 3d PRESSURE VERSUS LENGTH OF CONDUIT

$\bar{d}_p$ =   2 mm (0.00656 ft
                TYLER MESH. 9)

ϵ =   0.60

(50 psia 158')

5 fps

PRESSURE psia vs *CONDUIT LENGTH (ft)*

FIGURE 3 A, B, C, D

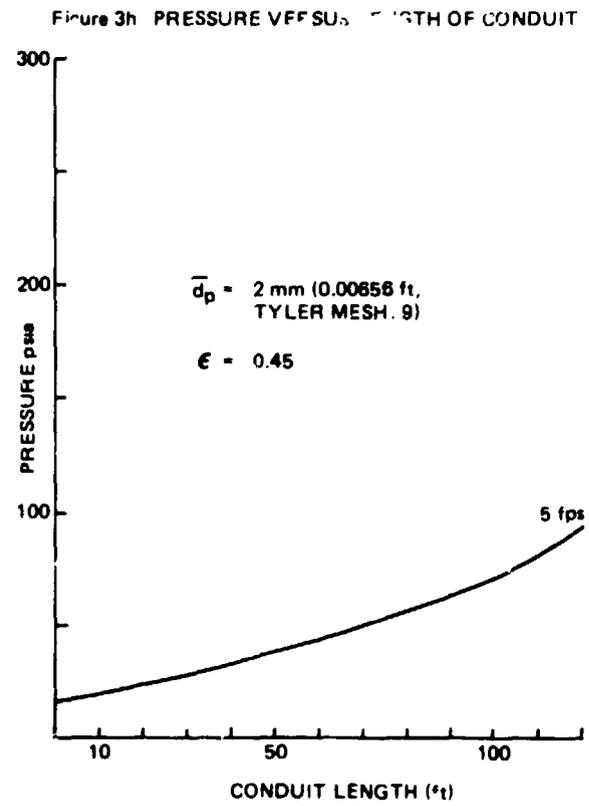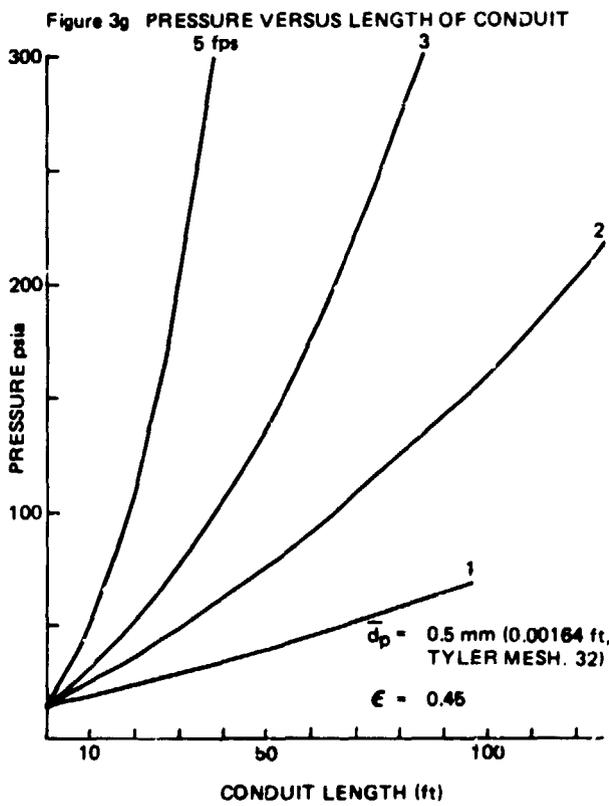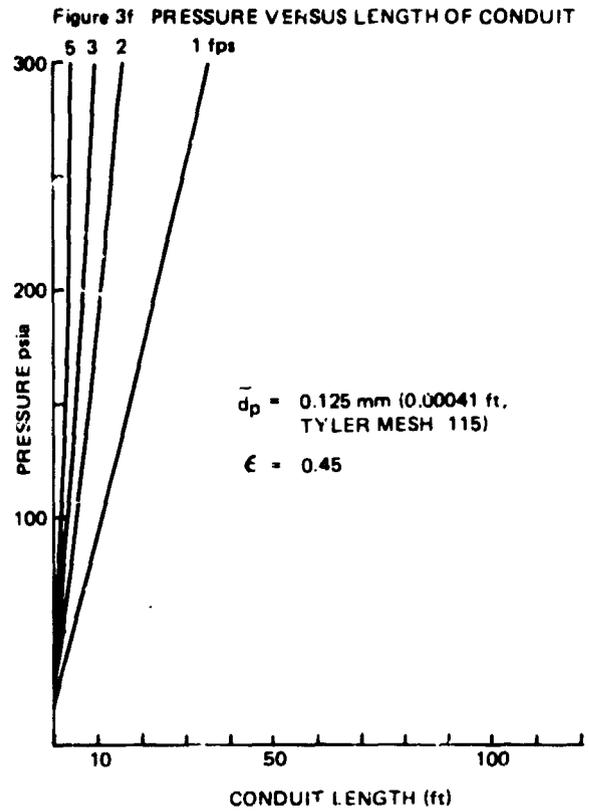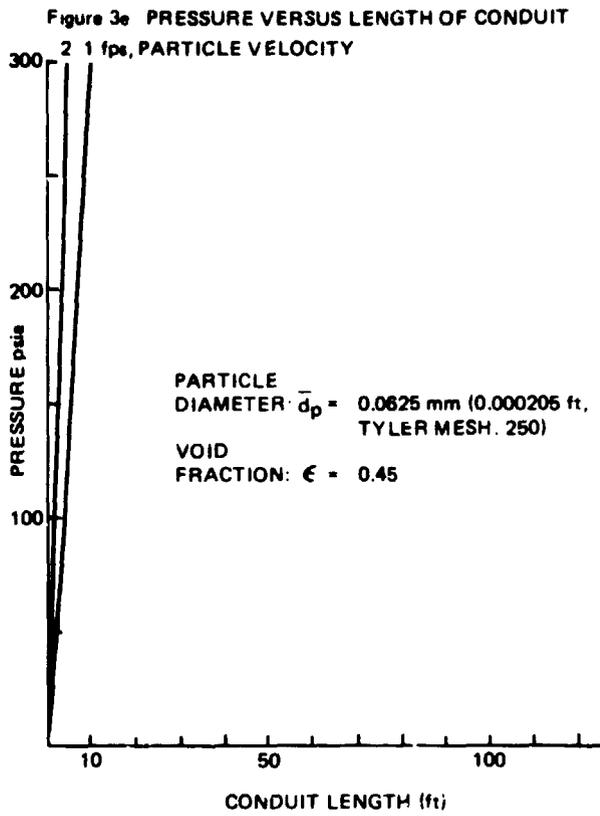**PERFORMANCE – PRESSURE VS. LENGTH, VOID FRACTION 0.45**

Figure 3e PRESSURE VERSUS LENGTH OF CONDUIT

PARTICLE
DIAMETER $\bar{d}_p$ = 0.0625 mm (0.000205 ft,
TYLER MESH. 250)
VOID
FRACTION: ϵ = 0.45

CONDUIT LENGTH (ft)

Figure 3f PRESSURE VERSUS LENGTH OF CONDUIT

$\bar{d}_p$ = 0.125 mm (0.00041 ft,
TYLER MESH 115)

ϵ = 0.45

CONDUIT LENGTH (ft)

Figure 3g PRESSURE VERSUS LENGTH OF CONDUIT

$\bar{d}_p$ = 0.5 mm (0.00164 ft,
TYLER MESH. 32)

ϵ = 0.45

CONDUIT LENGTH (ft)

Figure 3h PRESSURE VERSUS LENGTH OF CONDUIT

$\bar{d}_p$ = 2 mm (0.00656 ft,
TYLER MESH. 9)

ϵ = 0.45

CONDUIT LENGTH (ft)

FIGURE 3 E, F, G, H

PERFORMANCE — PRESSURE VS. LENGTH, VOID FRACTION 0.35

Figure 3i PRESSURE VERSUS LENGTH OF CONDUIT

5 3 2   1 fps, PARTICLE VELOCITY

PARTICLE
DIAMETER: $\overline{d_p}$ = 0.125 mm (0.00041 ft,
TYLER MESH: 115)
VOID
FRACTION: ϵ = 0.35

PRESSURE psia

CONDUIT LENGTH (ft)
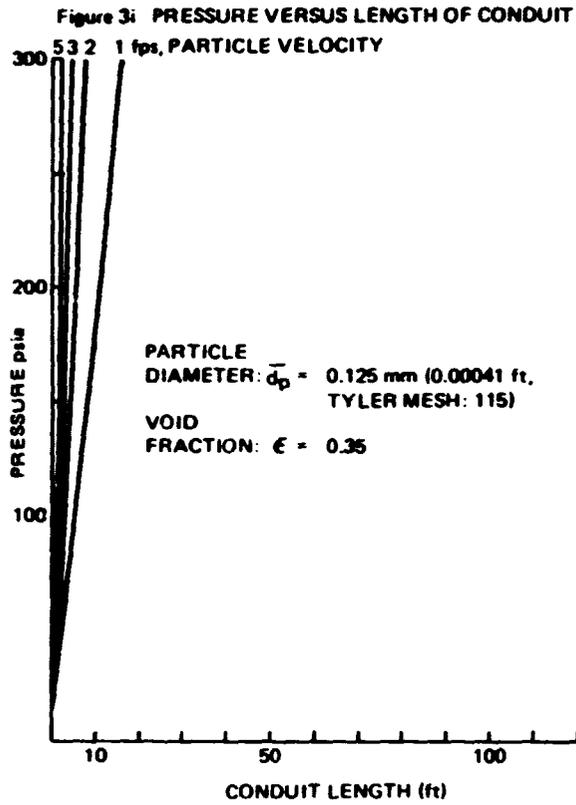
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Figure 3j PRESSURE VERSUS LENGTH OF CONDUIT

5 fps   3 fps   2 fps   1 fps

$\overline{d_p}$ = 0.5 mm (0.00164 ft,
TYLER MESH: 32)

ϵ = 0.35

PRESSURE psia

CONDUIT LENGTH (ft)

Figure 3k PRESSURE VERSUS LENGTH OF CONDUIT

5 fps   3 fps

$\overline{d_p}$ = 2 mm (0.00656 ft,
TYLER MESH: 9)

ϵ = 0.35
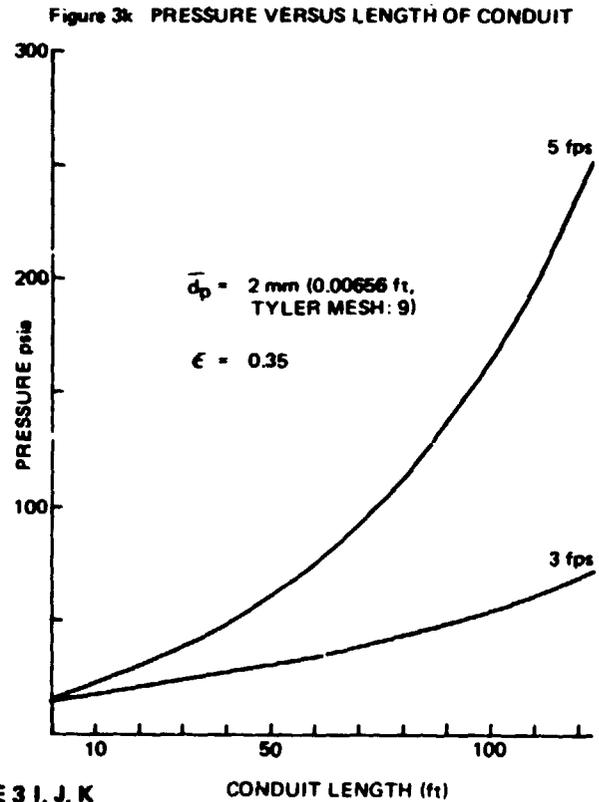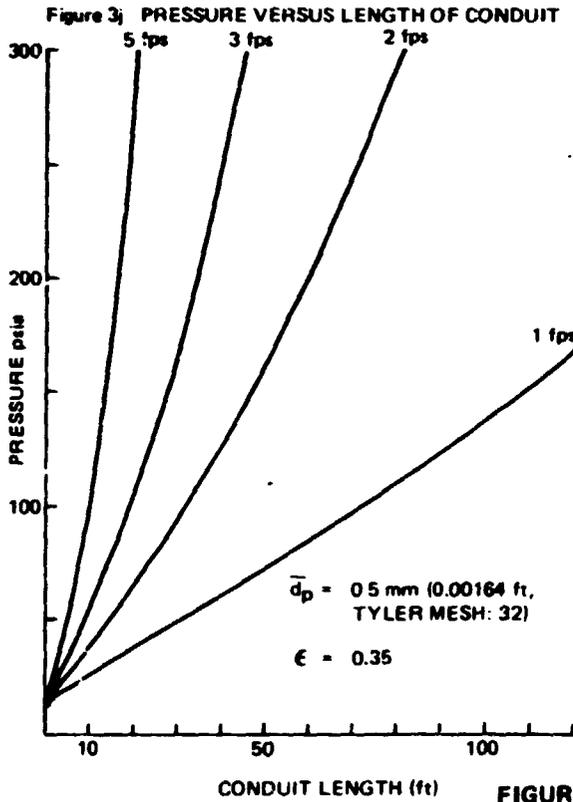
PRESSURE psia

CONDUIT LENGTH (ft)

FIGURE 3 I, J, K

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The length of column required to pump solids from 15 psia to 300 psia in this system is 16 feet.

The results are further summarized in Figure 4 showing the length of conduit necessary to overcome 300 psia pressure (feed at 15 psia) for three feeds of different particle size (mass mean diam.) and for solids velocity of 2 fps. The performance can be readily ascertained for the feeds used at the R&D agencies.

Mean Particle Size	Voids Fraction	Feeder Column Length Required	Typical Process
.21 mm, 65 mesh	0.45	40 ft	(Acceptor Process –
	0.35	19	Consolidated Coal)
.17 mm, 80 mesh	0.45	27	(IGT "HYGAS")
	0.35	13	
0.075 mm, 200 mesh	0.45	6	(BCR "BI-GAS," USBM
	0.35	2.7	"SYNTHANE," Koppers-Totzek)

The voids fractions are felt to lie between the two values cited. The larger represents solids of uniform size; the smaller, a representative case for a distribution of sizes. The latter is more likely.

To obtain the feeder column length needed to reach 1,000 psia, the values shown above may be tripled. The use of two or more screw feeders in sequence should be feasible.
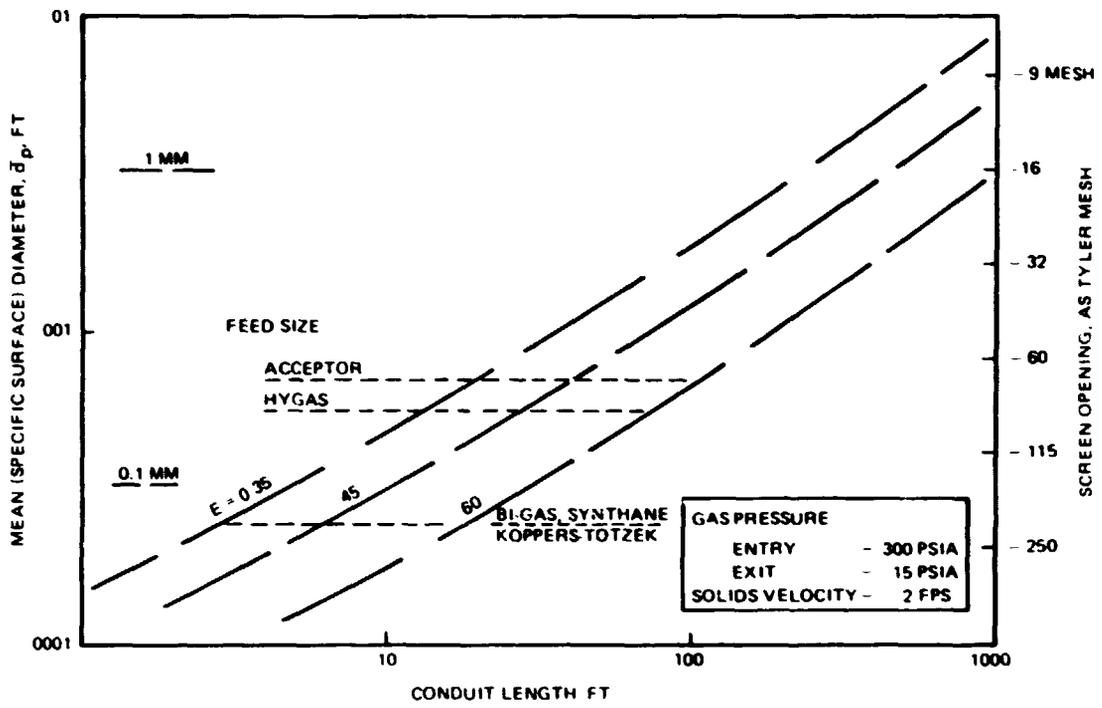
Figure 4. EFFECT OF PARTICLE SIZE ON CONDUIT LENGTH

COMMENT

The application of the screw feeder for charging coal to pressurized gasifiers is regarded as worthy of further study based on the considerations noted below:

1. The major development programs in coal conversion use pulverized feed which is fine enough to be adaptable to screw feeder operation. Solids should be capable of being fed to pressures as high as 1,000 psia, dry. The porosity is that characterizing normally loose-packed solids.

2. Localized malfunction of the column of solids is essentially eliminated by the positive action of the screw along the entire length of the system.

3. Feed is continuous and can operate at zero backflow of gases.

4. The feeder operates without maintenance of close fitting surfaces for sealing.

5. The feeder is an extension of existing technology. Commercial feeders and extruders are presently operating at the pressure gradients (psi/ft) in the range of those applying to the proposed systems. Flow stability has been studied experimentally.

6. The cost of a screw pump is evidently not an outstanding consideration.

NOMENCLATURE

$$C_1 = \frac{150}{144 \, g_c} \cdot \frac{(1-\epsilon)^2}{\epsilon^3} \cdot \frac{\mu}{(\phi_s \mathfrak{d}_p)^2} \,, \quad \text{a constant representative of}$$

the particulate character of a given stream of solids

$$C_2 = \frac{1.75}{144 \, g_c} \cdot \frac{(1-\epsilon)}{\epsilon^3} \cdot \frac{1}{\phi_s \mathfrak{d}_p} \,, \quad \text{a constant similar in character}$$

to C_1

C_3 = constant of integration, corresponding to $L_1 = 0$

$C_4 = C_1 U_g'$ for the case $u_g = 0$; i.e., $-C_1 \epsilon u_s$

$C_5 = C_2 (U_g')^2 \, M/RT$ for the case $u_g = 0$; i.e., $C_2 (\epsilon u_s)^2 \, M/RT$

$\mathfrak{d}_p$ = Mean specific surface diameter, ft

g_c = Conversion constant, 32.2 lb(m) ft/lb(f)-sec^2

G = Mass velocity lb(m)/ft^2 sec

L = Distance along channel, ft

M = Molecular weight, lb(m)/mole

p = Pressure, absolute, psia

R = Gas constant, 10.71 psia/mole – $^{\circ}$R

T = Temperature, $^{\circ}$R

u = Velocity, referenced to a station at fixed value of L, fps

U = Superficial velocity, based on cross section of column, fps

ϵ = Voids fraction, dimensionless

ϕ_s = Sphericity, dimensionless

μ = Viscosity, lb(m)/ft-sec)

ρ = Density, lb(m)/ft^3

Superscript:

' = Prime. Denotes velocity referenced to a station moving with
      the velocity of the solids

Subscripts:

1,2 = Denote stations at the ends of the column

g = Denotes gas

s = Denotes solids

REFERENCE

(1) Ergun, Sabri, "Fluid Flow Through Pack Columns," Chemical Engineer-
      ing Progress, Vol. 48, No. 2, p. 89-94 (1952).