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PNEUMATIC CONVEYING OF FLOUR MILL STOCKS

By

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INTRODUCTION

Pneumatic conveying is a very widely used method of transport for granular and pulverized materials in a great range of industries all over the world. Despite many years of research on and study of pneumatic conveying systems by manufacturers and users, this method of handling solids still remains an art rather than a scientific procedure.

Pneumatic conveying was first introduced to flour milling industry by an engineer called "Walter Reinhardt" who patented it in 1909. But the first full scale pneumatic flour mill was built in 1943 in Switzerland. Over the years classic researchers like Professor William Cramp in England, and Dr. Gasterstadt and Professor Segler in West Germany conducted extensive tests on the conveying of wheat and other grains pneumatically and developed mathematical correlations for the principles involved in pneumatic conveying. On a parallel level, scores of researchers in the chemical industry have conducted extensive research on gas, solid - 2 phase transport phenomena and have developed and refined the science of pneumatic conveying. But much of what is done already is applicable to only a few selected materials of particular particle size range in certain particular transport systems.

Specifically within the milling industry there was a growing concern that pneumatic conveying systems consume excessive power in comparison with mechanical systems and there was a general trend discouraging further building of pneumatic plants. Because of the fundamental shortage of technical information, many pioneering consulting engineers like Hudson (21) in this country have developed emperical formulas for designing pneumatic systems based on their experience. But these are again very specific in their use and there are no universally applicable emperical formulas for designing any system. The basic reason for the diversity of such data on pneumatics is the variety of materials that can be conveyed, and in turn, each material could be conveyed by a wide range of air velocities, at various material to air loadings. Again, the conveying air velocities themselves are functions of particle size spectrum, density, shape and other physical characteristics of the material and the direction of flow (33). Most of the companies involved in the manufacture of pneumatic conveyors for flour mills are reluctant to share the research done by their companies with the milling industry. All this has resulted in the condition that the purchaser or the miller who is the actual user of the system, is entirely dependant on the manufacturing firm or on a few consultants for his needs, and mostly does not know what he is buying. Better understanding of pneumatic systems by the miller is necessary for him to harness this wonderful tool and use it for his best advantage.

OBJECTIVE

The main objective of this research is to study the system resistance in a typical pneumatic lift pipe using air and various stocks from a wheat flour mill. The experimental lift built is identical to lifts used in the Kansas State University pilot flour mill.

Experimental data regarding the pneumatic conveying of milled stocks has not been published. It is the aim of this research to generate information about pneumatic conveying of milled stocks which can at least serve as a basis for future experiments. It is also our aim to watch for any specific trends between the variables that may show up in the observations made during the research.

REVIEW OF LITERATURE

CLASSIFICATION OF PNEUMATIC CONVEYING SYSTEMS

According to one basic classification there are basically three varieties of pneumatic conveyors:

1. pipe line conveyors
2. air activated gravity conveyors
3. tube conveyors.

Pipe Line Conveyor: The solid particles are conveyed by the airstream by the conversion of kinetic energy to dynamic pressure and aerodynamic lift. Most of the pneumatic conveying systems fall in this category.

Air Activated Gravity Conveyor: The transport of fluidizable solids is activated through nearly horizontal chutes fitted with air permeable bottoms. Air flows through the permeable bottom from a plenum chamber, aerates the material and changes its angle to repose, making it flow better. In these kind of systems the physical properties of the material are very important especially the rate at which the intersticial air in the material is lost affects the fluidizability of the material (33).

Tube Conveyors: Small packages or tightly packed material in small slugs are conveyed in a tubulor container with air seal rings (33).

SYSTEM CLASSIFICATION BY PRESSURE RANGE

Another logical classification of pneumatic systems falls in the category related to the normal operating pressure ranges used by the air mover (23).

1. Low Pressure System

   Single stage centrifugal fans are used with pressure up to two-thirds of a PSI (lb/sq. in.).

2. Medium Pressure System

High speed centrifugal fans with operating pressures up to 1½ PSI are used.

Multistage centrifugal fans capable of up to 4 PSI pressures are also used.

3. High Pressure Systems

Single stage positive displacement blowers with a pressure range of 4 to 10 PSI or two stage positive displacement blowers with a range of 10 to 20 PSI are often used.

Yet another classification of the pneumatic systems is by whether the stock is pushed or pulled through the system. Combination systems that both pull and push are also used.

Actually in a pulling system, the fan or blower creates a partial vacuum at the inlet of the system where stock and air enter the system. This system is also called "negative pressure system" because inside the system the pressures are below the atmospheric pressure of 14 PSI absolute. This is also otherwise called suction system.

In the pushing type system, the blower creates enough pressure to push the material to its destination. This system is also called "positive pressure system."

VARIOUS TYPES OF NEGATIVE PRESSURE SYSTEMS

Stock Passing Through the Fan: This is the simplest form of pneumatic conveying, differing very little from the dust collecting systems. Use should be limited to products which will not damage or be damaged by the fan.

Stock Dropping Out Ahead of Fan: Fan is located after the cyclone or the filter so that the stock is dropped out of the air stream before the fan.

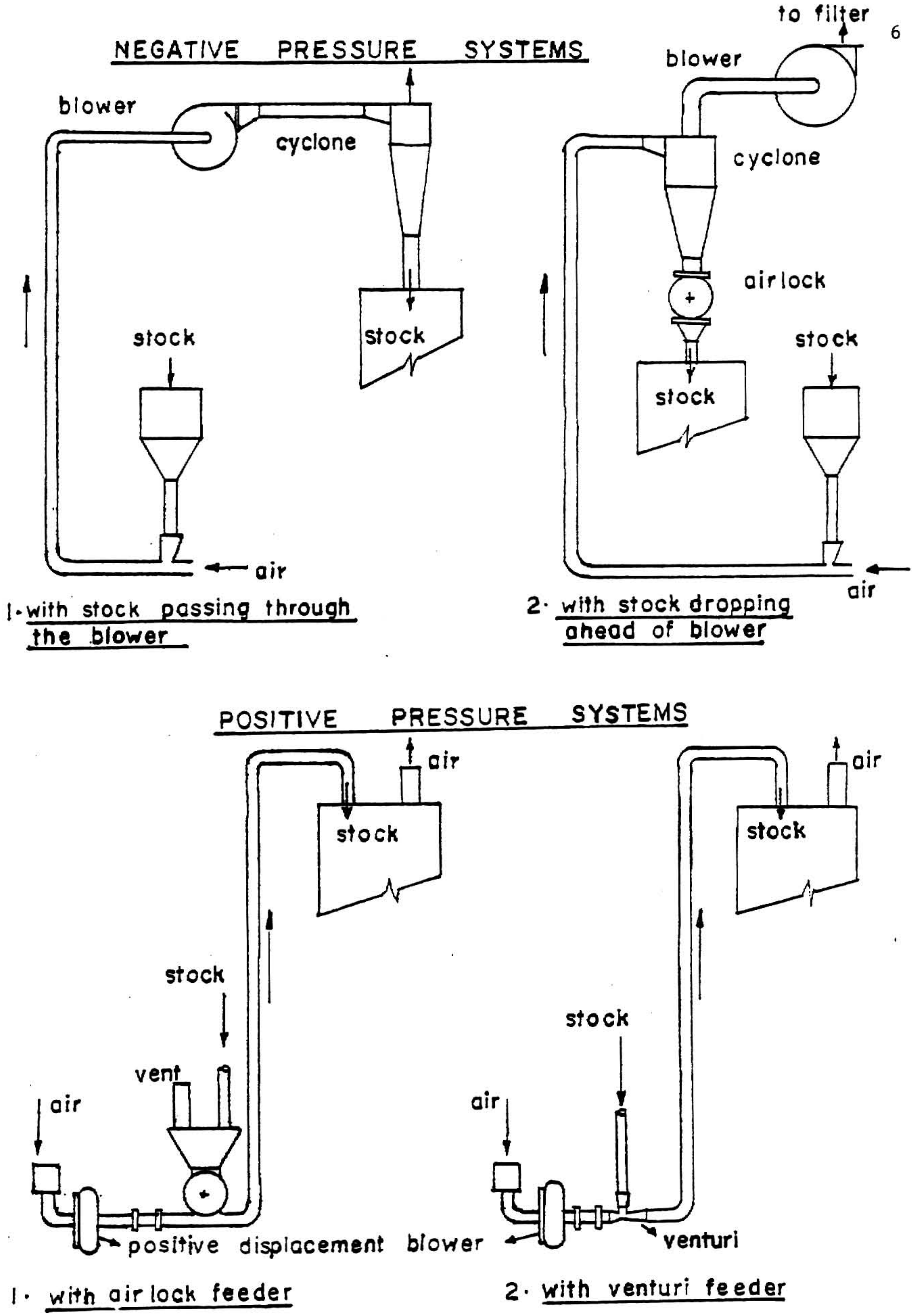

NEGATIVE PRESSURE SYSTEMS
blower
cyclone
stock
stock
air
1- with stock passing through the blower
to filter
blower
cyclone
airlock
stock
stock
air
2- with stock dropping ahead of blower
POSITIVE PRESSURE SYSTEMS
air
stock
stock
vent
air
positive displacement blower
1- with air lock feeder
air
stock
stock
air
venturi
2- with venturi feeder

fig (1)

An air lock must be used with the cyclone or filter. This system can be arranged such that a single blower device may be manifolded to a number of separate lifts, each with its own inlet blender, pipe, cyclone and air lock. This is the most utilized system in flour mill pneumatics.

TYPES OF POSITIVE PRESSURE SYSTEMS

With Air Lock Feeder: Stock is introduced into the pipe through an air lock feeder, without much loss of air, through the stock inlet despite the high pressure in the take away pipe.

With Venturi Feeder: This arrangement utilizes the venturi principle to introduce stock into the pressure line. It replaces the conventional air lock feeder. Stock is drawn through the throat of the venturi by negative pressure created at the throat but flows through the pipe under positive pressure. Power requirements are rather high because of pressure losses in the venturi.

Combination System: Stock moves by negative pressure through the inlet tube to a separator just ahead of the blower where it drops out of air but is again picked up by positive pressure air supplied by the same blower and gets delivered at the outlet.

John Fischer (24) in his article summarized the theory on pneumatic conveying and suggested two general rules to follow in designing the systems.

(1) When conveying from several points to one point use a negative pressure system.

(2) When conveying from one point to many different points use a positive pressure system.

Yet another classification, which is based on the average particle concentration in the pipe line, is dilute, medium and dense phase systems (13).

Dilute Phase System: Uses large volumes of high velocity air. The air stream carries the material as discrete particles. Conveying velocities of up to 150 ft/sec are involved. Material to air ratios up to 5 to 1 are used in dilute phase systems.

Medium Phase System: Uses lower velocities and higher solids loading. Material to air ratios up to 5 to 50 are used at high pressures.

Dense Phase System: The basic method of dense phase conveying is to arrange the material to be conveyed in the form of short plugs. All the workable systems use air pressure to split the material into plugs. Material to air ratios of above 50 to 1 are used in dense phase conveying.

BASIC PRINCIPLE OF PNEUMATIC CONVEYING

In order to understand the principle of pneumatic conveying one should understand the concept of terminal velocity.

Terminal Velocity: It is a matter of considerable technological importance to understand what is the velocity of air stream necessary to lift a particle of known size and density at a particular air temperature and humidity. As the particle is lifted by the air stream, the velocity of the particle relative to the air increases until the point where the weight of the particle is balanced by the frictional force exerted on the surface of the particle by the moving air. The velocity of air at this point, which is just able to keep the particle in suspension, is called the "terminal velocity." When the case of a particle freely falling in air is considered, the particle velocity increases as it moves downwards until the point where weight of the particle is balanced by the air friction and after that point the particle will fall at that constant velocity. This velocity is called the "settling velocity" (16).

In the first case, if the speed of air is increased beyond the suspension or terminal velocity of the particle, then the particle will start to rise and accelerate in the direction of air flow (28).

During 1851, George Stokes analytically derived a formula for the terminal velocity of a smooth sphere moving in a viscous fluid at slow speed. This is widely known as Stoke's law (41).

Geoffrey Martin (16) working in conjuction with the Portland Cement Industry of England conducted extensive tests and summarized the laws of "Air Elutriation." For smooth spheres with up to a critical radius and moving at slow speeds the terminal velocity is proportional to the square of the radius and the resistance of fluid is proportional to the velocity.

Allen (3) suggested an equation for the terminal velocities of particles of greater radius moving at intermediate velocities. He suggested that terminal velocities of such materials are proportional to the radius less a constant and that the resistance of the fluid is proportional to the velocity raised to the power of 3/2.

Sir Issac Newton (36) suggested, for materials of still greater particle size and moving at high velocities, an equation which says that the terminal velocities of such particles vary as the square root of the radius and that the resistance of the fluid is proportional to the square of the velocity.

John Blizard (25) using dimensional analysis arrived at the following relationship for the terminal relocity of a particle falling in a viscous medium.

$$\frac{V^2}{ga} = F\left(\frac{Va}{\gamma}, \frac{\int}{\delta}\right)$$

where V is the terminal velocity in cm/sec; g = acceleration due to gravity cm/sec^2; a = radius of the particle in cm; δ = density of the particle in gr/c.c.; $\int$ = density of fluid in gr/c.c.; γ = kinematic viscosity of fluid expressed in C.G.S. units.

For very small values of $\frac{Va}{\gamma}$, the inertia forces of the medium are insensible and so the resistance of the medium will be independent of its density and will be a function of V, a and γ. When the size of the particle becomes very large and velocity becomes very high, the velocity will be independent of viscosity. Blizard (25) summarized that terminal velocity is a function of mean velocity, the density of the particle, the density of the fluid, mean linear size of the particle, surface roughness of particle and the pipe inside roughness. Dollavalle (9) stated that terminal velocity varies with the shape of the particle, its mass and with the Reynold's number.

The bulk of the research on terminal velocities has been conducted on isometric particles. L. B. Toubrin and W. H. Gauvin (44) made a good review of the few articles of research published on the settling velocities on nonisometric particles. They themselves conducted experiments to find the effect of particle rotation, roughness and shape of the irregular shaped particles on solid gas flow. They suggested that the effect of surface irregularities may be dependent on the state of turbulence of the fluid and that the shape characteristic of a solid particle can exert profound influence on its ability to absorb momentum from a moving fluid stream.

In the context of terminal velocities of milled stocks, as the materials are highly heterogeneous, terminal velocities can at best be expressed as a range of velocities or as the velocity of air capable of keeping the heaviest of the particles in suspension. Stein (40), Hopf (20) and Barth (5) have published information about terminal velocities of milled stocks based on their experiments.

ADVANTAGES OF PNEUMATIC CONVEYING

Basically pneumatic conveying facilitates the advantages of bulk conveying over the sack or packaged type of transporting solids (33).

(1) Savings due to elimination of packaging labor and packaging material cost

(2) Savings due to reduced freight rates

(3) Convenient handling of dry bulk materials within the plant

(4) Capability to use large capacity bins and silos for storage

In addition to the above, there are many operational advantages for pneumatic conveying over other forms of transport. Truniger (30) enumerated them in his article.

(5) Offers clean and dust free operation

(6) Infestation is controlled

(7) Condensation of mill stocks is eliminated

(8) Fire hazard is eliminated and thereby savings due to reduced insurance costs

(9) Self cleaning system and thereby less maintenance costs

(10) Cools the grinding rolls and increases the grinding efficiency

(11) Mill stocks are cooled and fluffed aiding in the sifting efficiency

(12) Easy and inexpensive installation

(13) Great flexibility in the choice of lay out

(14) Better space utilization in the mill due to convenient placing of lift pipes

(15) Better ventillation and bright interiors

(16) Occupies less building space which results in savings in building construction

The disadvantage voiced against the pneumatic systems is the excessive power consumption needed by these systems. Henry Simon Ltd., of England, have introduced low pressure pneumatic systems which eliminated the horizontal runs and elbows but introduced mechanical diffusers to introduce material from rolls into the vertical lifts as well as provide initial acceleration. Presumably the elimination of pressure drops in horizontal runs and elbows is the basis for the reduced power consumption as claimed by the manufacturers of these low pressure systems (4). According to Abbott (1) these systems resulted in the lack of flexibility.

Nagel (35) disagrees with the claim made by Ansley (4) and argues that by using high or medium pressure systems with judiciously chosen pipe diameters while keeping air volume to a minimum possible, the power consumption can be controlled. The authors of Cereal Millers Hand Book (6) claim that less energy is needed in a smaller tube at higher pressure than in a larger tube at lower pressure to get the same air velocity. This is due to the larger volume of air required in a larger tube than in a smaller tube. Theoretically, medium and high pressure systems are more efficient than low pressure systems.

VERTICAL PNEUMATIC CONVEYING

For vertical pneumatic conveying of granular solids, Leung (31) suggested two different types of gas solid systems - 1. the choking system, and 2. the nonchoking system. At very high gas velocities solids are conveyed in apparently uniform suspension known as lean or dilute phase flow. As the velocity is reduced two different types of behaviour are possible, one with fuzzy transition from lean phase to dense phase and then to packed bed flow while the other has sharp transitions - see Fig. 3.

FLOW PATTERNS IN HORIZONTAL TRANSPORT

fig (2)

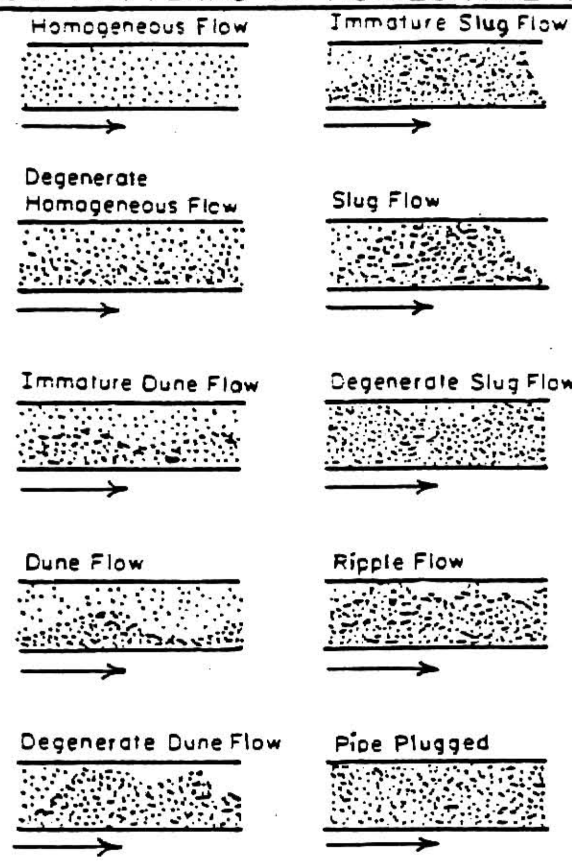
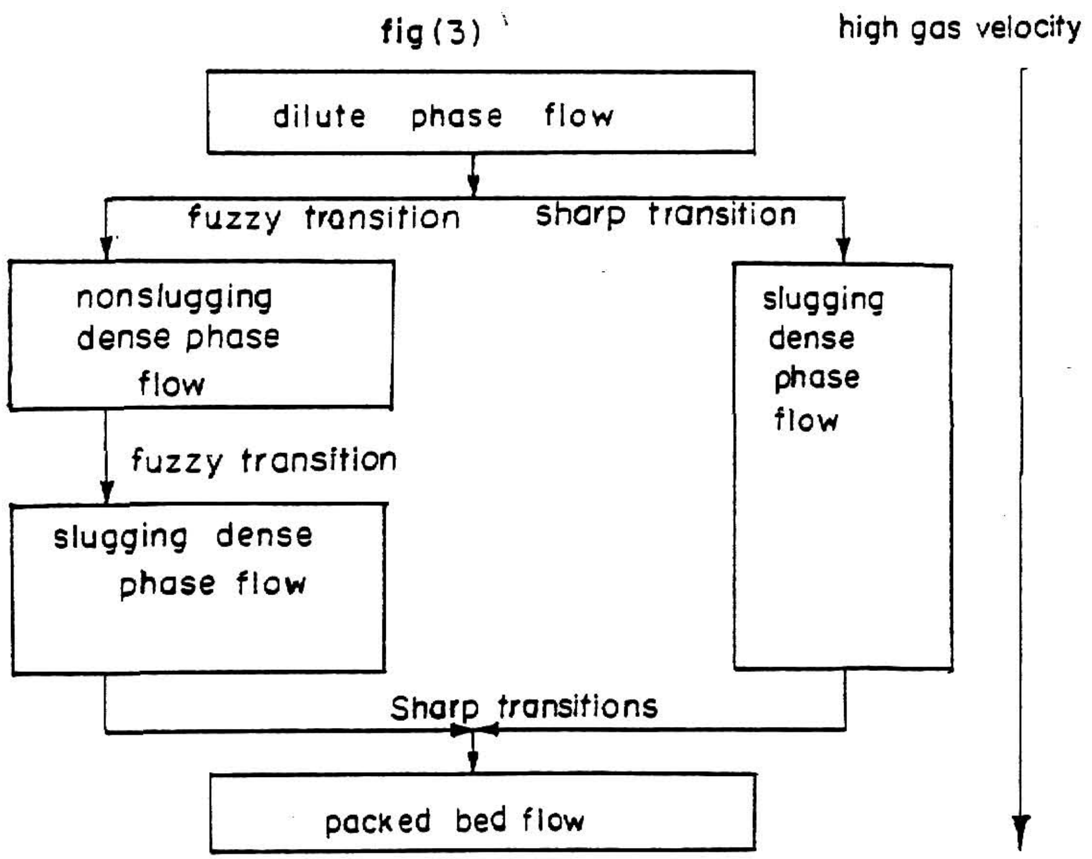


fig (3)



FLOW PATTERNS IN VERTICAL TRANSPORT

HORIZONTAL PNEUMATIC CONVEYING

Wen and Obrein (47) defined a homogeneous horizontal flow as a flow in which the variations of solids density in axial and radial directions are small enough that clusters of solids and any settling of particles in the bottom of pipe can not be identified. They present the various flow patterns in Fig. 2. They observe that the flow patterns are affected by solids to gas ratio, Reynold's number and the specific properties of solids. Abbott (1) and Jun et al. (28) write that in order to convey the heterogeneous mill stocks, the air velocity must be greater than the terminal velocity of each of the particles. In order to convey horizontally the air velocity must be still higher because of the tendency of the particles to ride along the bottom of the pipe as a result of the force of gravity.

VARIOUS COMPONENTS OF A TYPICAL SUCTION PNEUMATIC LIFT

In a bottom discharge suction pneumatic lift there will be:

1. Conveying tube: It is important to select a narrow range of tube sizes with 1/4" increments with smooth inside walls for proper balancing of all the lifts in this system.
2. Pneumatic pickup shoe: There should be a tangential air inlet to provide for acceleration of product with air stream.
3. Elbows: Long sweep elbows to provide for streamlined deceleration and acceleration of solid, gas flow and to minimize the pressure loss.
4. Pneumatic Cyclone Dust Collector: Proper design, size and smooth inside are necessary to achieve maximum separation.

Convergent Nozzle or Pneumatic Air Regulator

5. Convergent Nozzle: In older systems a plate nozzle is used to adjust air quantity used by each lift.
6. Pneumatic Air Regulator: This will automatically adjust and balance air flow and suction of each lift. These are installed after the cyclone and before the central pneumatic duct.
7. Sight Glasses: To inspect the conveying.
8. High Pressure Fan: Proper fan selection and proper balancing of all lifts to enable the fan to operate at designed static pressure are very important to achieve an efficient system and to minimize power consumpion (30).

DESIGN OF MILL PNEUMATICS

Truniger (30) in his presentation pointed out that a good design of mill pneumatics is not an exact science but a combination of science and practical experience gained and accumulated by the flour miller and engineer. Every pneumatic system is unique and the products handled vary in their characteristics. When designing a pneumatic system certain information should be available to base the calculations. The products to be conveyed have to be analyzed and bulk density, particle size and other special characteristics such as flowability, moisture content, fat content, and abrasiveness have to be noted. System stream capacity and possible minimum and maximum fluctuations in the stream capacity in each lift also have to be fixed. Conveying distance (horizontal and vertical), number of elbows and other physical dimensions of the system have to be fixed according to building layout (33, 42, 30).

Air to Solid Ratio: Before trying to do anything further, one should know the expected maximum load per unit time coming to each lift and also establish the material to air ratio. Usually for flour mill streams material to air ratio of 2.5 to 1 - 3.5 to 1 are usually used.

Air Quantity: From the above, the weight of air used per unit time is calculated. The density of air at the usual atmospheric conditions is determined and the air quantity in cubic feet per unit time is calculated.

$$\frac{\text{Load coming to the lift in lb.}}{\text{Material to air ratio}} = \text{Weight of air in lb/unit time}$$

$$\text{Air Quantity} = \frac{\text{Weight of air in lb/unit time}}{\text{Density of air in lb/cu. ft.}} \text{ in cu. ft.}$$

Conveying Velocity: The conveying velocities are then fixed. Abbott (1) and (6) point out that the designer has to provide conveying velocities 5 to 6 times faster than terminal velocities. For safe conveying of stocks (40) and (20) have suggested multiplication factors to be used with terminal velocities of the stock based on their experience.

Selection of Pipe Size: Cross sectional area of the pipe is calculated from air quantity and velocity and then the diameter of the inside of the pipe is calculated. It is advisable to select a close range of pipe diameters to facilitate the balancing of lifts.

COMPUTATION OF SYSTEM PRESSURE AND SELECTION OF FAN

Now comes the task of determining system pressure and selection of air mover. The system pressure should overcome the pressure demands of the lift with the greatest pressure requirement together with back pressure from components after the fan. The analysis of pressure drops encountered in a lift may be considered as the sum of the following contributions (6, 15, 23).

(1) Acceleration of air to the conveying velocity

(2) Acceleration of solid particles by a momentum balance

(3) Dynamic losses due to air turbulence resulting from change of direction and speed (23)

(4) Support of the column of air

(5) Support of the column of solids

(6) Friction between air and pipe wall

(7) Friction between particles and particles and particles and pipe wall

Friction losses in vertical and horizontal runs vary as the velocities in them. In a horizontal run friction losses concentrate on the lower half of the pipe while in vertical pipe centrifugal forces have great effect. Static head is important in a vertical pipe where as in a horizontal pipe it is zero. Initial acceleration at the point of entry and acceleration after the elbows requires energy which must be supplied by the carrier gas (18).

The length of the pipe in which the solids undergo acceleration is a function of solids flow rate, fluid velocity and particle characteristics. It is reported that acceleration persists in many instances as far as 15 feet from the solids feed point (47, 49).

Experimental and theoretical studies of pressure drops in horizontal and vertical sections are carried out by Chately (7), Cramp and Priestly (8), Davis (10), Zenz (49), Gasterstadt (15), Segler (38), and Wood and Bailey (48). Out of these studies came the concept of correlating the specific pressure drop to the material to air or mixture ratio. Specific pressure drop is the ratio of "pressure drop with solids flowing with fluid" to "pressure drop with fluid only." Gasterstadt found with his studies on wheat that specific pressure drop and mixture ratio are linearly related and the slope of the line depends on air velocity used and that slope is constant for a given velocity. The later studies of Vogt and White (46), Farbar (12), and Korn (29) retained the concept of specific pressure drop. But in their studies they found that the slope of the straight line fitted is not a simple function of air velocity alone but involved additional variables like particle size, particle and fluid density and fluid viscosity.

The important independent variables in pneumatic transport can be devided into groups:

1. pipe size and roughness
2. particle size, shape, density and roughness, and mass rate of flow
3. velocity of the fluid
4. density and viscosity of the fluid.

Korn (29) suggests that the motion of particles depend on their size.

While keeping all the above observations in mind, Mehta et al. (34) suggested that a method has to be developed which does not assume that the pressure drop due to air is unaffected by solids and which takes into effect different flow patterns for different solids. From their results they put forward the following correlation for the pressure drop in a lift for the combined flow of solids and air.

$$\text{Total pressure drop} = fm(\Delta l)Va^2 \rho a \times \frac{\left\{1+\left(\frac{Vs^2 \rho s}{Va^2 \rho a}\right)^a\right\}}{2gD}$$

for horizontal conveying

and

$$fm(\Delta l)Va^2 \rho a + \frac{\left\{1+\left(\frac{Vs^2 \rho s}{Va^2 \rho a}\right)^a\right\}}{2gD} + \frac{Gs}{Vs} \times \Delta l$$

for vertical conveying

fm = mixture friction factor

Va = velocity of air

Vs = velocity of solids

ρs = density of solid

ρa = density of air

g = acceleration due to gravity

D = diameter of pipe

The concept of mixture friction factor was first introduced by Segler (38) and is similar to the Fanning friction factor in Fanning equation (32). More recent investigators (39, 26, 27, 19) and scores of others have published a wealth of information for pressure drop correlations regarding chemical catalysts, but unfortunately very little data are ever published on the conveying of flour mill stocks.

FLOW OF FLUIDS

Alden (2) in his classic book writes that a unit mass of fluid flowing through a pipe is acted upon simultaneously by two distinct pressures. One is known as "static pressure", the force tending to compress the fluid, and the other is known as "velocity pressure" which is required to accelerate the fluid mass from rest to the existing velocity. Velocity pressure acts in the direction of flow. Static pressure acts equally in all directions. Static pressure is used in overcoming the resistance to the flow of fluid in the pipe. Hence, static pressure is sometimes called frictional or resistance pressure. Fan engineering (11) adds that static pressure is a measure of potential energy and it may exist whether the fluid is resting or in motion and is virtually the means of producing flow and maintaining it against resistance. The algebraic sum of static pressure and velocity pressure is called the total pressure. If it is a negative pressure system, static pressure will be negative, and positive if it is a positive pressure system, but velocity pressure is always positive.

AIR FLOW MEASUREMENTS

Static pressure is measured at right angles to the direction of flow in order to avoid the influence of fluid velocity. Velocity pressure is difficult to measure directly, so it is conveniently found by deducting static pressure from total pressure.

U Tube Manometer: is the most common of the self-indicating manometers. It is used for mainly reading static pressures. It is made in U shape with a 3/16" to 1/4" bore glass tube. When colored water is partially filled in it and one leg is connected to the static pressure tap, the difference in the water level gives the static pressure at the particular point (11).

Pitot Tube: Pitot is the standard instrument to find air velocities. The device consists of two concentric tubes, one serving to measure total or impact pressure existing in the air stream and the other for measuring static pressure only. When the annular space and the central tube are connected simultaneously across a U tube monometer, the difference of level indicated on the manometer gives the velocity pressure directly (22).

AIR VOLUME

Orifice Meter: A convenient method of measuring air volume is by means of finding the pressure drop caused by the insertion of orifice plates in the pipe line. The pressure drop can be measured from pressure taps and as the conditions are similar to those in abrupt contraction in a pipe, the air volume can be computed. These meters have to be standardized before using. (11).

Venturi Meter: Venturi meters also can be used for air flow measurements. These contain a convergent divergent nozzle and are more accurate than orifice meter readings.

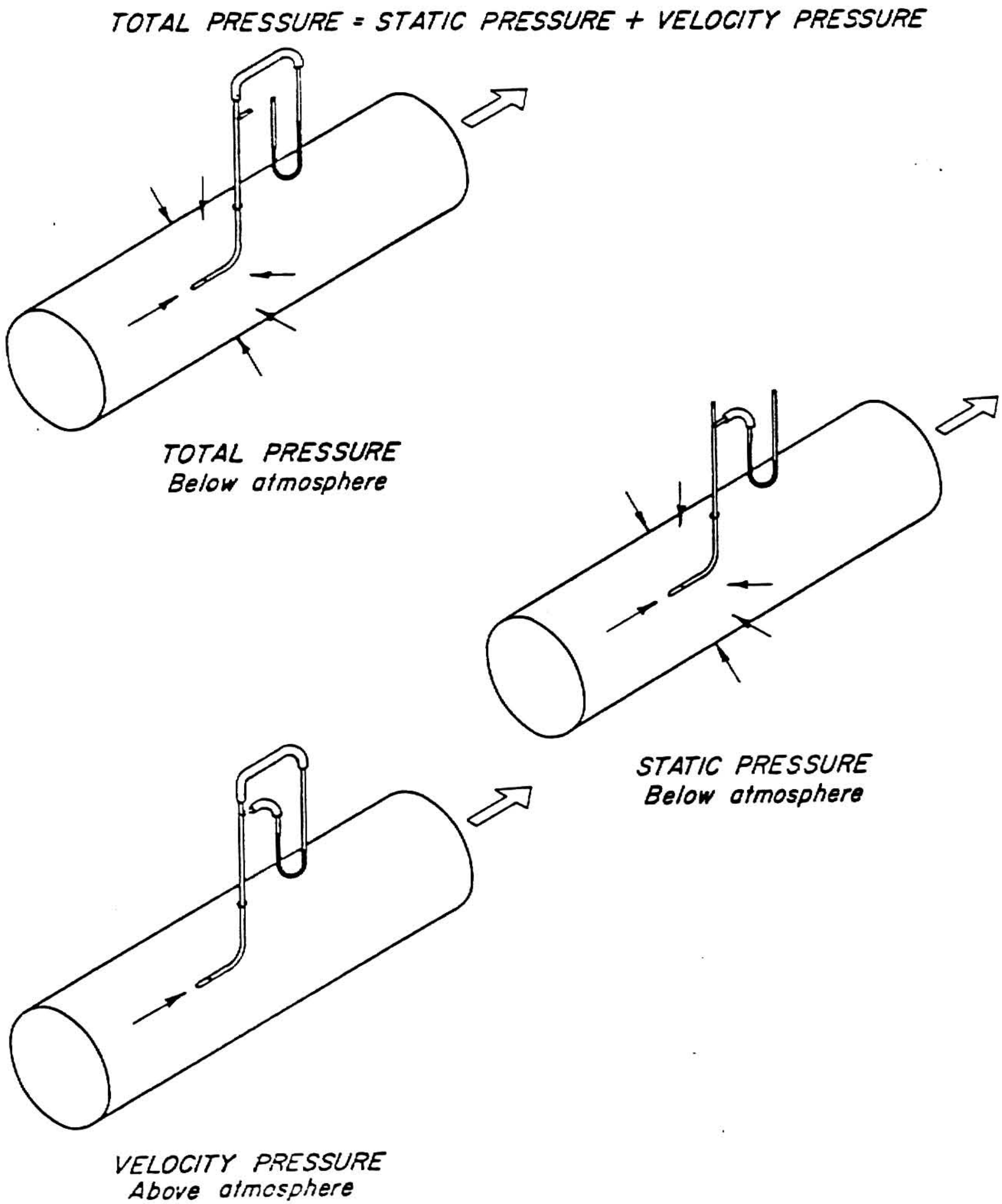

TOTAL PRESSURE = STATIC PRESSURE + VELOCITY PRESSURE
TOTAL PRESSURE
Below atmosphere
STATIC PRESSURE
Below atmosphere
VELOCITY PRESSURE
Above atmosphere

fig (4)

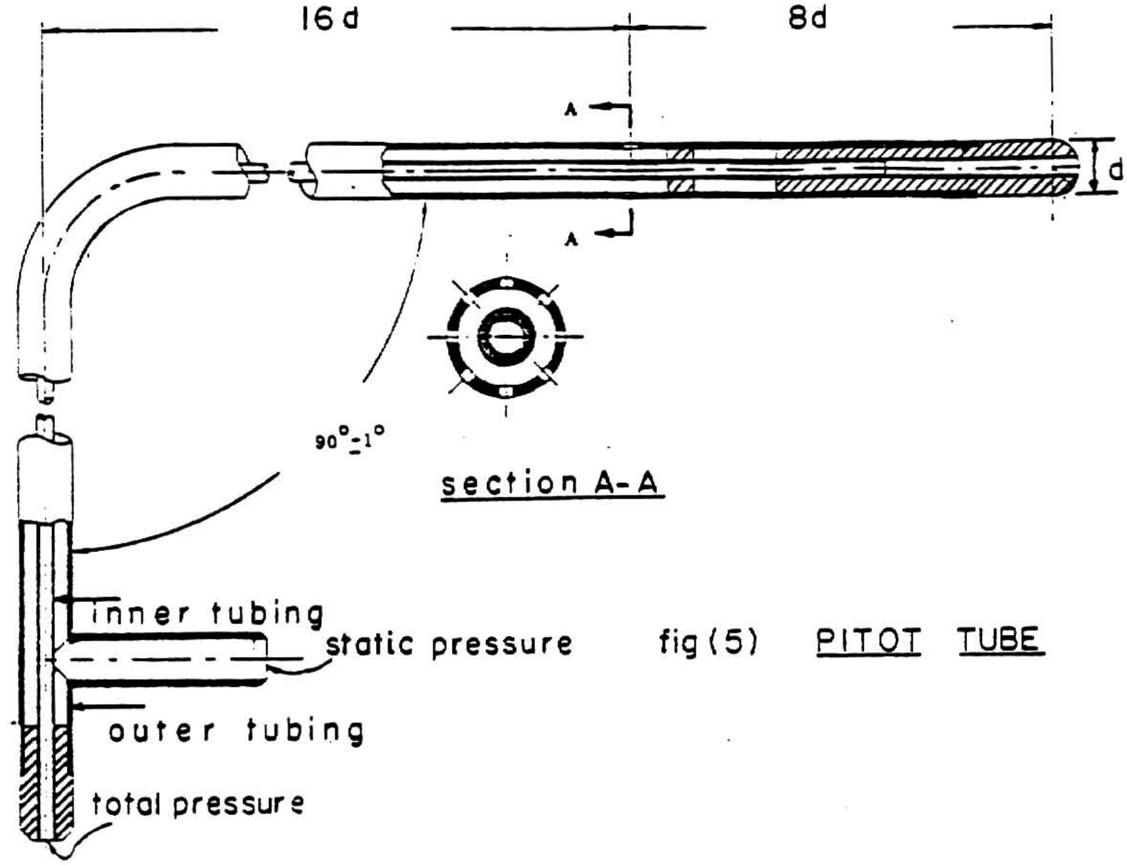
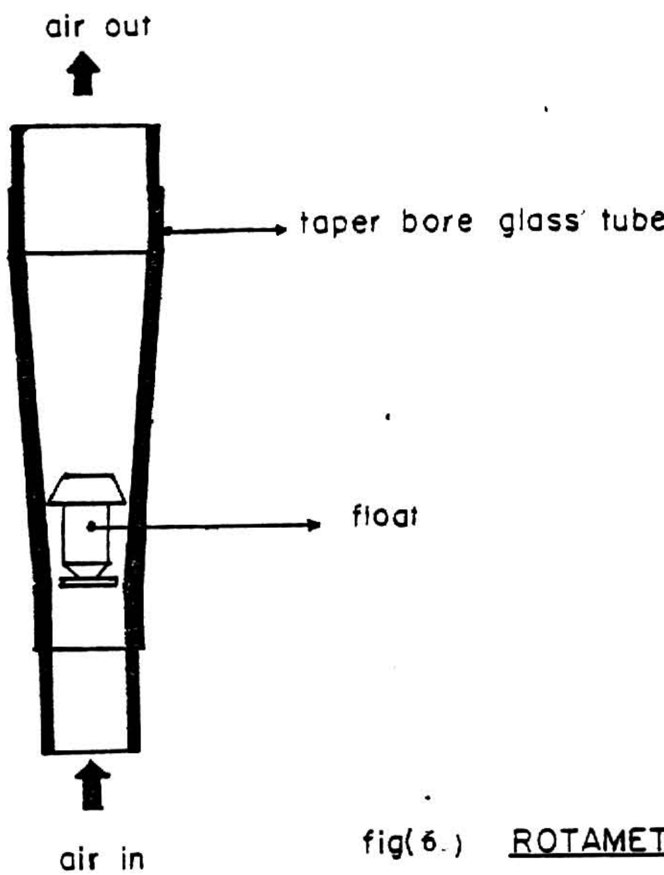


fig (5) PITOT TUBE



fig(6.) ROTAMETER

Rotameter: A more innovative and recent development in air quantity measurements is the rotameter (43). Rotameter consists of a taper bore metering tube made of glass and a solid float in the shape of a bob or cone which is free to move inside the taper bore tube.

MATERIALS AND METHODS

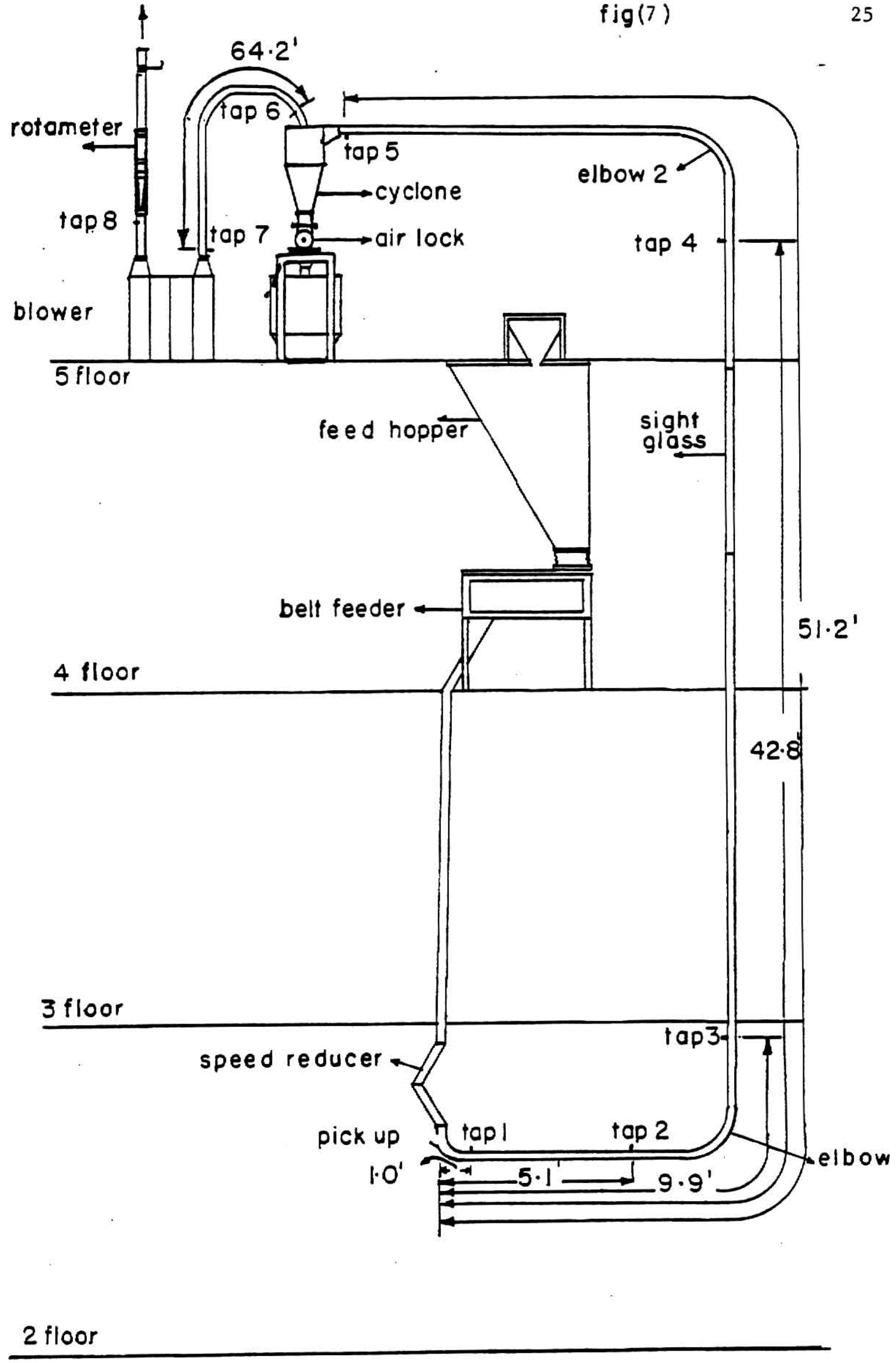
In the summer of 1982, experiments on "Pneumatic conveying of milled stocks and whole grain wheat" were conducted in the specially erected experimental rig in the pilot flour mill at Kansas State University.

Materials

1. Experimental Rig: A pneumatic lift pipe of internal dia 2.4" aluminum drawn type was used. A four foot long inspection tube was fitted in the line on the fourth floor. At the pick up point in second floor a speed breaking attachment was fixed in the downgrade piping just above the "pickup" to introduce the stock into the lift pipe at as uniform rate as possible and to slow the velocity of the feed into the entrance. The lift pipe, as shown in the schematic diagram Fig. 7, contained two 2.4" I.D. long sweep pipe elbows, 12" spintrifugal cyclone, and a rotary air lock feeder running at 30 RPM. The pipe connecting the cyclone air outlet to blower was a three inch O.D. aluminum pipe. Material was metered into the system by a Wallace and Tiernan nine inch belt feeder situated on the fourth floor. The speed of the belt is nine FPM. Stock was fed to the scale thru a feed hopper with feed point on fifth floor. A Kice multistage blower was used to move the air through the system. The blower was run at 3340 RPM.

Static pressure taps are at the entrance after the pickup, before the first elbow, after the first elbow, before the second elbow, before and after the cyclone and before the blower, respectively. These are connected to the manometer panel situated on fifth floor by 1/4" copper capillary tubing. An additional pressure tap is located just before the rotameter and is connected to a slack tube manometer to measure the system static pressure.

fig(7)



<u>SCHEMATIC DIAGRAM OF EXPERIMENTAL LIFT</u>

2. Material: 150 lbs each of hard red winter wheat tempered to 16% moisture, Kansas State University standard white flour and bran, were taken from pilot mill. 150 lbs each of intermediate milled stocks namely 1 Bk, 4 Bk, coarse sizing, 1 middling, 6 middling, and 1 tailing were collected "under the rolls" from ADM Milling Company at Salina, Kansas. All these materials were kept in departmental cold storage prior to usage.

Instruments

1. Fischer and Porter series 10A1027A 3" size all glass flowrator-Rotameter - used to measure air volume
2. Model 2176A digital thermometer - used to measure temperature of discharging air at the rotameter
3. Slack tube manometer, flex tube well type manometers and common U tube manometer - all from Dwyer to measure static pressures
4. Sling psychrometer - to record room temperature and relative humidity in the mill
5. Tachometer - to measure the speed of air lock and blower
6. Stopwatch

When trial runs were performed it was found that the blower used was discharging at 3340 RPM, 500 cfm of air at 70" w.g. pressure. As only 150 cfm of air is needed for these experiments, the blower had to be throttled to a great extent. This resulted in temperature build up on the discharge side of the blower. Attempts to reduce the speed and thereby reducing the volume handled, did not give good results because the pressure developed was not sufficient to take care of system resistance and the resistance across the flowrator (rotameter). The flowrator alone needed 20" w.g. pressure to operate. The blower was speeded up to the original level and utilized by throttling at the outlet. The temperatures at the discharge were continuously increasing thru out the experiment. But it was found that if the temperature was allowed to raise ∿ 200°F before experiment, the change of temperature during the experiment was narrow. A digital thermometer was used to accurately monitor the air temperature. This flowrator used was calibrated at 17.7 psia and 150°F to give direct SCFM readings of air flow. But now as the pressure and temperature varied from those of standardization of the meter, the air volumes read on the rotameter had to be corrected for pressure and temperature according to the method given by the manufacturer.

It was estimated that the air lock was pumping one cfm of air on an average into the system in addition to the air coming from the pickup through the pipe. So, the correction of one cfm was done on all rotameter readings before correcting for temperature and pressure.

The bulk density (loose) of all the test materials were determined by filling a container of known volume loosely.

Particle density was determined by using displacement method using Benzene (0.87 sp. gr).

Particle size determination was done for the test materials except wheat, using the method suggested by Pfost and Headley (37). For wheat, all the physical tests performed are reported in Table 1.

Procedure

For the purposes of this experiment, it was decided to conduct for every test material, runs at two different velocities of air and at five to six different material to air ratios. The velocities used were one that is usually used in commercial applications and the other about 250 FPM less than first. Taking into consideration the density of standard air as 0.075 lb./cu. ft., the weight of air used per minute was calculated and at material to air ratios of 2.5, 2.0, 1.5, 1.0, 0.5 to 1 the actual feed rates to be set for the test materials were calculated.

On the belt scale, the feed gate settings corresponding to the various feed rates established for each material are fixed by doing actual feed rate tests.

Before the experiment was started, the room atmospheric conditions were recorded using a sling psychrometer. The blower and air lock were started. The air quantity corresponding to the velocity being used was fixed and set on the flowrator. The blower was allowed to run idle for some time to build the temperature at discharge to 200°F. Then once again the flowrator was set for the required air quantity. Various pressure tap readings were noted along with flowrator and temperature readings for air. Then the different material feed rates were set on the belt scale. When the material started flowing in the system, the quantity of air flowing in the pipe was reduced. The flowrator setting was brought back to the established value in order to maintain the air velocity in the system constant. After correcting the flowrator setting, the pressure tap readings, flowrator and temperature readings were again noted. The material discharging from the air lock was transferred manually to the feed hopper to maintain a continuous supply of material through out the experiment. The procedure was repeated for the second velocity.

The experiments at both velocities, for all test materials are duplicated on the same day following the same procedure.

METHOD OF CALCULATION

The flowrator readings were corrected as per the manufacturer's instructions for pressure and temperature. From the corrected air quantities, the air velocity and velocity pressure were calculated. S.P. tap #5 just before the cyclone was the last point before material gets separated from air. So, tap #5 static pressure readings were considered for the purposes of calculation of "specific pressure drop" and "mixture friction factor." Tap #7 readings were used to calculate air horsepower.

From the psychrometer readings, referring to psychrometric charts, the relative humidity and density of air in the mill were determined.

Then the viscosity of air was determined by following the method shown by Martin (17).

From the density of air, the weight of air used per minute was calculated and the material to air ratios were corrected for the actual air weight used.

To calculate the specific pressure drops, the total pressure at tap #5 was found by deducting the velocity pressure from static pressure and the ratio of the total pressure at tap #5 for solids and air to air flow only was calculated. These ratios are the specific pressure drops for the different material to air ratios.

Horsepower required to move air was calculated by using static pressure at tap #7 and the corrected air volume. Horsepower for moving material from pickup to cyclone was also calculated.

Mixture friction factors as originally suggested by Segler (38), were calculated by using the static pressure reading at tap #5.

Plots were drawn between "Material to air ratio" and 'specific pressure drop', 'horsepower', and 'mixture friction factor' for each material at both velocities.

Plots were also drawn between "conveying length in feet and static pressure in inches of water," at all material to air ratios for each material at both velocities.

THEORY AND FORMULAS USED FOR CALCULATION

$$\text{Specific pressure drop} = \frac{\text{Pressure drop due to (air + material) flow}}{\text{Presure drop due to air flow}}$$

Mixture Friction Factor:

$$\text{Static pressure in a system} = \lambda m \times \frac{L}{D} \times \frac{Va^2}{2g} \times \rho a \times k \ \text{"}H_2O$$

λm = Mixture friction factor

L = Equivalent length of the pipe in feet

D = Internal diameter of pipe in feet

g = Acceleration due to gravity in feet/sec^2

Va = Air velocity in feet/min

ρa = density of air in lb./cu. ft.

k = conversion factor = 0.1921317

Horsepower:

Horsepower required is conceived as the sum of the horsepower needed to lift air and the horsepower needed to elevate the material.

$$\text{Air horsepower} = \frac{Q.P.\ 623}{12x33000} = 0.0001575\ QP \quad \text{Ref (45)}$$

P = Static pressure in inches water

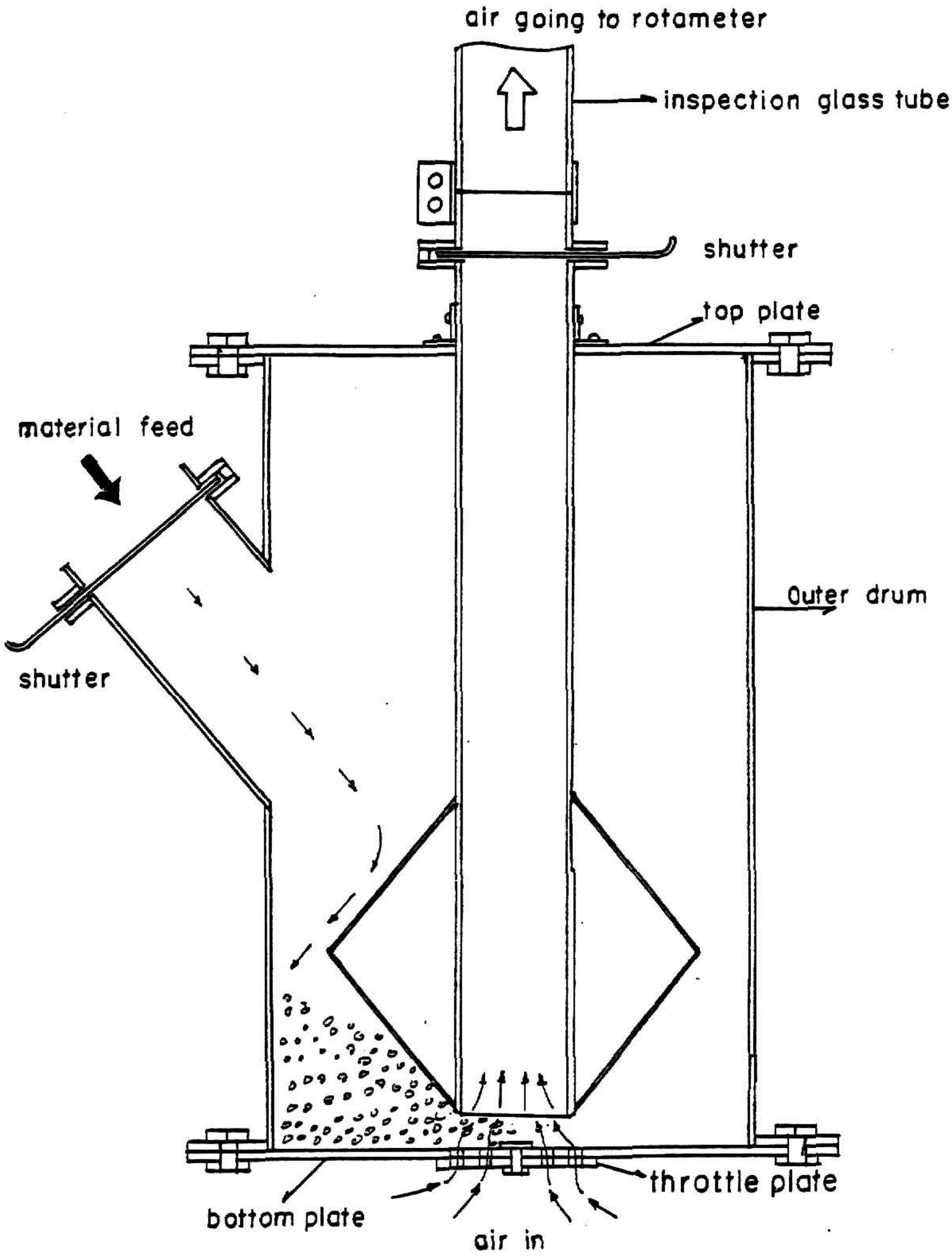
Q = Air quantity in cfm.

$$\text{Horsepower to elevate material} = \frac{WL}{33000}$$

where W = feedrate/minute of material in lb/min

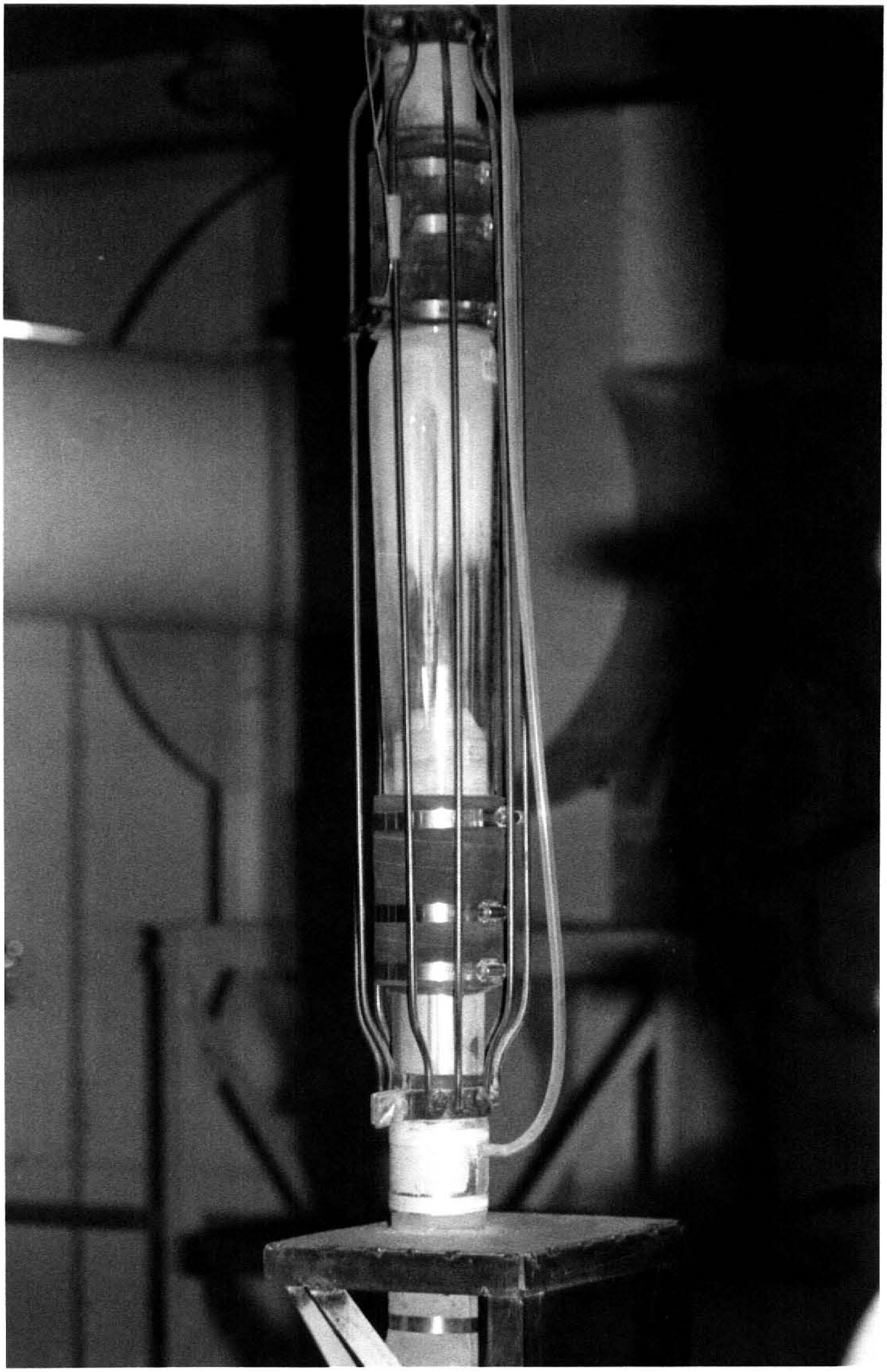
L = equivalent length of pipe in feet

Horsepower = 0.0001575PQ + WL/33000

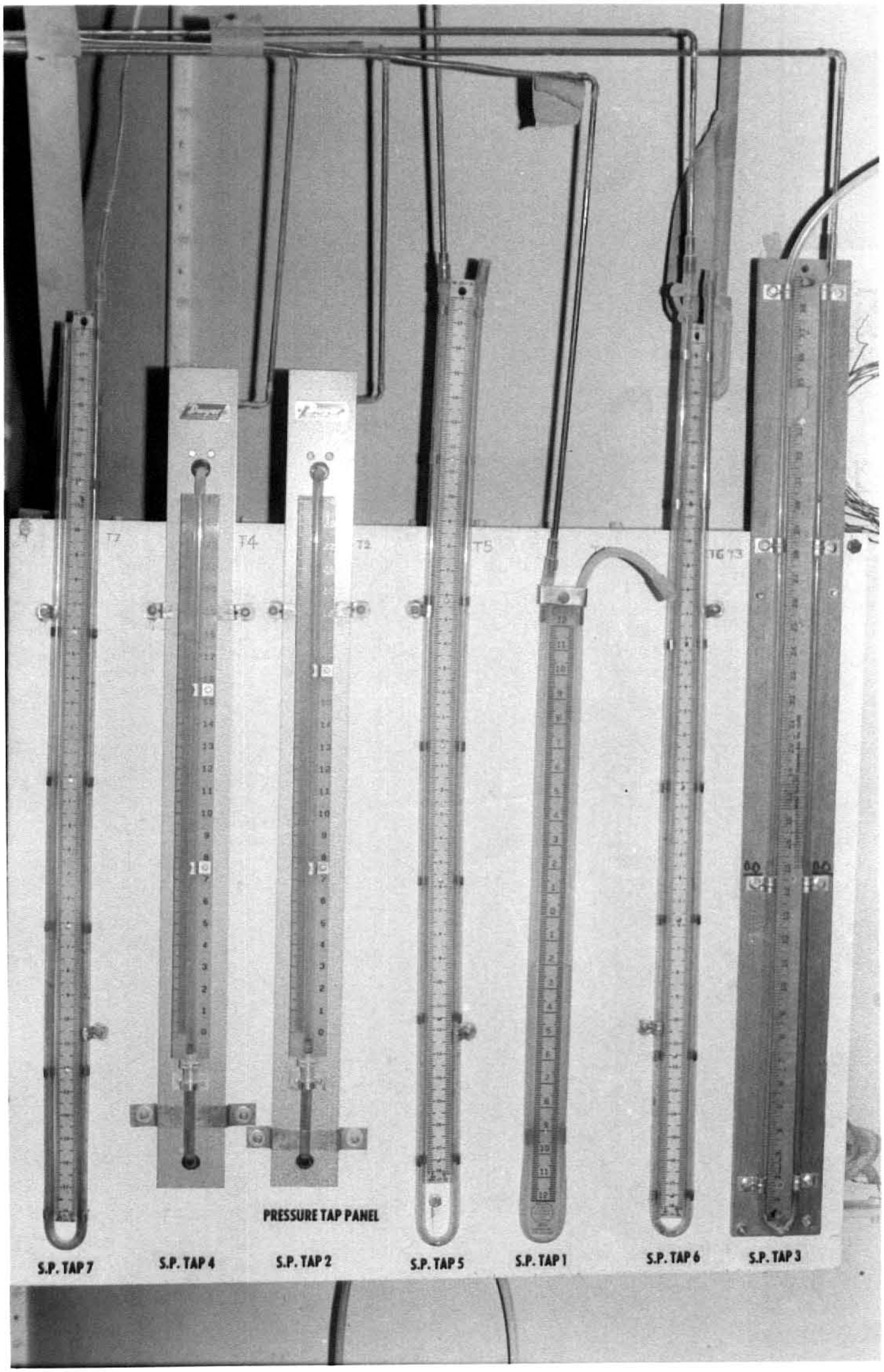


TERMINAL VELOCITY ATTACHMENT

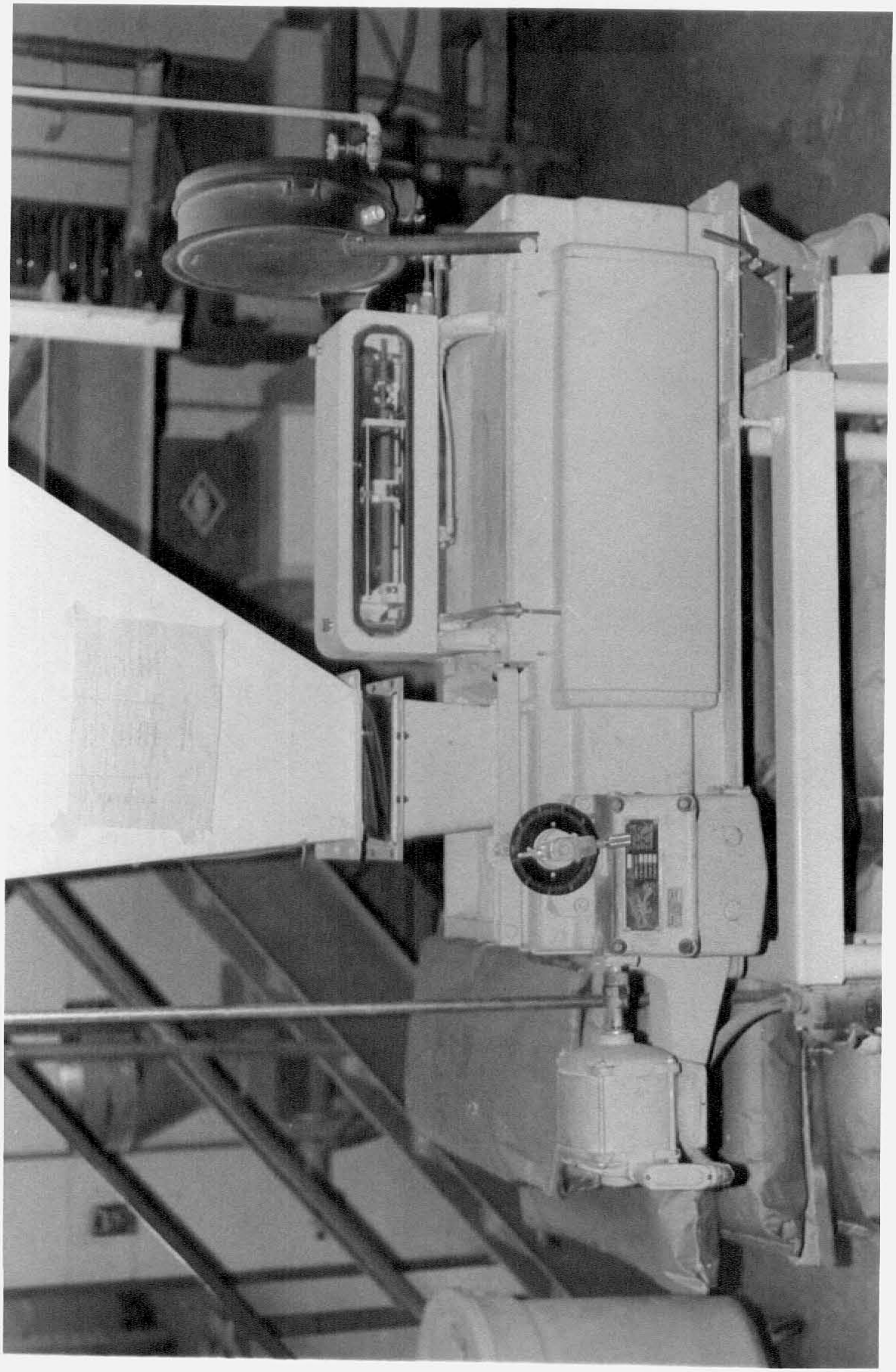
fig (8)



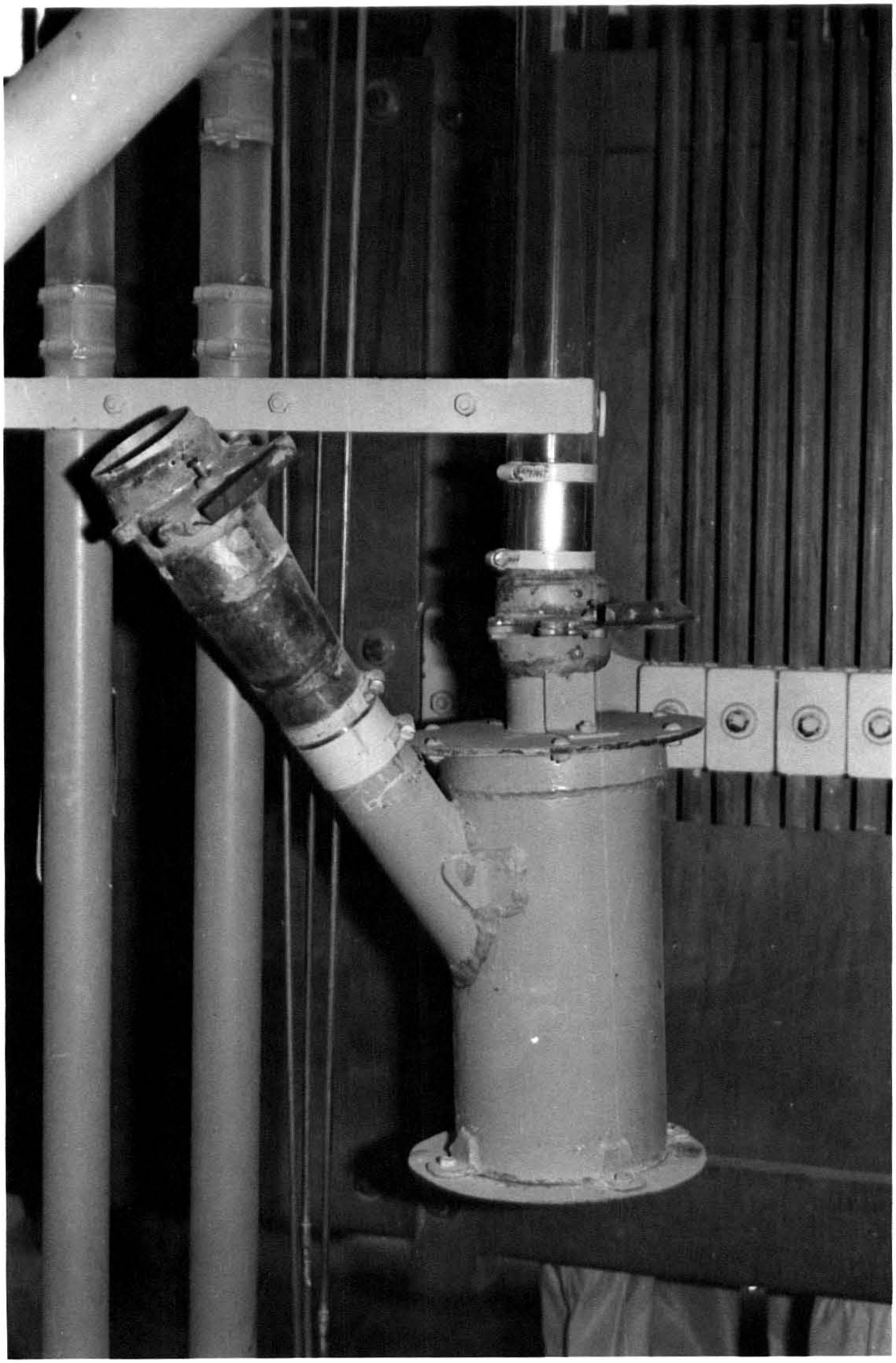
ROTAMETER



PRESSURE TAP PANEL



BELT FEEDER



TERMINAL VELOCITY ATTACHMENT

SPEED REDUCER

PROCEDURE FOR FINDING TERMINAL VELOCITIES

Description of the Terminal Velocity Attachment:

As shown in Fig. 8, the attachment consists of a drum fitted with a branch pipe to feed material. The drum is fitted with a bottom plate and a top plate. The bottom plate has a number of holes drilled at the center and is fitted with throttle plate with identical holes. To the top plate a central pipe is fitted. This pipe passes through the top plate. The pipe is fitted with a club-like construction at the bottom end which is ½" above the bottom plate. The top end of the pipe is fitted with a shutter and the whole attachment is fitted to the inspection tube in fourth floor. A shutter is also fitted to the material feed pipe to avoid suction through that end.

The blower was started and allowed to run until the temperature at the discharge is built up to 200^{o}F. The shutter in the central pipe of attachment was kept closed. Material was introduced thru the feed pipe and that shutter was closed. The shutter in the center pipe was opened fully and quickly closed. In that process some material was trapped on the shutter. Then by adjusting the shutter slowly the material was allowed to float in the inspection tube region. Finer adjustments were done using bottom throttle by finely controlling air supply. The rotameter reading at that point was noted along with slack tube manometer and temperature measurements. The process was repeated until repeatable readings were obtained for each material.

PROCEDURE FOR FINDING AIR FLOW CHARACTERISTICS

The blower was started and run idle until the temperature buildup on the discharge side was around 200^{o}F. The flowrator (rotameter) was set starting from 50 cfm to 140 cfm at 10 cfm increments. For each setting, the pressure tap readings from the manometer panel, slack tube manometer reading and temperature were recorded. The experiment was duplicated.

The flowrator readings were corrected for temperature and pressure. From the air quantities, the velocity of air and velocity pressure were calculated. The design of pressure tap location isolated pressure drops due to entrance, elbows and cyclone and vertical lift. Difference in readings of tap #6 and tap #5 gave the static pressure drop across cyclone. Difference in readings of tap #5 and tap #4 gave the static pressure drop across elbow 2 and so on. Between tap #4 and tap #3 for vertical lift, between tap #3 and tap #2 for elbow 1 and the reading of tap #1 could be taken as the pressure drop at entrance.

Plots were drawn between "velocity pressure in inches water" and "static pressure drop in inches water" across entrance, elbow 1, vertical lift, elbow 2 and across cyclone, respectively.

RESULTS AND DISCUSSION

Terminal Velocities

Knowledge of terminal velocities of the stocks is very important in the design of pneumatic conveying experiments. The velocities of air, which are enough to suspend the various milled stocks, were measured and are tabulated in Table 2. The results indicate that terminal velocity of any stock basically is dependent on its bulk density as well as its particle size and shape.

Coarse sizing has an average particle size smaller than fourth break stock, but its bulk density is two and a half times that of fourth break. Eventually, coarse sizing owing to its heavier bulk density has a higher terminal velocity than fourth break stock. When fourth break stock and 1 Middling are compared, though 1 Middling has higher bulk density, fourth break stock requires a higher suspension velocity owing to its larger mean particle size and shape. Fourth break stock has a mean particle size which is three times that of 1 Middling. Owing to the same reason, fourth break stock and bran have higher terminal velocities than 1 Tailing, 6 Middling and flour. When 1 Middling and 1 Tailing are compared, 1 Middling has higher terminal velocity. Here, its higher bulk density is the influencing factor. When compared to all the other stocks considered, wheat and first break stock have higher terminal velocities owing to their large particle size and bulk densities. Flour registered the minimum suspension velocity, owing to its very small particle size, but it is evident from the results that both bulk density and particle size and shape are the most important factors governing the terminal velocities of the stocks.

TABLE 1. Physical Characteristics of Test Materials

Material	Weight of Material Over Sieve in Grams						Geometric mean particle diameter μ	Geometric mean standard deviation	Surface area of particles in 100 gr. samp. in CM²	No. of particles in 100 gr. samp.	Bulk density lb/cu.ft.	Particle density gr/cc
	1st Sieve	2nd Sieve	3rd Sieve	4th Sieve	5th Sieve	6th Sieve						
First Break	2362μ 25.61	1981μ 13.99	1397μ 22.19	589μ 15.01	351μ 13.08	61μ 0.98	1194	2.44	59.8	15,061	27.43	1.33
Fourth Break	1981μ 12.12	1190μ 30.25	589μ 16.37	351μ 6.31	104μ 25.24	38μ 9.00	591	3.11	154.6	1,135,133	16.41	1.23
Coarse Sizing	701μ 8.55	589μ 40.72	351μ 44.11	250μ 4.84	105μ 0.98	61μ 0.47	528	1.32	86.0	6,865	38.29	1.43
1 Middling	589μ 0.10	351μ 1.73	250μ 11.10	150μ 48.22	61μ 30.09	38μ 9.91	175	1.17	279.4	151,495	36.22	1.48
6 Middling	589μ 0.19	351μ 0.46	250μ 0.50	150μ 41.99	61μ 53.53	38μ 3.28	128	1.55	412.8	808,359	29.30	1.43
1 Tailing	589μ 13.72	351μ 43.73	250μ 25.03	150μ 12.30	61μ 4.50	38μ 0.70	354	1.69	155.6	55,586	22.22	1.34
Bran	2362μ 9.27	1981μ 14.83	1397μ 44.18	589μ 26.45	351μ 1.39	104μ 1.05	1439	1.64	39.54	721	11.62	1.33
Flour	149μ 2.07	124μ 18.90	104μ 48.29	61μ 21.79	43μ 6.47	38μ 1.36	103	1.34	486.4	961,078	39.84	1.53
Wheat	= 1000 kernel weight = 28.96 grams pearling value = 91% test weight = 61.53 lbs										48.22	1.32

TABLE 2. Terminal Velocities

Material	Air volume used CFM	Terminal velocity FPM
Wheat	60.80	1937
First Break	54.70	1743
Fourth Break	25.40	809
Coarse Sizing	31.30	996
1 Middling	24.30	773
6 Middling	18.80	597
1 Tailing	19.40	618
Bran	21.90	697
Flour	18.30	578

TABLE 3. Laboratory Analysis

Material	Moisture %	Protein %	Ash %
Wheat	12.7	12.1	1.5
First Break	13.1	13.7	1.9
Fourth Break	12.7	15.7	4.3
Coarse Sizing	15.3	10.2	0.62
1 Middling	14.7	10.8	0.41
6 Middling	11.8	14.1	2.0
1 Tailing	12.9	16.1	3.9
Bran	11.5	15.1	6.4
Flour	13.2	11.3	0.42

AIR FLOW CHARACTERISTICS

The results clearly indicate that velocity head were linearly related with loss in static pressure across both elbows, across vertical length of lift pipe and across cyclone. Velocity head was not related linearly with static pressure drop at entrance (Figures 1a, 1b, 1c, 1d, 1e, and Table 4a). The loss in static pressure across the horizontal run of the lift pipe could not be isolated because of the way the lift was built. Another shortcoming of the design was that no provision is given for the initial acceleration necessary to attain an equilibrium conveying velocity before entering the first elbow. Plots between velocity head and static pressure loss across the different components of the lift pipe clearly showed the linear relationship.

From Table 4 and Figure 1f, it was observed that drop in static pressure increased with increase in conveying distance and also with increase in conveying velocity.

PNEUMATIC CONVEYING OF FLOUR MILL STOCKS

Conveying air velocities for various stocks were first determined by taking into consideration the terminal velocities measured earlier and the conveying air velocities used in milling industry on a practical basis. It was decided to conduct the test at two different conveying air velocities which are less than those usually used.

WHEAT

Tests were conducted at average conveying air velocities of 4430 FPM and 4198 FPM. At both velocities it was possible to load up to 2.73:1 material to air ratio. It was found that at both conveying air velocities

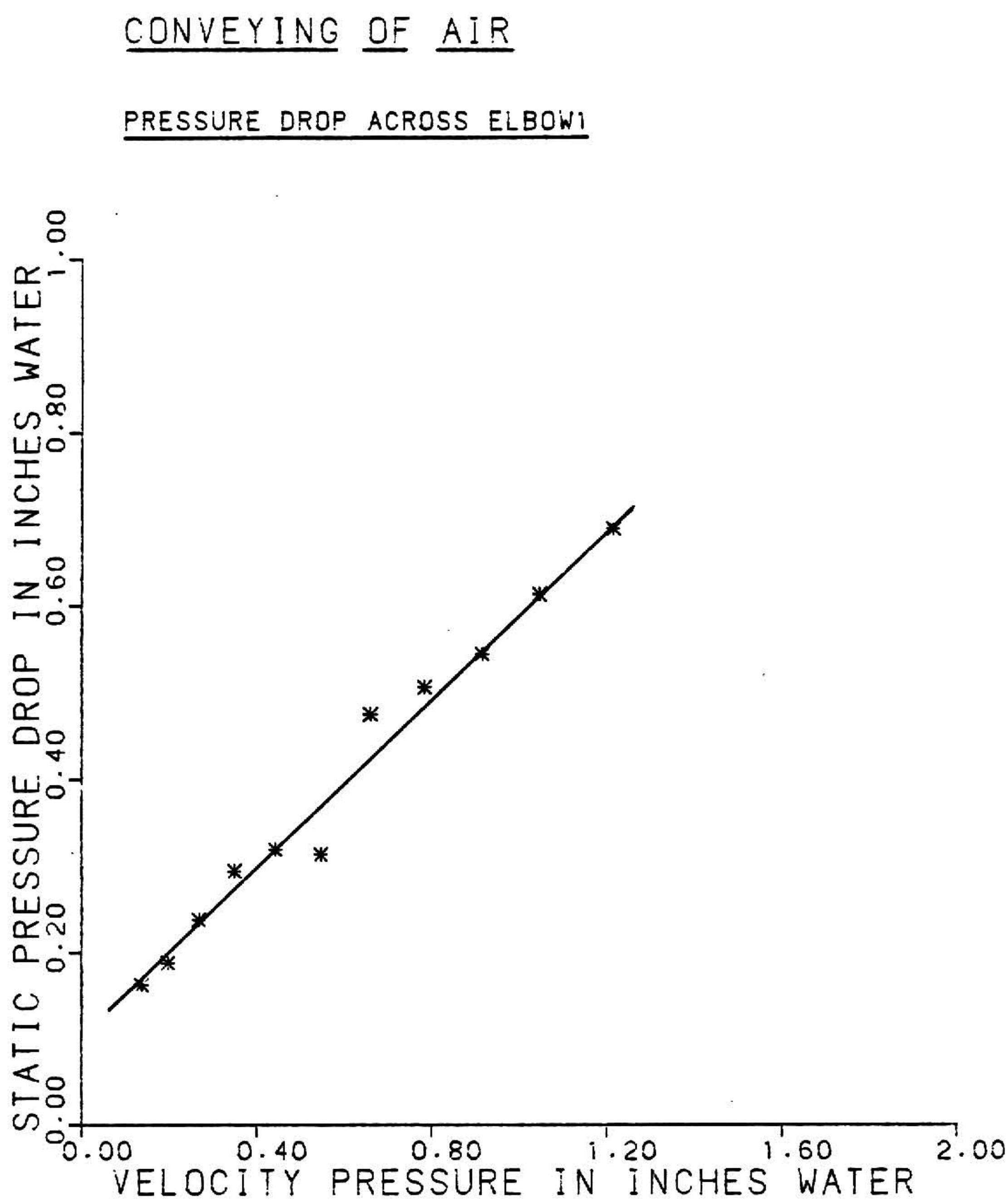
TABLE 4. Conveying of Air - Static Pressure Data

Material	Static Pressure in Inches Water							Volume of air	Velocity of air	Velocity pressure
	Tap #1	Tap #2	Tap #3	Tap #4	Tap #5	Tap #6	Tap #7	CFM	FPM	inches water
	0.00	0.15	0.31	1.00	1.10	1.75	1.78	46.64	1484	0.14
	0.01	0.25	0.44	1.33	1.50	2.18	2.08	53.90	1779	0.20
Air	0.01	0.33	0.56	1.70	1.90	2.83	2.98	65.22	2076	0.27
	0.04	0.43	0.72	2.10	2.40	3.48	3.73	74.50	2371	0.35
	0.06	0.53	0.84	2.53	2.90	4.28	4.63	83.81	2668	0.44
	0.10	0.60	0.94	3.00	3.48	5.08	5.55	93.07	2963	0.55
	0.13	0.73	1.18	3.48	4.08	5.95	6.45	102.32	3257	0.66
	0.23	0.90	1.41	4.08	4.73	7.00	7.55	111.28	3550	0.79
	0.25	1.05	1.59	4.65	5.44	8.05	8.65	120.55	3837	0.92
	0.33	1.20	1.83	5.30	6.13	9.20	9.95	129.76	4130	1.05
	0.33	1.28	1.97	6.00	6.98	10.45	11.25	138.88	4421	1.22

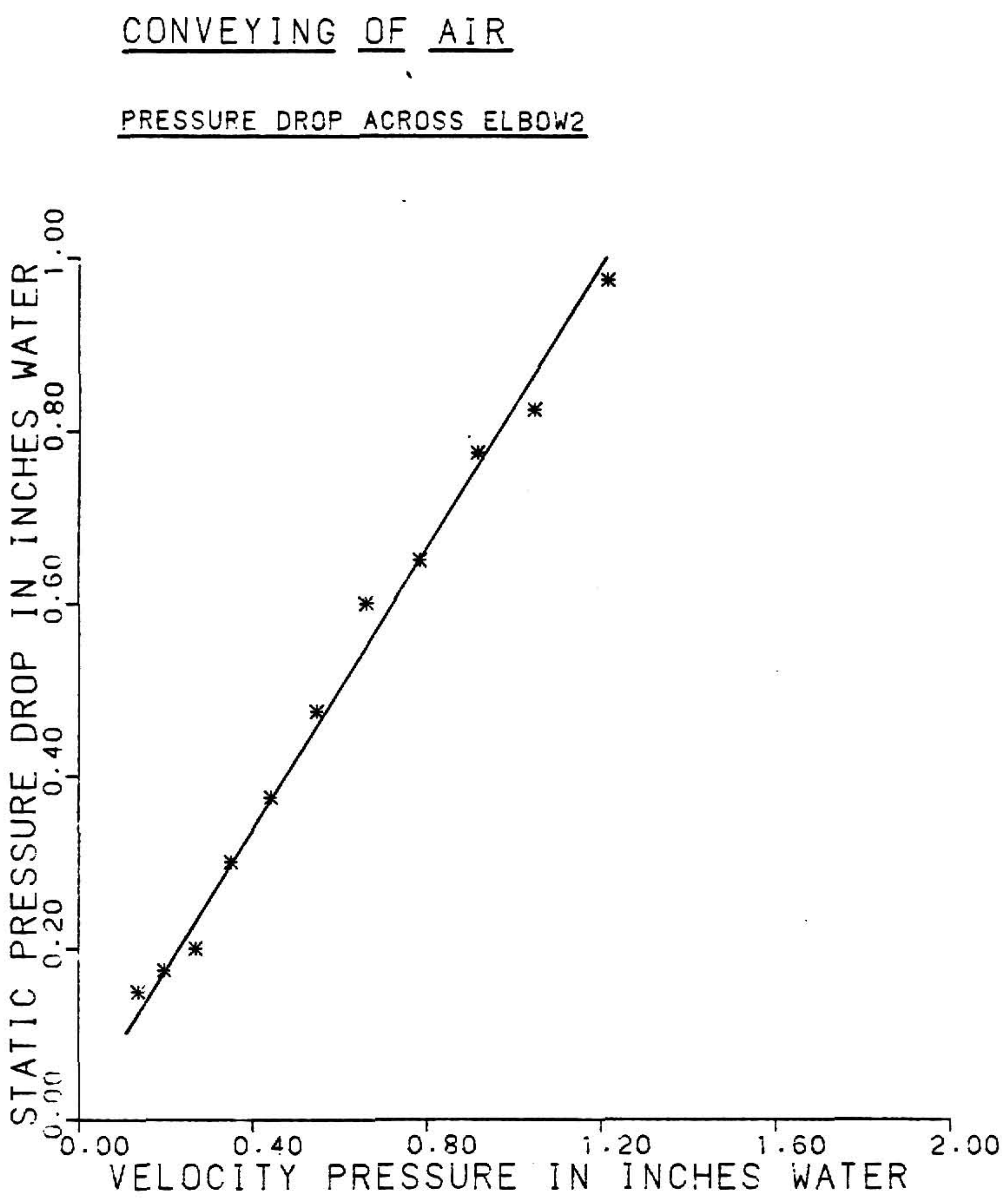
TABLE 4a . Effect of Various Components on Air Flow

Air volume CFM	Air velocity FPM	Air velocity pressure inches water	Static Pr. loss across elbow 1 inches water	Static Pr. loss across elbow 2 inches water	Static Pr. loss across vertical lift inches water	Static Pr. loss across cyclone inches water	Static Pr. loss across entrance inches water
46.64	1484	0.14	0.16	0.15	0.69	0.48	0.00
53.90	1779	0.20	0.19	0.18	0.49	0.68	0.01
65.22	2076	0.27	0.24	0.20	1.14	0.93	0.01
74.50	2371	0.35	0.29	0.30	1.38	1.08	0.04
83.81	2668	0.44	0.32	0.38	1.68	1.38	0.06
93.07	2963	0.55	0.31	0.48	2.06	1.59	0.10
102.32	3257	0.66	0.48	0.60	2.28	1.88	0.13
111.28	3550	0.79	0.51	0.65	2.62	2.28	0.23
120.55	3837	0.92	0.54	0.78	3.06	2.63	0.25
129.76	4130	1.05	0.61	0.83	3.49	3.08	0.33
138.88	4421	1.22	0.69	0.98	4.03	3.48	0.33

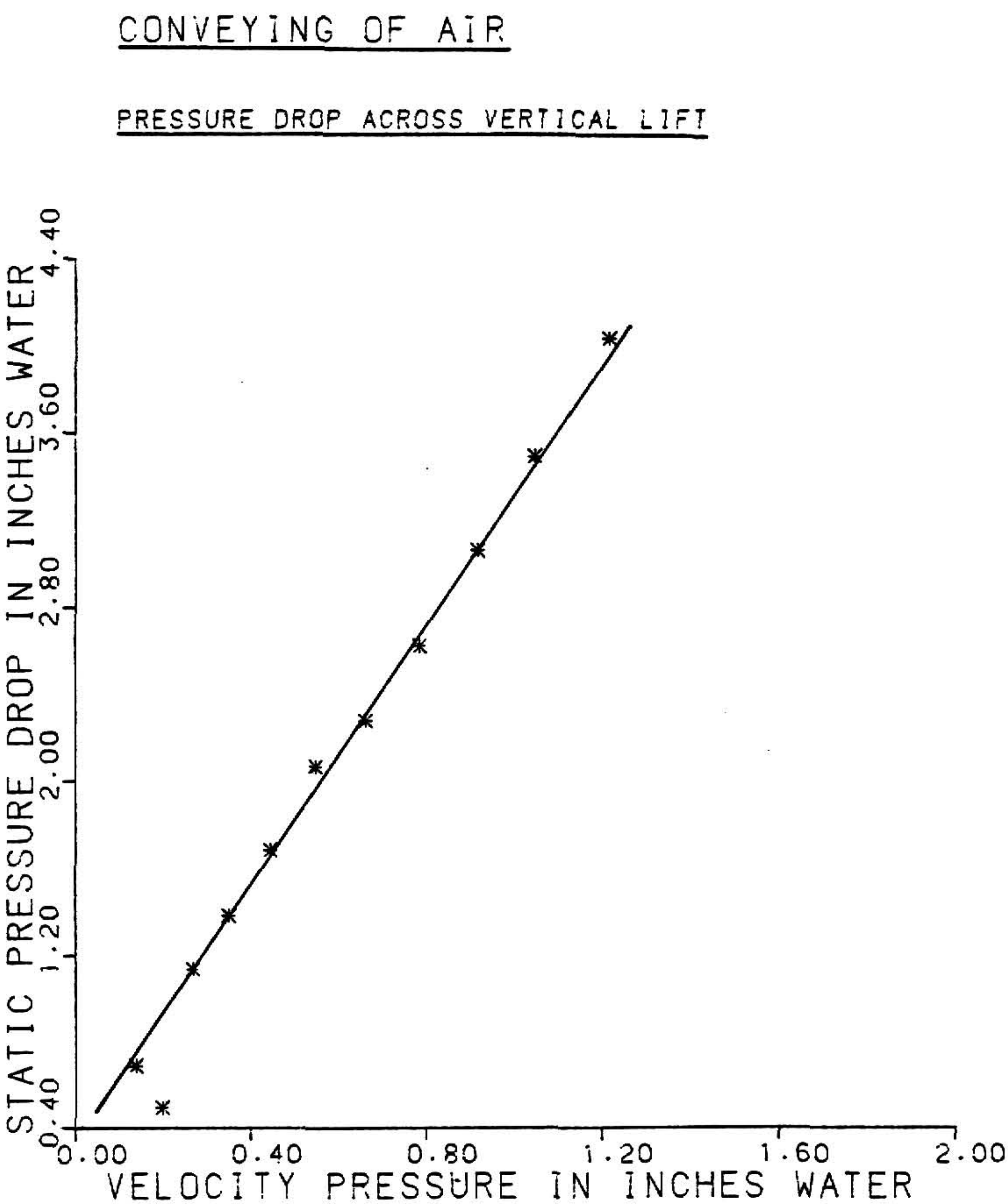
fig (Ia)


CONVEYING OF AIR
PRESSURE DROP ACROSS ELBOW1
STATIC PRESSURE DROP IN INCHES WATER
0.00
0.20
0.40
0.60
0.80
1.00
0.00
0.40
0.80
1.20
1.60
2.00
VELOCITY PRESSURE IN INCHES WATER

fig(Ib)_


CONVEYING OF AIR
PRESSURE DROP ACROSS ELBOW2
STATIC PRESSURE DROP IN INCHES WATER
0.00
0.20
0.40
0.60
0.80
1.00
0.00
0.40
0.80
1.20
1.60
2.00
VELOCITY PRESSURE IN INCHES WATER

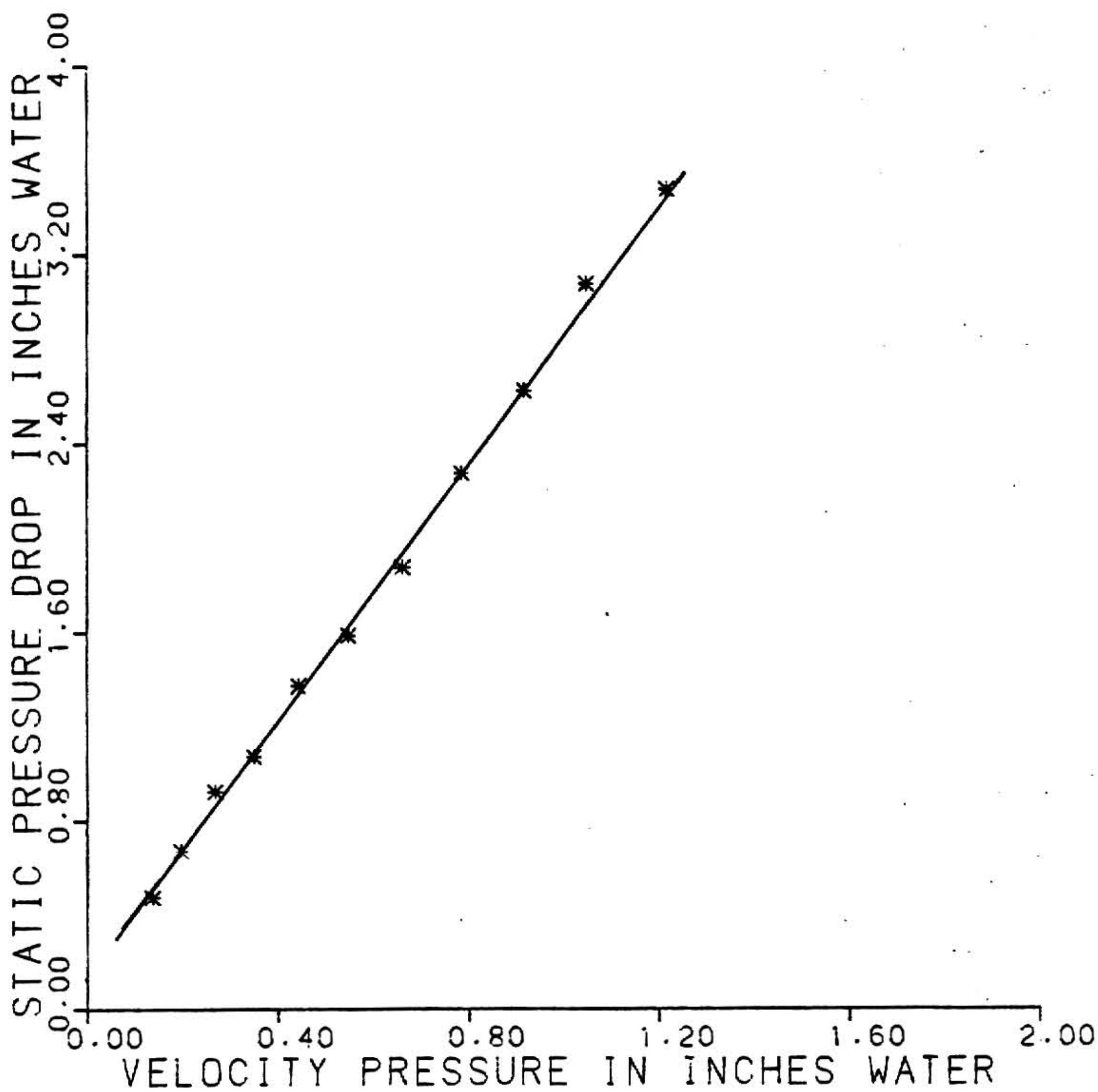
fig(Ic)


CONVEYING OF AIR
PRESSURE DROP ACROSS VERTICAL LIFT
STATIC PRESSURE DROP IN INCHES WATER
0.40
1.20
2.00
2.80
3.60
4.40
0.00
0.40
0.80
1.20
1.60
2.00
VELOCITY PRESSURE IN INCHES WATER

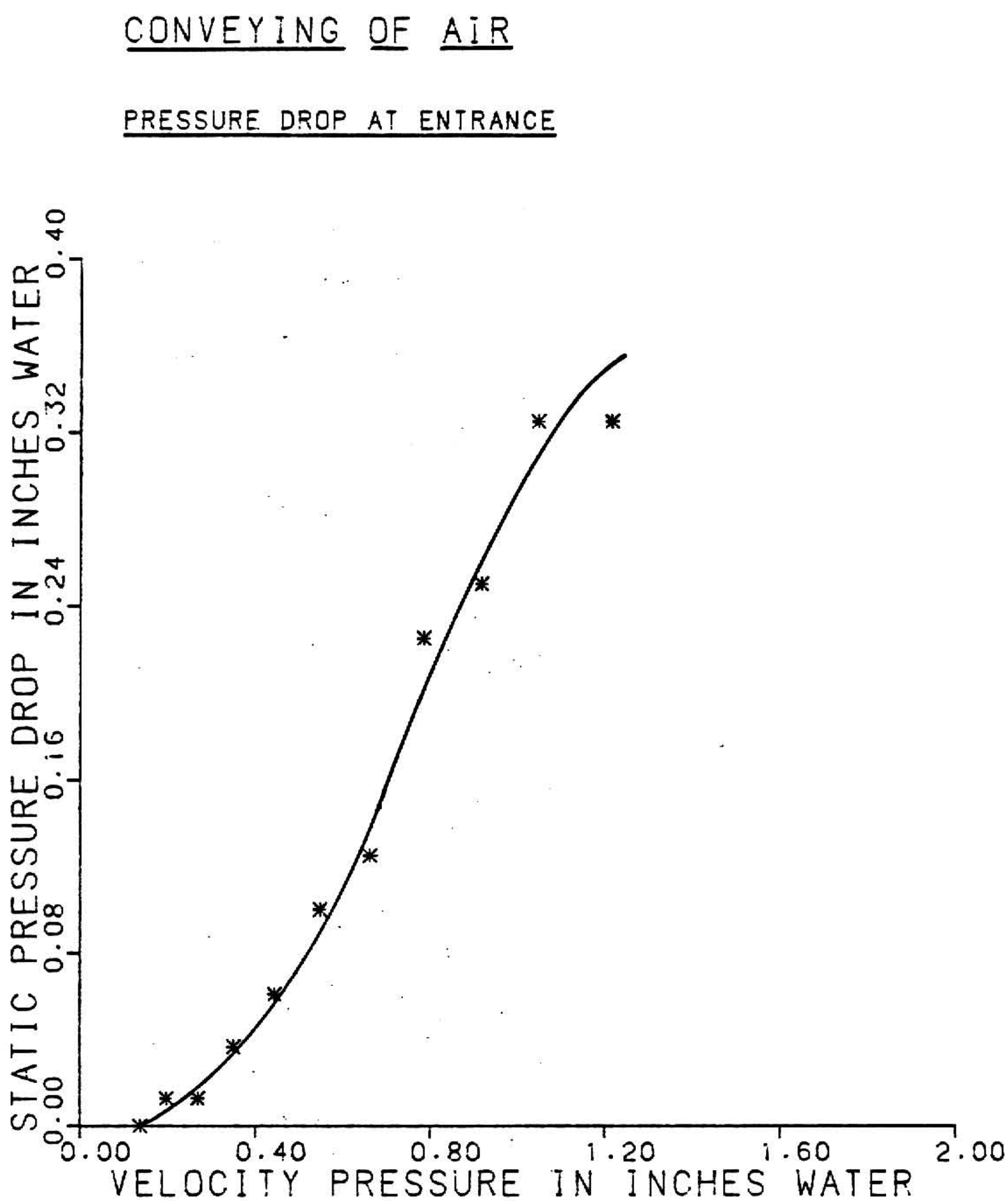
fig(1d)

CONVEYING OF AIR

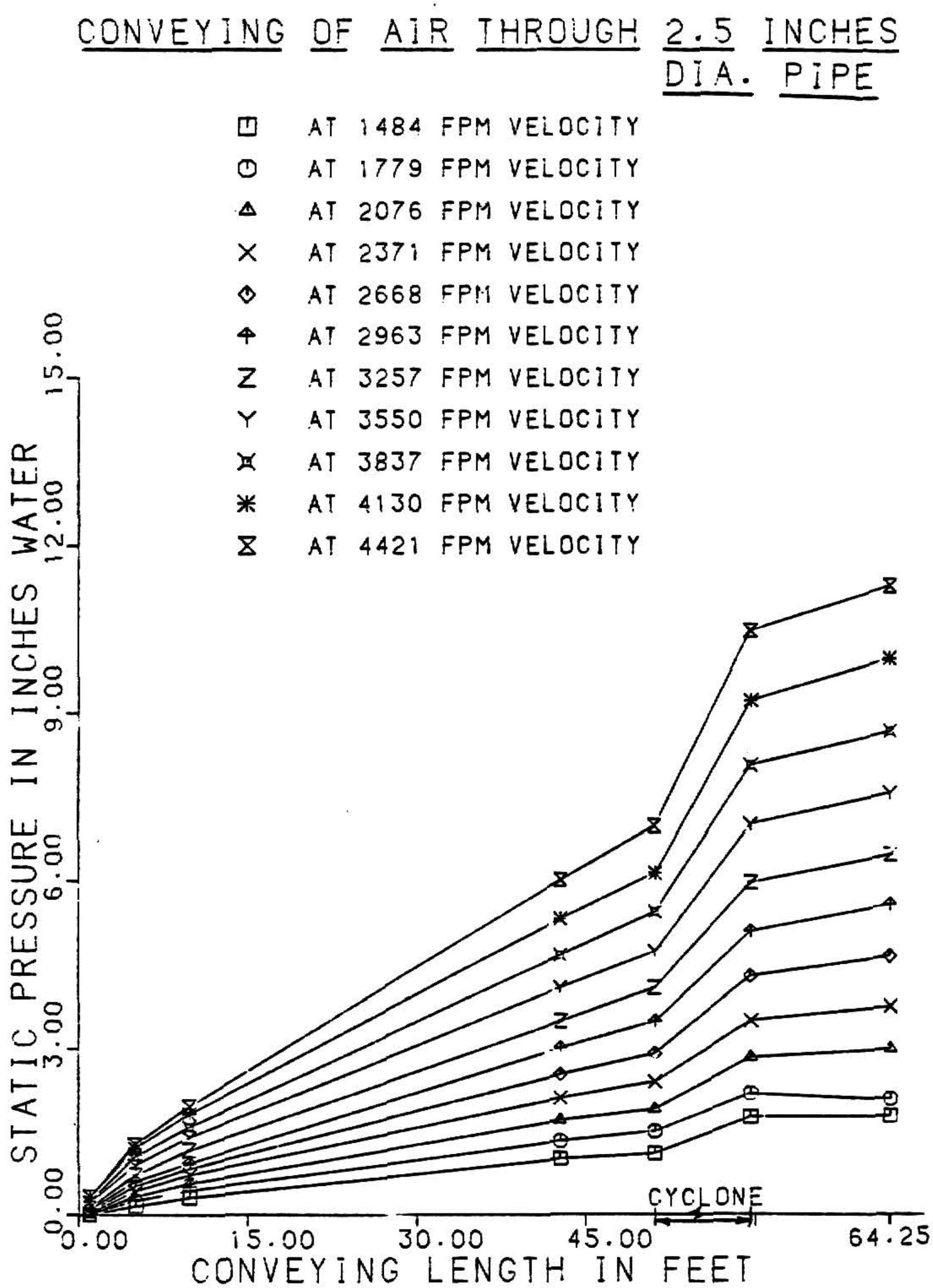
PRESSURE DROP ACROSS CYCLONE



fig(le)


CONVEYING OF AIR
PRESSURE DROP AT ENTRANCE
STATIC PRESSURE DROP IN INCHES WATER
0.00
0.08
0.16
0.24
0.32
0.40
0.00
0.40
0.80
1.20
1.60
2.00
VELOCITY PRESSURE IN INCHES WATER

fig(1f)


CONVEYING OF AIR THROUGH 2.5 INCHES DIA. PIPE
AT 1484 FPM VELOCITY
AT 1779 FPM VELOCITY
AT 2076 FPM VELOCITY
AT 2371 FPM VELOCITY
AT 2668 FPM VELOCITY
AT 2963 FPM VELOCITY
AT 3257 FPM VELOCITY
AT 3550 FPM VELOCITY
AT 3837 FPM VELOCITY
AT 4130 FPM VELOCITY
AT 4421 FPM VELOCITY
STATIC PRESSURE IN INCHES WATER
0.00
3.00
6.00
9.00
12.00
15.00
CYCLONE
0.00
15.00
30.00
45.00
64.25
CONVEYING LENGTH IN FEET

specific pressure drop was linearly related to material to air ratio. It was also observed that an increase in the specific pressure drop, caused by the unit increase in material to air ratio, was more at the lower conveying air velocity than at the higher conveying air velocity (Fig. 2a and Table 5a). Gasterstadt (15) was the first person to observe this behaviour.

Horsepower requirement was more at higher conveying air velocity than at lower conveying air velocity (Fig. 2b and Table 5a). This was due to the fact that out of the two components that constitute the horsepower requirement, air horsepower alone accounts for approximately 75 to 80%. Horsepower required to physically move the stock was less than 25% of the whole. Naturally, at higher conveying air velocities, air horsepower was due more to larger quantities of air moved.

Mixture friction factor as conceived by Segler (38) gives an estimate coefficient of friction when air and material are in motion. From the results it was observed that this factor was smaller at higher conveying air velocity (Fig. 2c and Table 5a). It was known from earlier investigations that the coefficient of friction is a function of Reynold's number. Presumably at higher Reynold's number, i.e. at higher conveying air velocity, the motion became less turbulent and smoothed out, reducing the friction losses between particles and pipe walls and between particles and particles. This resulted in smaller friction factors at higher conveying air velocity and larger factors at lower conveying air velocity.

From Fig. 2d, 2e, and Table 5, it was seen that static pressure drop increases with conveying distance. Increase in material to air ratio also increased the static pressure drop. It was also observed that static pressure drops increased at the same approximate rate for each material to air ratio tested, at both the conveying air velocities.

TALBE 5. Data for Conveying of Wheat

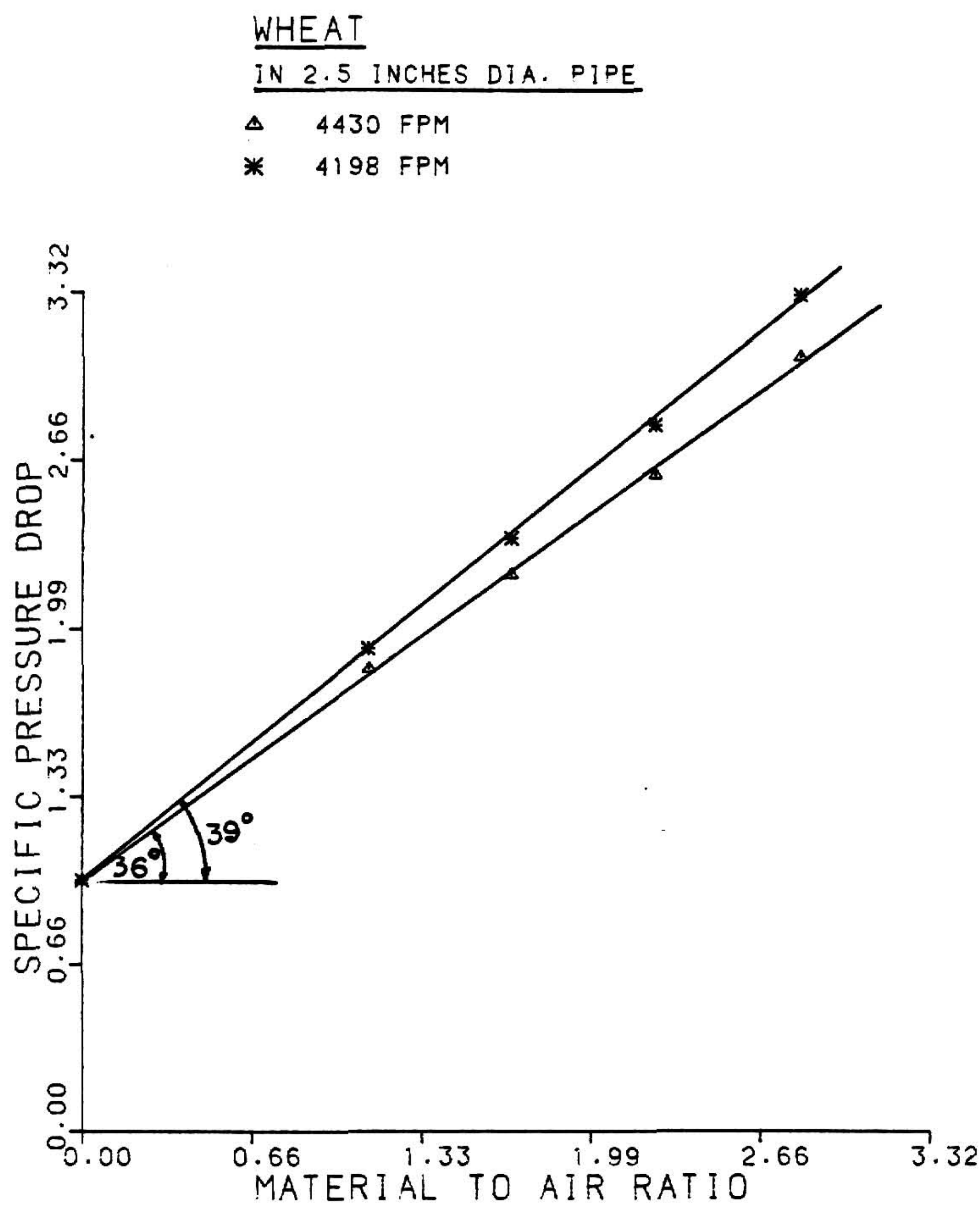
Material to air ratio	Static Pressure in Inches Water							Volume of air CFM	Velocity of air FPM	Velocity pressure inches water	Average velocity of air FPM
	Tap #1	Tap #2	Tap #3	Tap #4	Tap #5	Tap #6	Tap #7				
0:1 (air only)	0.35	0.85	2.47	4.95	5.95	9.08	9.90	132.88	4230	1.17	
1.12:1	0.55	2.23	3.19	8.70	10.35	12.50	13.25	132.01	4202	1.10	
1.68:1	0.55	2.25	3.38	10.28	12.45	14.45	15.20	131.87	4198	1.10	4198
2.25:1	0.58	2.18	4.47	12.60	14.60	16.60	17.40	131.53	4186	1.09	
2.82:1	0.63	2.23	5.41	15.10	19.20	19.20	20.10	130.61	4173	1.09	
0:1 (air only)	0.60	1.83	2.34	5.65	6.65	10.10	11.18	139.97	4455	1.24	
1:12:1	0.65	2.48	3.47	9.35	11.15	13.40	14.25	139.39	4437	1.23	
1.68:1	0.70	2.50	3.84	11.10	13.15	15.40	16.15	139.17	4430	1.22	4430
2.25:1	0.75	2.45	4.41	13.35	15.30	17.45	18.30	138.81	4418	1.22	
2.81:1	0.70	2.45	5.51	15.50	17.80	19.50	20.90	138.51	4409	1.21	

Relative Humidity = 71%
Temperature = 80°F
Viscocity of air = 12.45 X 10^{-6} lb/foot sec.
Density of air used = 0.0717 lb/cu. ft.

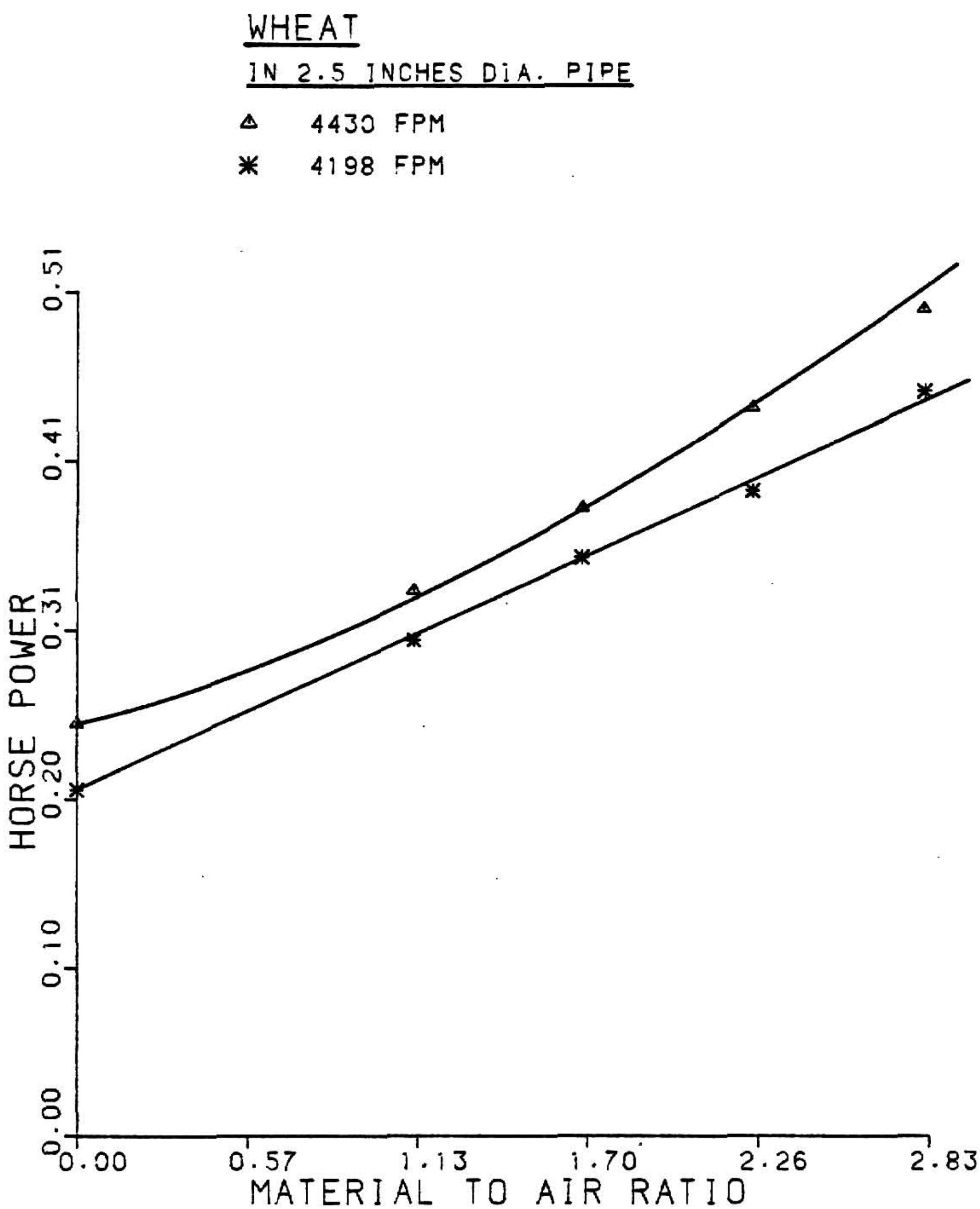
TABLE 5a. Calculated Data for Conveying of Wheat

Feed rate lb/min	Material to air ratio	Specific pressure drop	Horsepower required	Mixture friction factor (fm)	Average velocity of air FPM
0.00	0.0:1	1	0.21	0.0215	
10.61	1.12:1	1.91	0.30	0.0379	4198
15.91	1.68:1	2.35	0.35	0.0457	
21.21	2.25:1	2.79	0.39	0.0539	
26.52	2.82:1	3.31	0.45	0.0635	
0.00	0.0:1	1	0.25	0.0217	
11.19	1.12:1	1.83	0.33	0.0366	4430
16.78	1.68:1	2.20	0.38	0.0434	
22.38	2.25:1	2.60	0.44	0.0507	
27.97	2.81:1	3.07	0.50	0.0592	

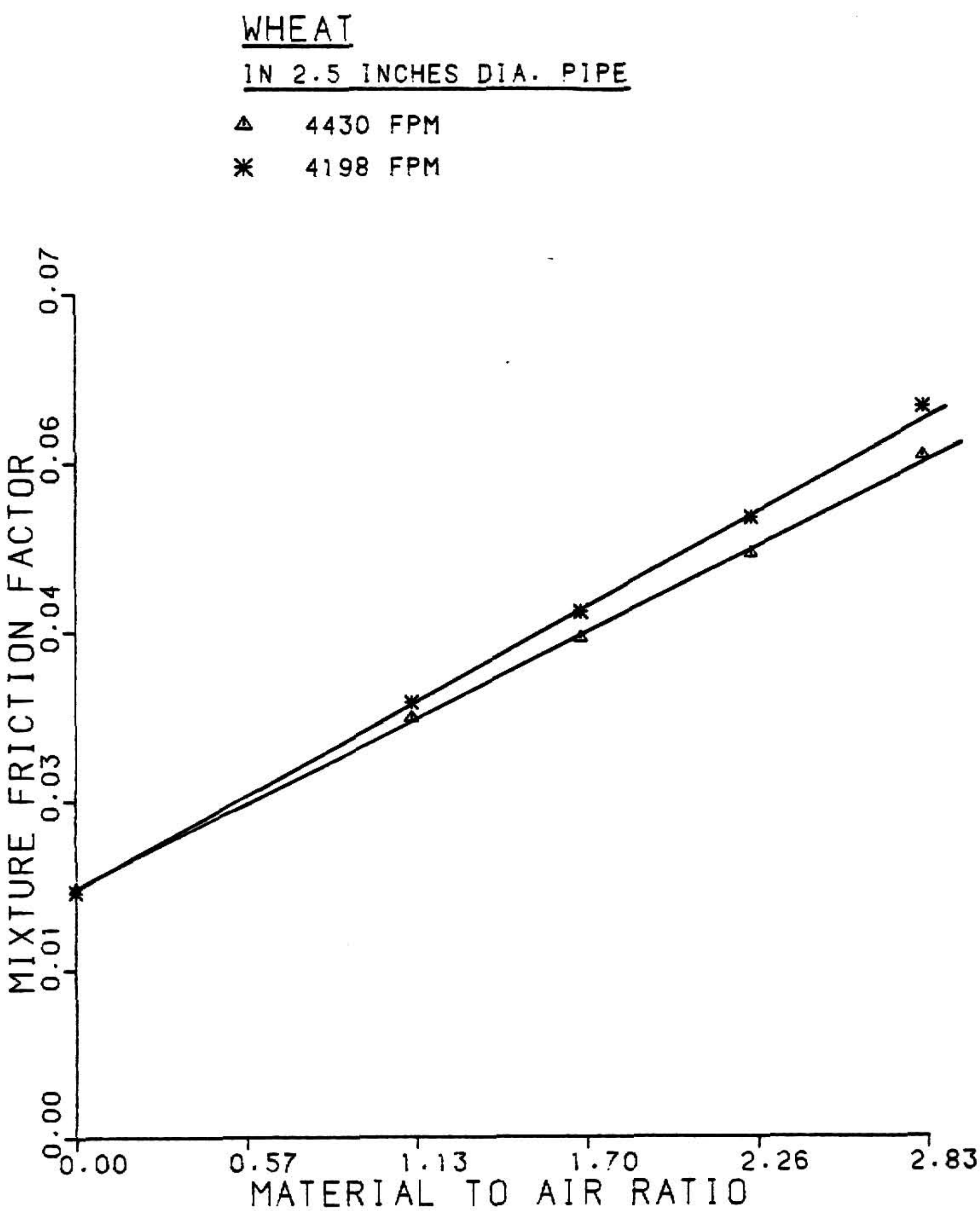
fig (2a)


WHEAT
IN 2.5 INCHES DIA. PIPE
△ 4430 FPM
✱ 4198 FPM
SPECIFIC PRESSURE DROP
0.00
0.66
1.33
1.99
2.66
3.32
39°
36°
0.00
0.66
1.33
1.99
2.66
3.32
MATERIAL TO AIR RATIO

fig(2b)


WHEAT
IN 2.5 INCHES DIA. PIPE
4430 FPM
4198 FPM
HORSE POWER
0.00
0.10
0.20
0.31
0.41
0.51
0.00
0.57
1.13
1.70
2.26
2.83
MATERIAL TO AIR RATIO

fig(2c)


WHEAT
IN 2.5 INCHES DIA. PIPE
4430 FPM
4198 FPM
MIXTURE FRICTION FACTOR
0.00
0.01
0.03
0.04
0.06
0.07
0.00
0.57
1.13
1.70
2.26
2.83
MATERIAL TO AIR RATIO

fig(2d)

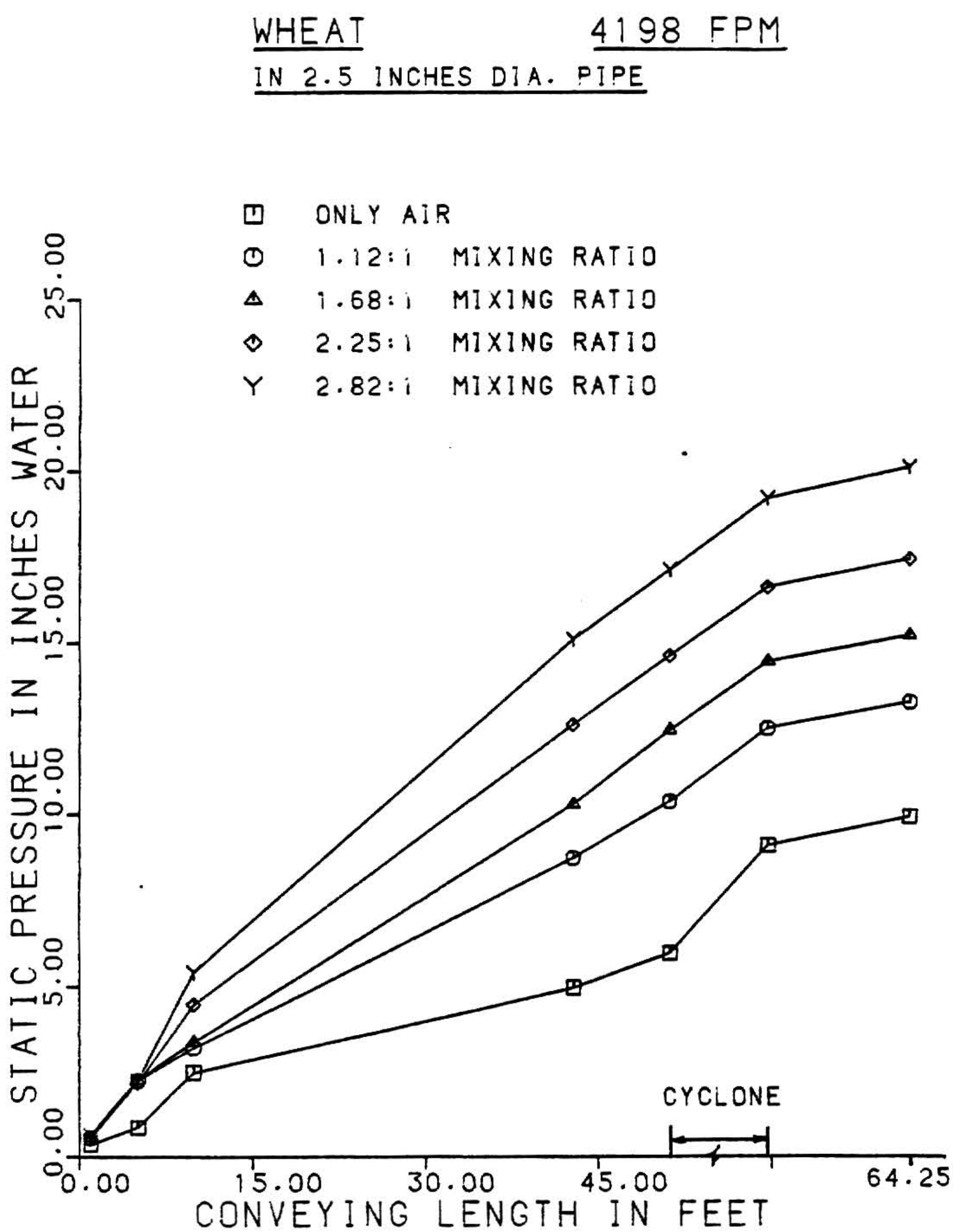
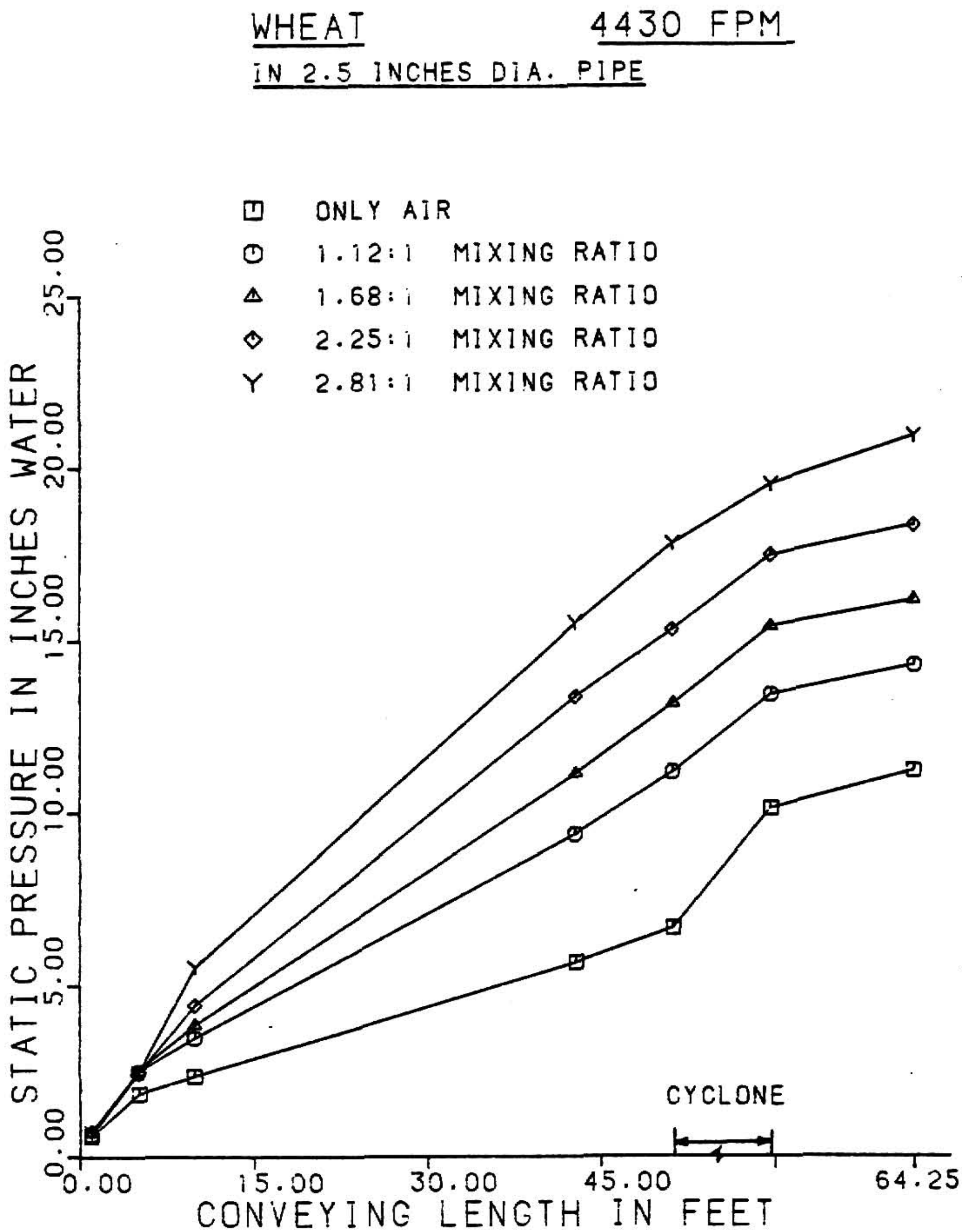

WHEAT 4198 FPM
IN 2.5 INCHES DIA. PIPE
ONLY AIR
1.12:1 MIXING RATIO
1.68:1 MIXING RATIO
2.25:1 MIXING RATIO
2.82:1 MIXING RATIO
STATIC PRESSURE IN INCHES WATER
0.00
5.00
10.00
15.00
20.00
25.00
CYCLONE
0.00
15.00
30.00
45.00
64.25
CONVEYING LENGTH IN FEET

fig (2e)


WHEAT 4430 FPM
IN 2.5 INCHES DIA. PIPE
ONLY AIR
1.12:1 MIXING RATIO
1.68:1 MIXING RATIO
2.25:1 MIXING RATIO
2.81:1 MIXING RATIO
STATIC PRESSURE IN INCHES WATER
0.00
5.00
10.00
15.00
20.00
25.00
CYCLONE
0.00
15.00
30.00
45.00
64.25
CONVEYING LENGTH IN FEET

FIRST BREAK STOCK

Tests were conducted at average conveying velocities of 4163 FPM and 3938 FPM, respectively. It was possible to load the system up to 2.25:1 material to air ratio. But, at 3938 FPM air velocity and 2.25:1 material to air ratio, the rotameter and static pressure tap readings were difficult to note because of unsteady conveying at that loading. Due to the extreme heterogeneous nature of the stocks, the feed rate settings could not be maintained on the feeder. This aggravated the inaccuracies in the readings noted.

When the results were plotted, (Fig. 3a and Table 6a), it was observed that specific pressure drop was linearly related to material to air ratio. Raise in specific pressure drop per unit increase in material to air ratio was observed to be more at higher conveying air velocity than at lower velocity, i.e. at higher conveying air velocity, higher static pressure drops were encountered at the same material to air ratios than at lower conveying air velocity.

Higher horsepower was required at higher conveying air velocity than at lower (Fig. 3b and Table 6a). Mixture friction factors were smaller at 4163 FPM and larger at 3938 FPM air velocity (Fig. 3c and Table 6a).

In general, the static pressure drops along the conveying distance, increased with increase in conveying air velocity and increase in material to air ratio. At both conveying air velocities, for each material to air ratio, the rate of increase in the static pressure drop was approximately the same (Fig. 3d, 3e, and Table 6).

FOURTH BREAK STOCK

Tests were conducted at average conveying air velocities of 3697 FPM and 3464 FPM, respectively. It was possible to load the system up to 2.27:1

TABLE 6. Data for Conveying of First Break Stock

Material to air ratio	Static Pressure in Inches Water							Volume of air CFM	Velocity of air FPM	Velocity pressure inches water	Average velocity FPM
	Tap #1	Tap #2	Tap #3	Tap #4	Tap #5	Tap #6	Tap #7				
Air only	0.30	1.25	1.88	5.40	6.30	9.30	11.00	130.39	4150	1.07	
0.56:1	0.40	2.25	2.69	7.50	9.00	11.00	11.60	130.38	4166	1.08	
1.12:1	0.43	2.45	3.00	9.15	11.90	13.50	14.10	131.08	4173	1.09	4163
1.68:1	0.50	2.55	3.50	11.15	13.50	15.60	16.20	130.81	4164	1.08	
2.25:1	0.50	2.60	4.00	13.55	15.90	17.50	18.60	130.66	4160	1.08	
Air only	0.30	1.05	1.81	5.00	5.80	8.60	9.20	123.83	3942	0.97	
0.56:1	0.38	2.05	2.44	6.93	8.05	10.10	10.70	123.90	3944	0.97	
1.12:1	0.43	2.23	2.81	8.78	10.40	12.30	12.83	123.76	3939	0.97	3938
1.68:1	0.43	2.30	3.44	10.55	12.60	14.50	15.10	123.63	3935	0.97	
2.25:1	0.43	2.40	4.19	12.35	14.40	16.50	16.50	123.43	3930	0.96	

Relative humidity = 74.7%
Temperature = 76.5°F
Viscocity of air = 12.38×10^{-6} lb/foot. sec.
Density of air = 0.0723 lb/cu.ft.

TABLE 6a. Calculated Data for Conveying of First Break Stock

Feed rate lb/min	Material to air ratio	Specific pressure drop	Horsepower	Mixture friction factor	Average velocity FPM
0.00	0.00:1	1.00	0.23	0.0235	
5.30	0.56:1	1.52	0.25	0.0333	
10.60	1.12:1	2.07	0.31	0.0439	4163
15.90	1.68:1	2.38	0.36	0.0450	
21.20	2.25:1	2.84	0.41	0.0590	
0.00	0.00:1	1.00	0.18	0.0240	
5.00	0.56:1	1.47	0.22	0.0332	
10.01	1.12:1	1.95	0.27	0.0430	3938
15.02	1.68:1	2.41	0.31	0.0522	
20.02	2.25:1	2.78	0.35	0.0599	

fig (3a)

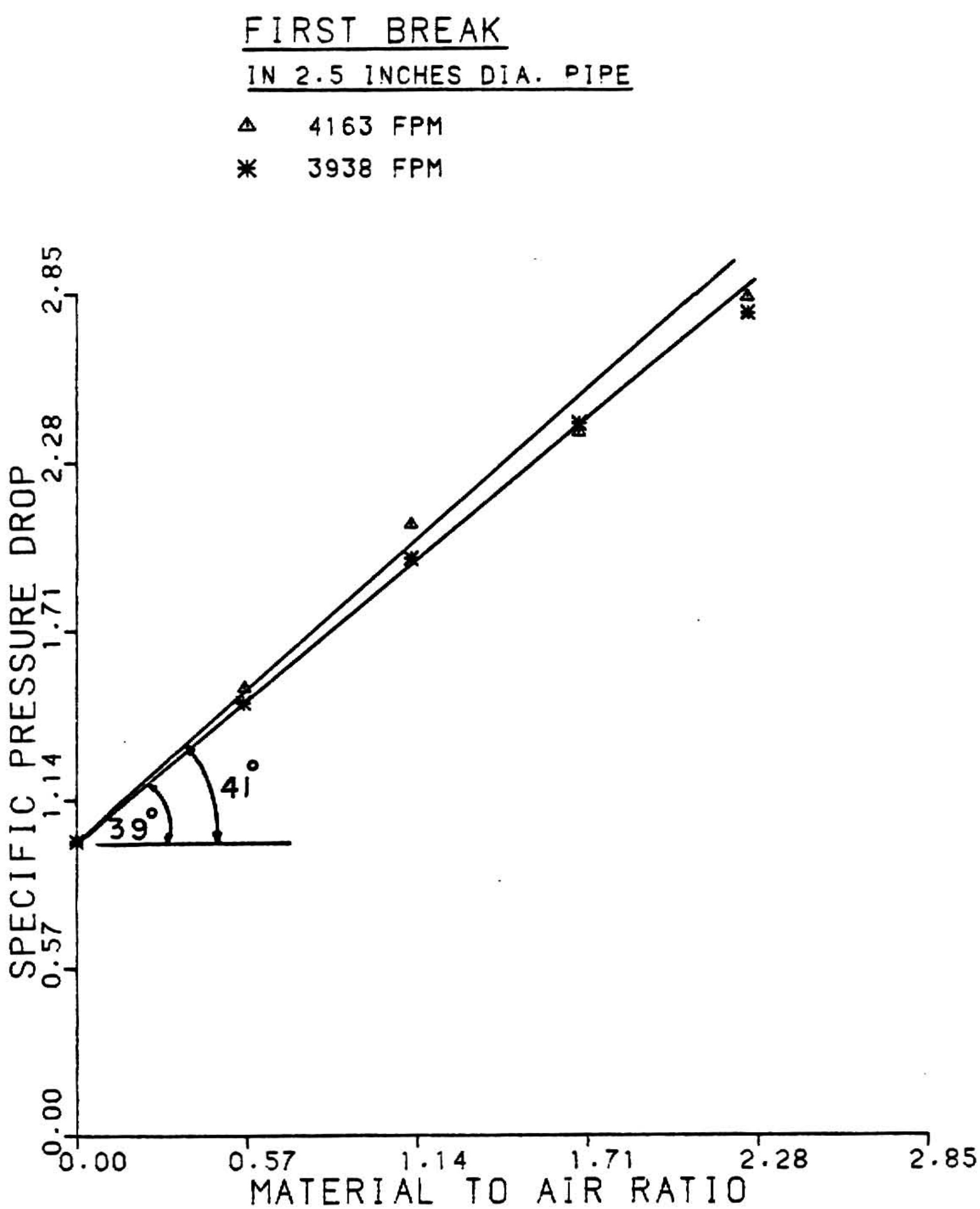

FIRST BREAK
IN 2.5 INCHES DIA. PIPE
4163 FPM
3938 FPM
SPECIFIC PRESSURE DROP
0.00
0.57
1.14
1.71
2.28
2.85
39°
41°
0.00
0.57
1.14
1.71
2.28
2.85
MATERIAL TO AIR RATIO

fig (3b)

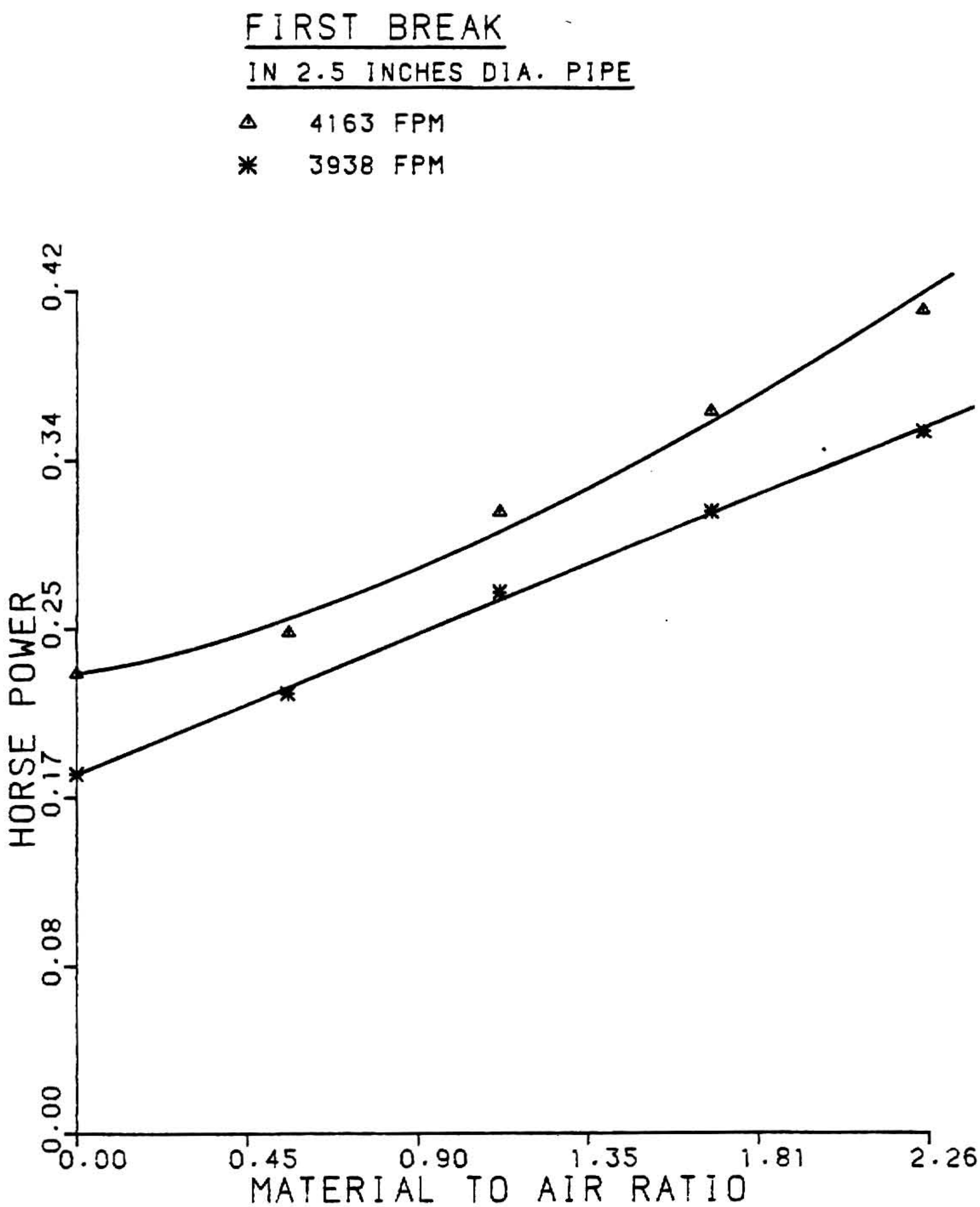
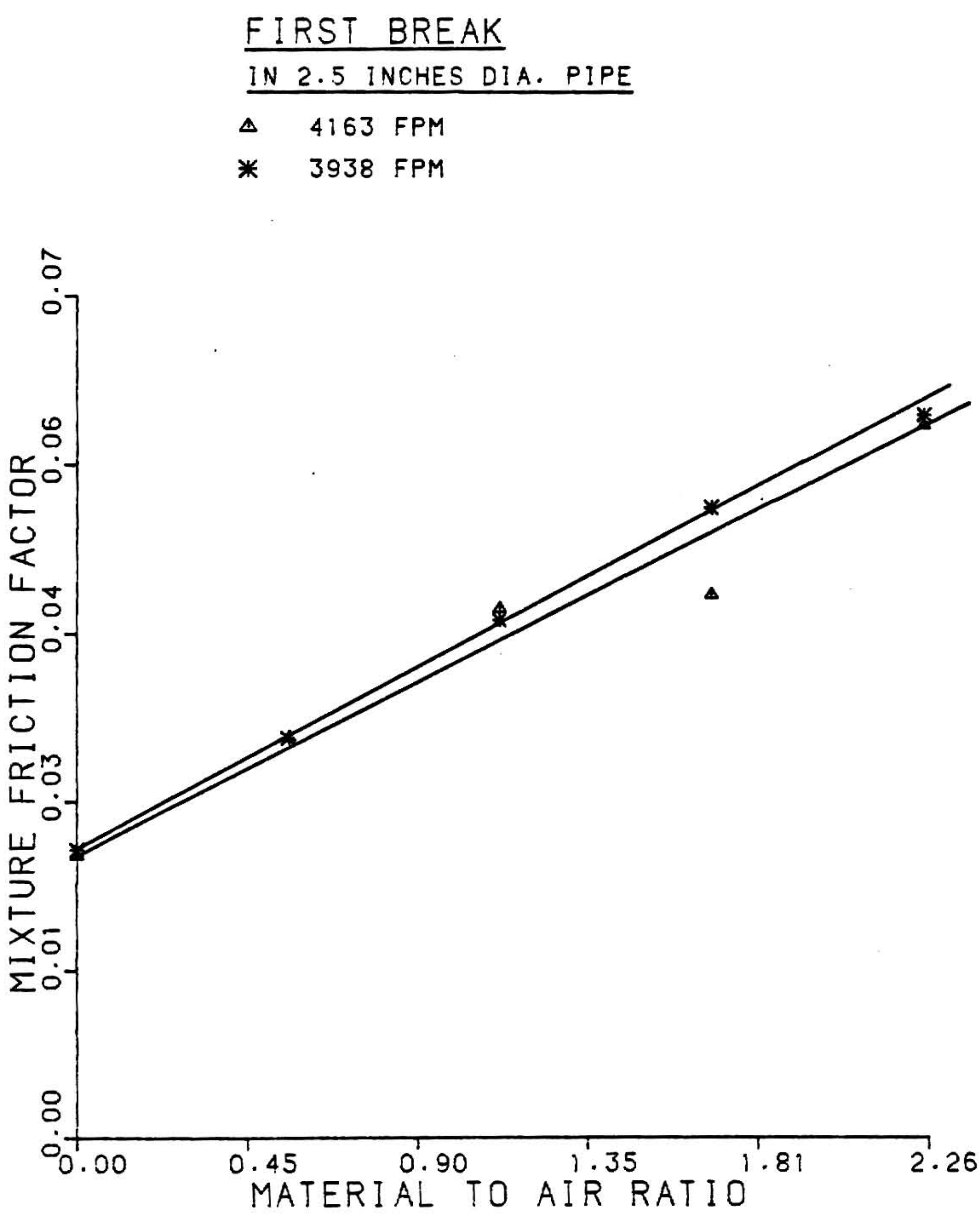

FIRST BREAK
IN 2.5 INCHES DIA. PIPE
4163 FPM
3938 FPM
HORSE POWER
0.00
0.08
0.17
0.25
0.34
0.42
0.00
0.45
0.90
1.35
1.81
2.26
MATERIAL TO AIR RATIO

fig (3c)


FIRST BREAK
IN 2.5 INCHES DIA. PIPE
4163 FPM
3938 FPM
MIXTURE FRICTION FACTOR
0.00
0.01
0.03
0.04
0.06
0.07
0.00
0.45
0.90
1.35
1.81
2.26
MATERIAL TO AIR RATIO

fig(3d)

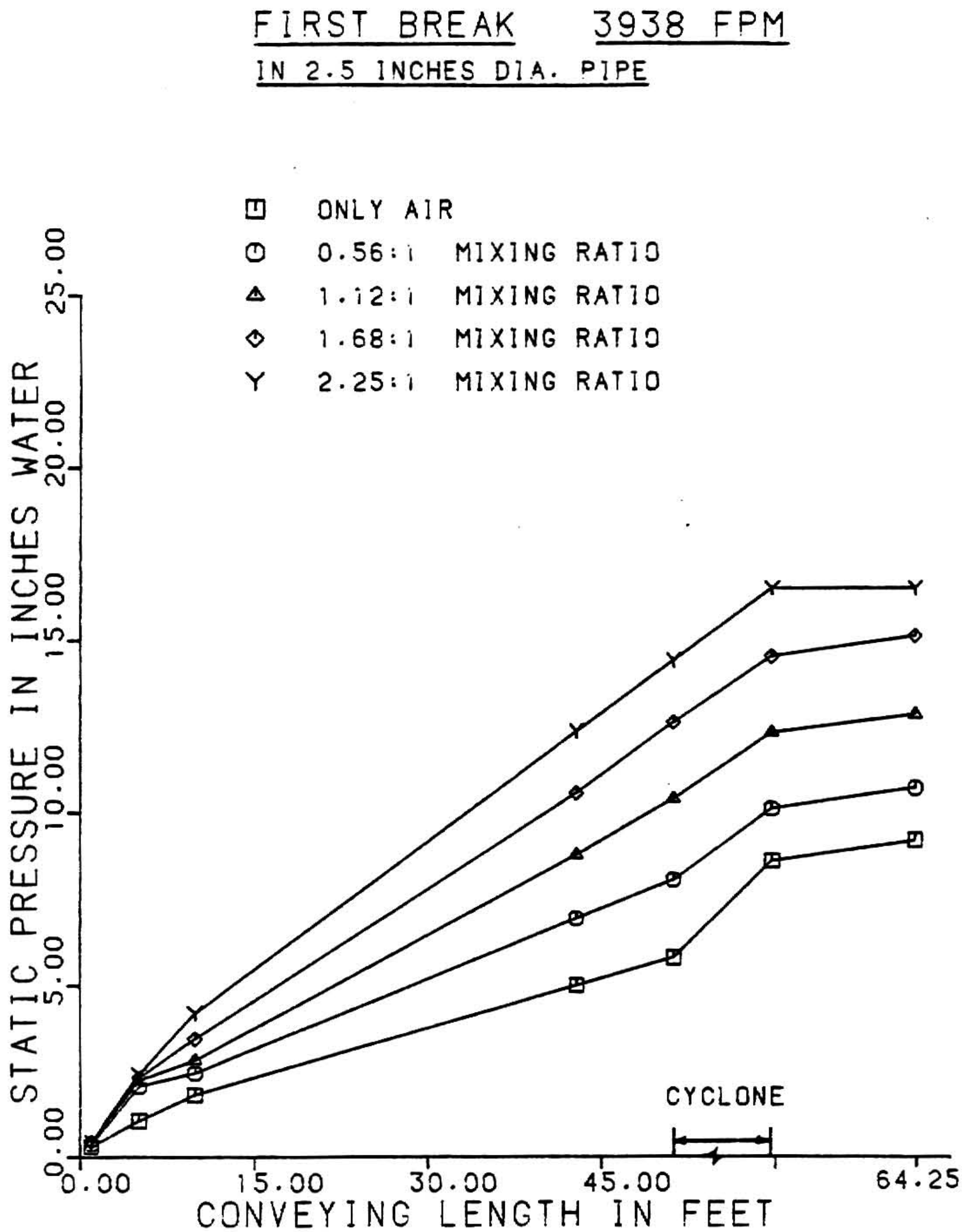
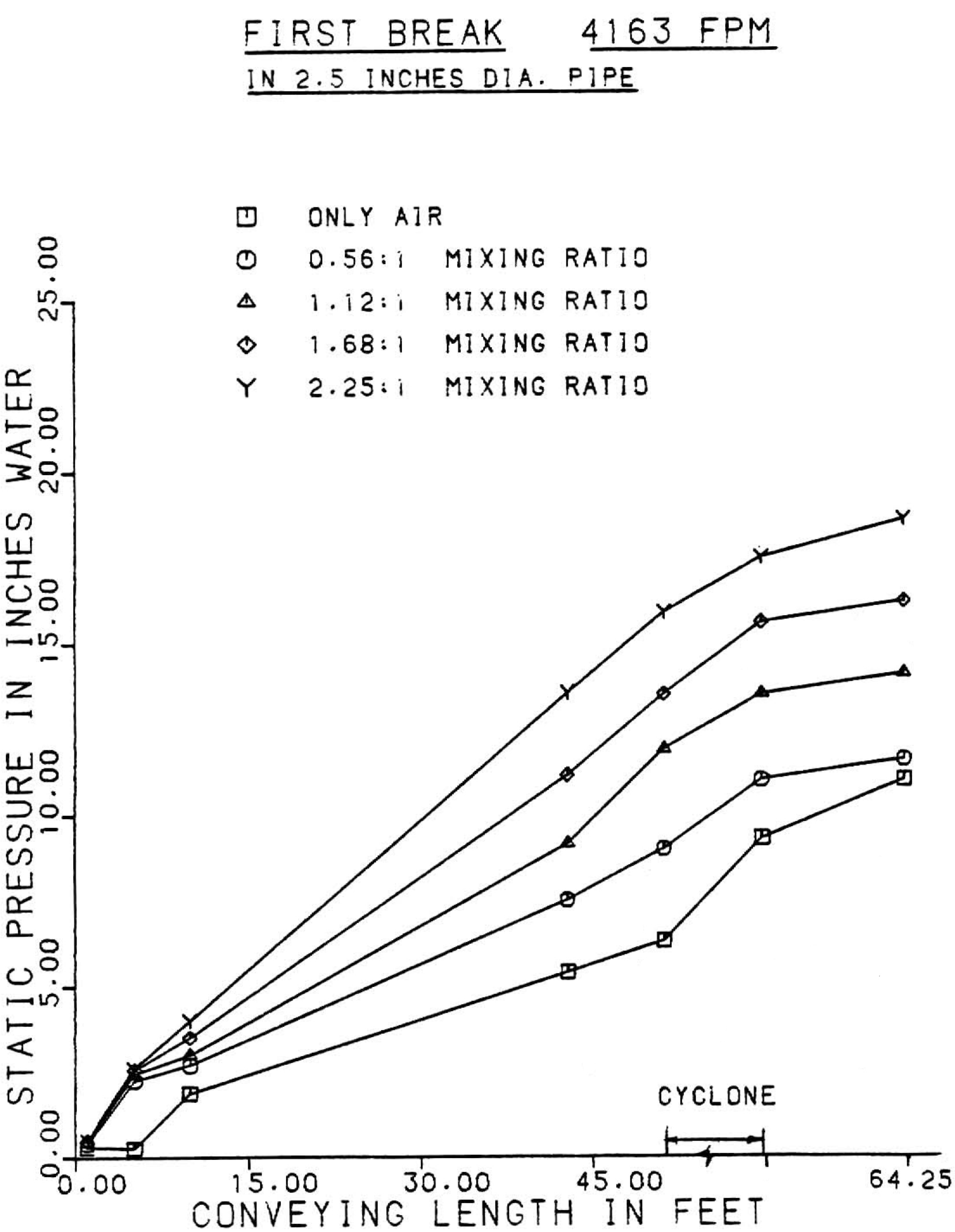

FIRST BREAK 3938 FPM
IN 2.5 INCHES DIA. PIPE
ONLY AIR
0.56:1 MIXING RATIO
1.12:1 MIXING RATIO
1.68:1 MIXING RATIO
2.25:1 MIXING RATIO
STATIC PRESSURE IN INCHES WATER
0.00
5.00
10.00
15.00
20.00
25.00
CYCLONE
0.00
15.00
30.00
45.00
64.25
CONVEYING LENGTH IN FEET

fig (3e)


FIRST BREAK 4163 FPM
IN 2.5 INCHES DIA. PIPE
ONLY AIR
0.56:1 MIXING RATIO
1.12:1 MIXING RATIO
1.68:1 MIXING RATIO
2.25:1 MIXING RATIO
STATIC PRESSURE IN INCHES WATER
0.00
5.00
10.00
15.00
20.00
25.00
CYCLONE
0.00
15.00
30.00
45.00
64.25
CONVEYING LENGTH IN FEET

material to ratio. The size of the air lock was a limiting factor because of the low bulk density and high volume of stock.

Specific pressure drop was linearly related to material to air ratio at 3697 FPM air velocity, but at the lower velocity it was not linear. The relationship fitted a quadratic equation which implied that the rate of increase in pressure drops corresponding to increase in material to air ratio was much steeper. This indicated that 3464 FPM conveying air velocity was critical and for trouble free operation, conveying velocities greater than 3464 FPM had to be used (Fig. 4a, Table 7a). It was also noted that like in the case of wheat for instance, as the conveying air velocity was increased, the increase in specific pressure drop per unit increase in material to air ratio decreased.

Horsepower requirement in general was higher at high conveying air velocity (Fig. 4b and Table 7a). Mixture friction factors were smaller at high air velocity than at low conveying air velocity (Fig. 4c and Table 7a).

Static pressure drop was more at high conveying air velocity and increased almost at the same rate for each material to air ratio tested, at both conveying air velocities (Fig. 4d, 4e, and Table 7).

COARSE SIZINGS

Tests were conducted at average conveying air velocities of 3680 FPM and 3454 FPM, respectively. The system was loaded up to 2.84:1 material to air ratio. At 2.84:1 material to air ratio conveying was slightly unsteady making it difficult to record the readings.

From Fig. 5a and Table 8a, it can be seen that at both velocities of air, the specific pressure drop is having quadratic relationship with material to air ratio indicating that velocities at which tests are conducted were not suitable for trouble free operation. The inclination of the curves indicated

TABLE 7. Data for Conveying of Fourth Break Stock

Material to air ratio	Static Pressure in Inches Water							Volume of air CFM	Velocity of air FPM	Velocity pressure inches water	Average velocity FPM
	Tap #1	Tap #2	Tap #3	Tap #4	Tap #5	Tap #6	Tap #7				
Air only	0.20	1.20	1.75	4.75	6.10	6.80	7.70	117.05	3726	0.87	
0.56:1	0.34	1.55	2.18	5.98	7.35	9.05	9.50	116.37	3704	0.85	
1.13:1	0.43	1.75	2.50	7.23	9.38	11.00	11.60	116.06	3694	0.85	3697
1.70:1	0.45	1.93	3.25	9.55	11.10	12.70	13.50	115.94	3690	0.85	
2.27:1	0.40	2.00	4.00	10.10	12.50	14.10	15.00	115.32	3671	0.84	
Air only	0.38	1.00	1.38	4.00	5.40	6.70	7.30	109.38	3482	0.76	
0.56:1	0.31	1.38	1.91	5.50	6.65	8.00	7.90	108.92	3467	0.75	
1.14:1	0.35	1.55	2.25	6.88	8.33	9.45	10.40	108.75	3462	0.75	3464
1.68:1	0.43	1.70	3.13	8.78	10.30	11.90	12.80	108.52	3454	0.74	
2.26:1	0.40	1.85	3.75	9.70	12.10	13.90	14.50	108.57	3456	0.75	

Relative humidity = 68%
Temperature = $78^{o}F$
Viscocity of air = 12.41×10^{-6} lb/foot sec.
Density of air = 0.0722 lb/cu.ft.

TABLE 7a. Calculated Data for Conveying of Fourth Break Stock

Feed rate lb/min	Material to air ratio	Specific pressure drop	Horsepower required	Mixture friction factor (fm)	Average velocity of air FPM
0.00	0.00:1	1.00	0.14	0.0282	
4.71	0.56:1	1.24	0.18	0.0344	
9.58	1.14:1	1.63	0.23	0.0442	3697
14.05	1.68:1	1.96	0.27	0.0524	
18.85	2.26:1	2.23	0.30	0.0596	
0.00	0.00:1	1.00	0.13	0.0286	
4.42	0.56:1	1.27	0.15	0.0356	
8.84	1.13:1	1.63	0.19	0.0447	3464
13.33	1.70:1	2.06	0.24	0.0551	
17.82	2.27:1	2.45	0.28	0.0657	

fig(4a)

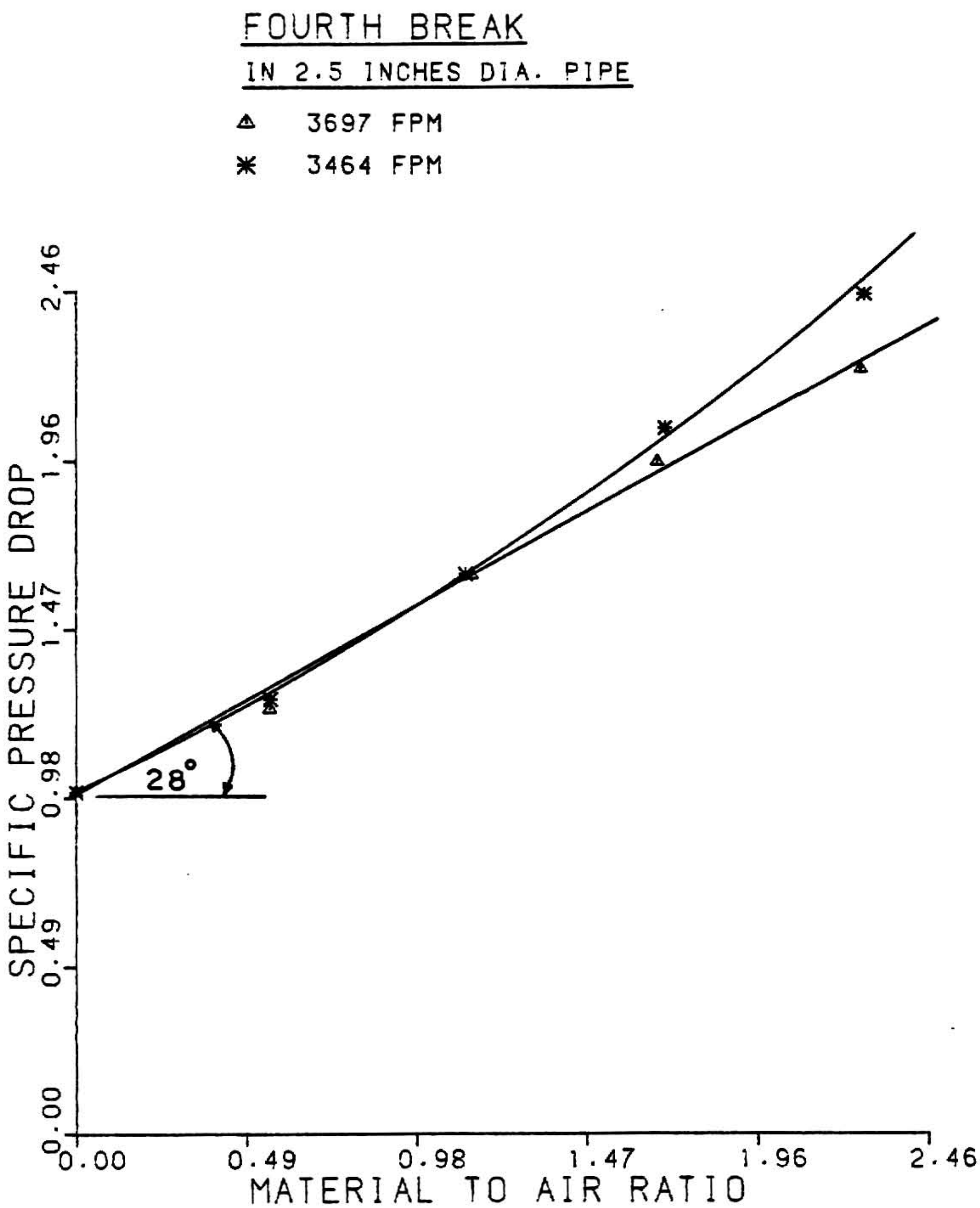

FOURTH BREAK
IN 2.5 INCHES DIA. PIPE
3697 FPM
3464 FPM
SPECIFIC PRESSURE DROP
0.00
0.49
0.98
1.47
1.96
2.46
28°
0.00
0.49
0.98
1.47
1.96
2.46
MATERIAL TO AIR RATIO

fig (4b)

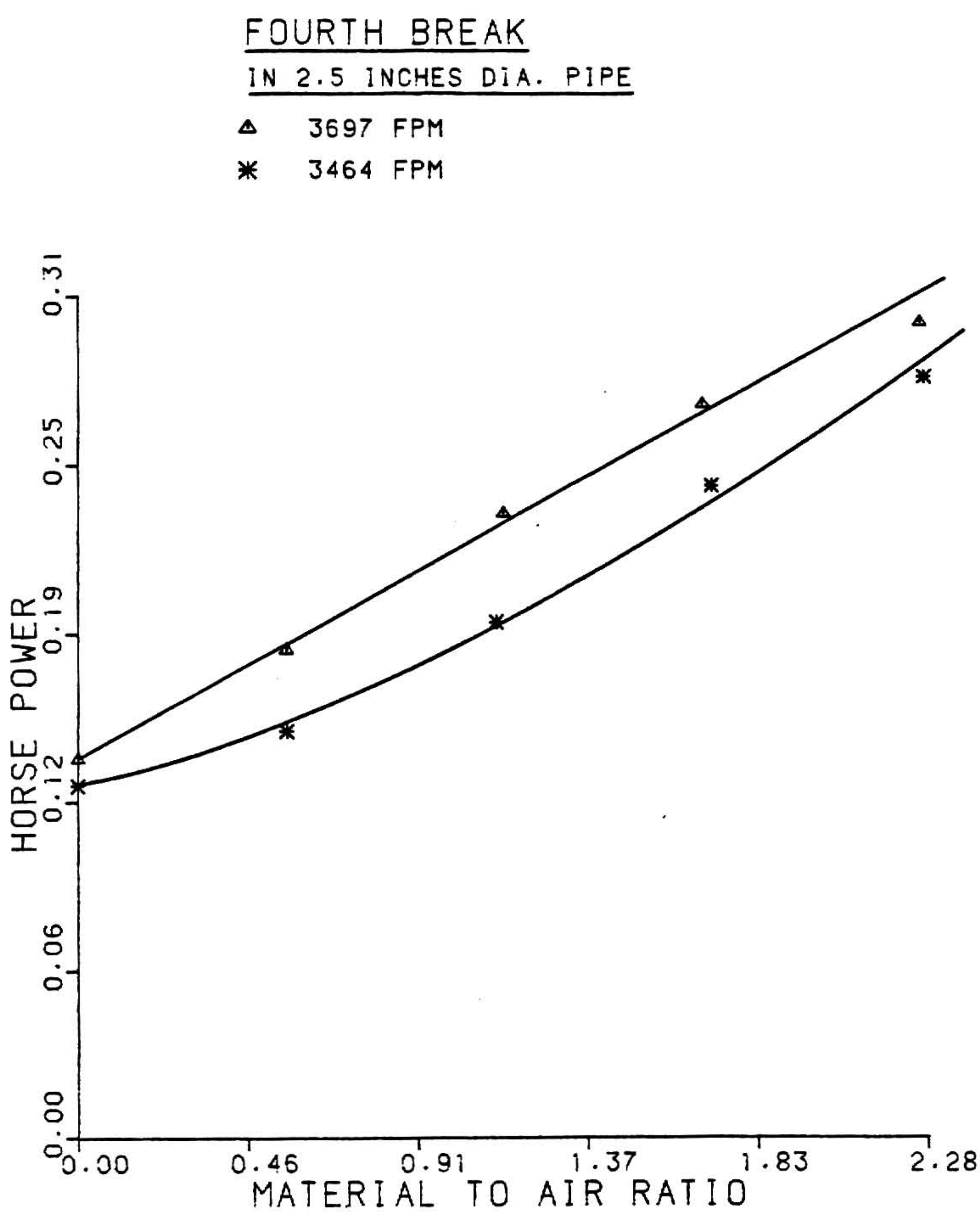
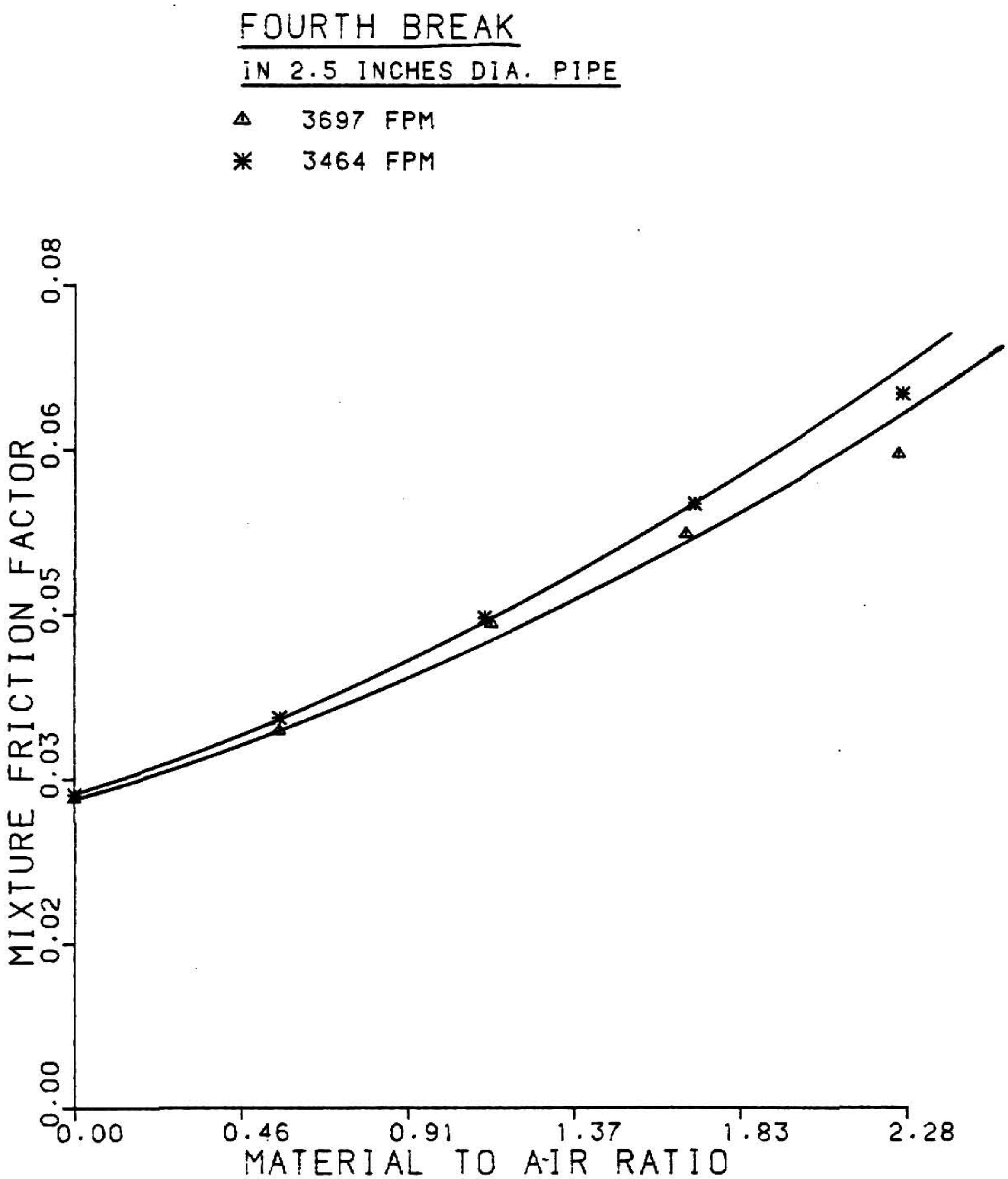

FOURTH BREAK
IN 2.5 INCHES DIA. PIPE
3697 FPM
3464 FPM
HORSE POWER
0.00
0.06
0.12
0.19
0.25
0.31
0.00
0.46
0.91
1.37
1.83
2.28
MATERIAL TO AIR RATIO

fig (4c)



FOURTH BREAK
IN 2.5 INCHES DIA. PIPE
3697 FPM
3464 FPM
MIXTURE FRICTION FACTOR
0.00
0.02
0.03
0.05
0.06
0.08
0.00
0.46
0.91
1.37
1.83
2.28
MATERIAL TO AIR RATIO

fig(4d)

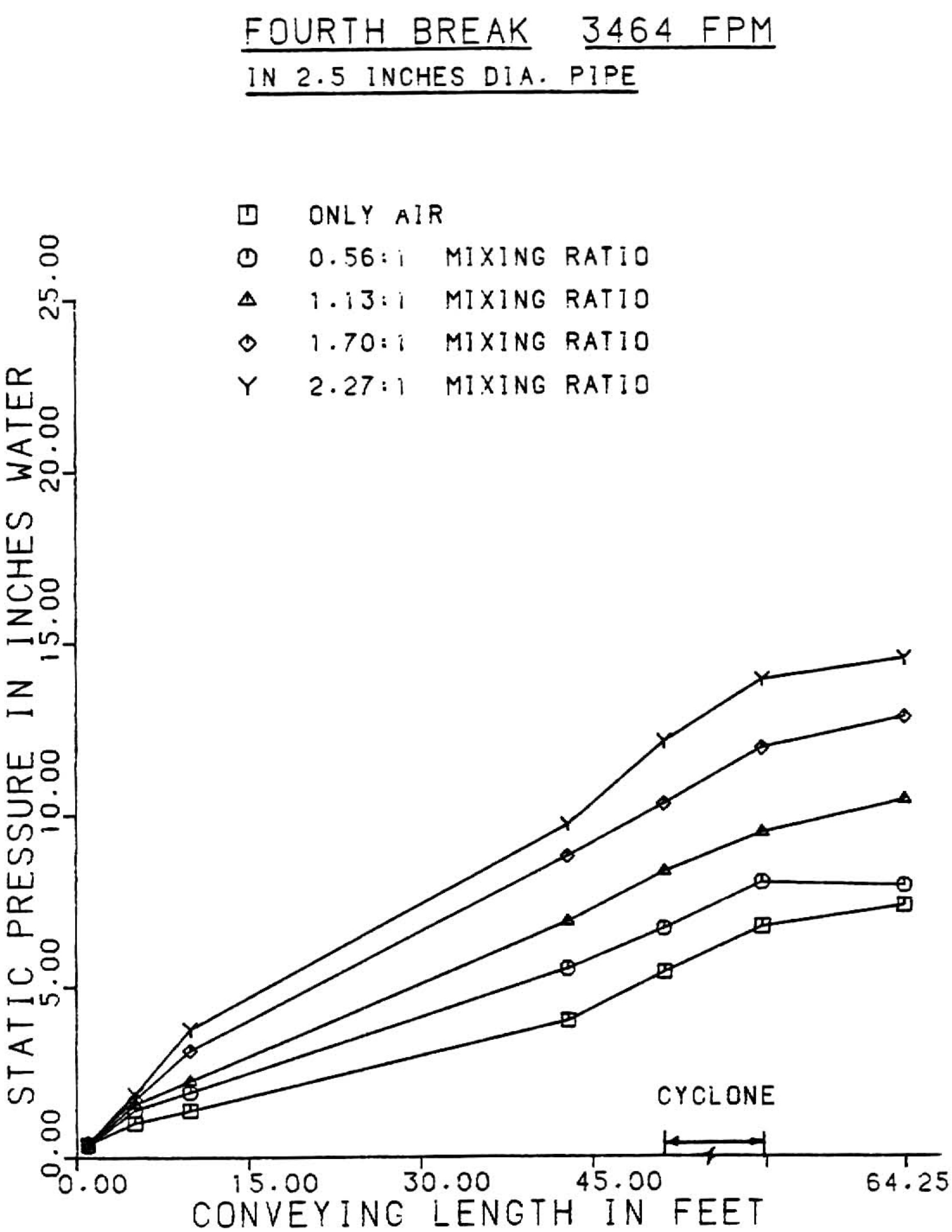
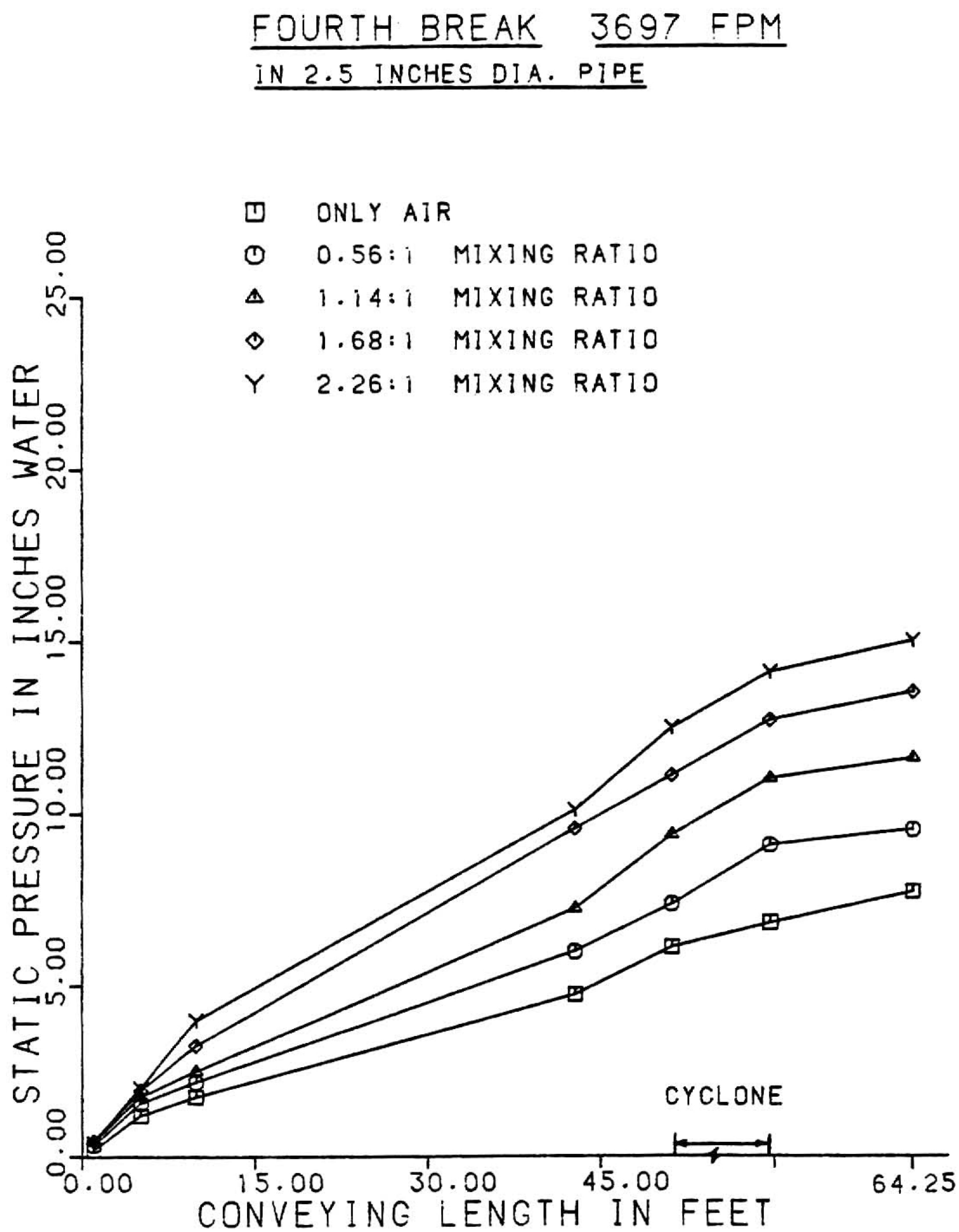

FOURTH BREAK 3464 FPM
IN 2.5 INCHES DIA. PIPE
ONLY AIR
0.56:1 MIXING RATIO
1.13:1 MIXING RATIO
1.70:1 MIXING RATIO
2.27:1 MIXING RATIO
STATIC PRESSURE IN INCHES WATER
0.00
5.00
10.00
15.00
20.00
25.00
CYCLONE
0.00
15.00
30.00
45.00
64.25
CONVEYING LENGTH IN FEET

fig (4e)


FOURTH BREAK 3697 FPM
IN 2.5 INCHES DIA. PIPE
ONLY AIR
0.56:1 MIXING RATIO
1.14:1 MIXING RATIO
1.68:1 MIXING RATIO
2.26:1 MIXING RATIO
STATIC PRESSURE IN INCHES WATER
0.00
5.00
10.00
15.00
20.00
25.00
CYCLONE
0.00
15.00
30.00
45.00
64.25
CONVEYING LENGTH IN FEET

the high rate at which pressure drops increased. Two main factors responsible for the increased pressure drops may be the high bulk density and larger number of particles for the same load which will cause more friction during conveying. This suggested that higher conveying air velocities had to be employed for choke free operation and presumably, at higher velocities, specific pressure drop may retain its linear relationship with material to air ratio. It should be noted that even at velocities tested, the raise in specific pressure drop per unit increase in material to air ratio was less for high air velocity and more at lower air velocity.

Horsepower requirement increased with increase in air velocity (Fig. 5b and Table 8a). Mixture friction factors were smaller at high velocity than for low velocity (Fig. 5c and Table 8a).

Static pressure drop along the conveying distance increased with increase in air velocity and also increase in material to air ratio. It increased at almost the same rate at both velocities for the material to air ratio (Fig. 5d, 5e, and Table 8).

1 Middling

Tests were conducted at average conveying air velocities of 3692 FPM and 3459 FPM, respectively. The system was loaded up to 2.25:1 material to air ratio. Even at 2.25:1 ratio, conveying motion was unsteady making it difficult to record pressure tap readings.

Specific pressure drops at both conveying velocities were related quadratically with material to air ratio as in the case of coarse sizing stock. In this case the loading was possible up to 2.25:1 material to air ratio while with coarse sizing, system was loaded up to 2.84:1 material to air ratio. Very steep increase in pressure drops at comparitively lower material to air ratios, as indicated by the slope of the curve, were possibly caused by high bulk density and more definitely by the very high number of particles involved for

TABLE 8. Data for Conveying of Coarse Sizing Stock

Material to air ratio	Static Pressure in Inches Water							Volume of air CFM	Velocity of air FPM	Velocity pressure inches water	Average velocity FPM
	Tap #1	Tap #2	Tap #3	Tap #4	Tap #5	Tap #6	Tap #7				
Air only	0.20	1.50	1.85	4.40	5.20	7.70	8.20	116.40	3706	0.86	
0.56:1	0.35	1.65	4.13	6.00	7.30	9.10	9.65	116.10	3694	0.85	
1.19:1	0.38	1.88	2.44	7.70	9.40	11.15	11.78	115.80	3685	0.85	3680
1.70:1	0.35	1.95	3.75	10.30	11.90	13.95	14.70	115.40	3675	0.84	
2.27:1	0.33	4.45	5.75	13.15	14.90	16.80	17.60	115.10	3663	0.84	
2.84:1	0.30	5.20	8.00	15.60	17.80	19.90	20.80	116.80	3655	0.83	
Air only	0.10	1.25	1.38	4.00	4.70	6.80	7.30	109.20	3478	0.75	
0.56:1	0.28	1.53	2.00	5.55	6.60	8.15	8.73	109.00	3471	0.75	
1.13:1	0.28	1.65	2.38	7.20	8.45	10.15	10.75	108.70	3460	0.75	3454
1.69:1	0.30	3.35	3.69	9.25	11.00	12.90	13.50	108.40	3449	0.74	
2.27:1	0.28	4.25	5.63	12.30	14.00	15.30	16.45	108.00	3438	0.74	
2.84:1	0.20	4.80	8.00	16.00	17.20	17.30	20.20	107.70	3427	0.73	

Relative humidity = 73.2%
Temperature = 77^{o}F
Viscocity of air = 12.39 X 10^{-6} lb/foot sec.
Density of air = 0.0722 lb/cu.ft.

TABLE 8a. Calculated Data for Conveying of Coarse Sizing Stock

Feed rate lb/min	Material to air ratio	Specific pressure drop	Horsepower	Mixture friction factor	Average velocity FPM
0.00	0.00:1	1.00	0.15	0.0243	
4.71	0.56:1	1.49	0.19	0.0344	
9.43	1.19:1	1.97	0.22	0.0445	3680
14.13	1.70:1	2.57	0.30	0.0566	
18.86	2.27:1	3.24	0.35	0.0713	
23.56	2.84:1	3.91	0.42	0.0856	
0.00	0.00:1	1.00	0.13	0.0250	
4.42	0.56:1	1.48	0.16	0.0352	
8.84	1.13:1	1.95	0.19	0.0453	3454
13.25	1.69:1	2.60	0.25	0.0594	
17.67	2.27:1	3.36	0.31	0.0761	
22.09	2.84:1	4.17	0.37	0.0941	

fig(5a)

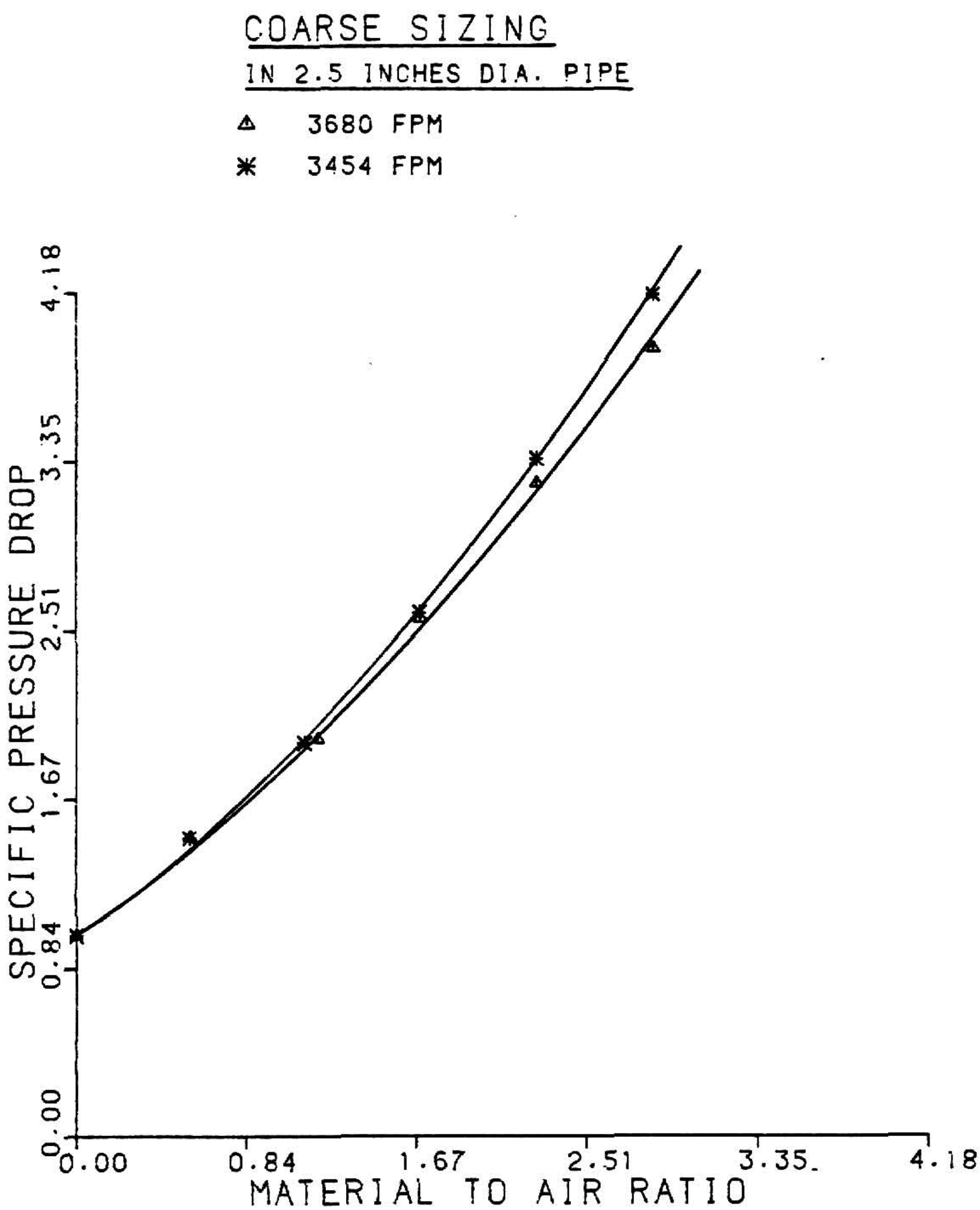

COARSE SIZING
IN 2.5 INCHES DIA. PIPE
3680 FPM
3454 FPM
SPECIFIC PRESSURE DROP
0.00
0.84
1.67
2.51
3.35
4.18
MATERIAL TO AIR RATIO
0.00
0.84
1.67
2.51
3.35
4.18

fig (5b)

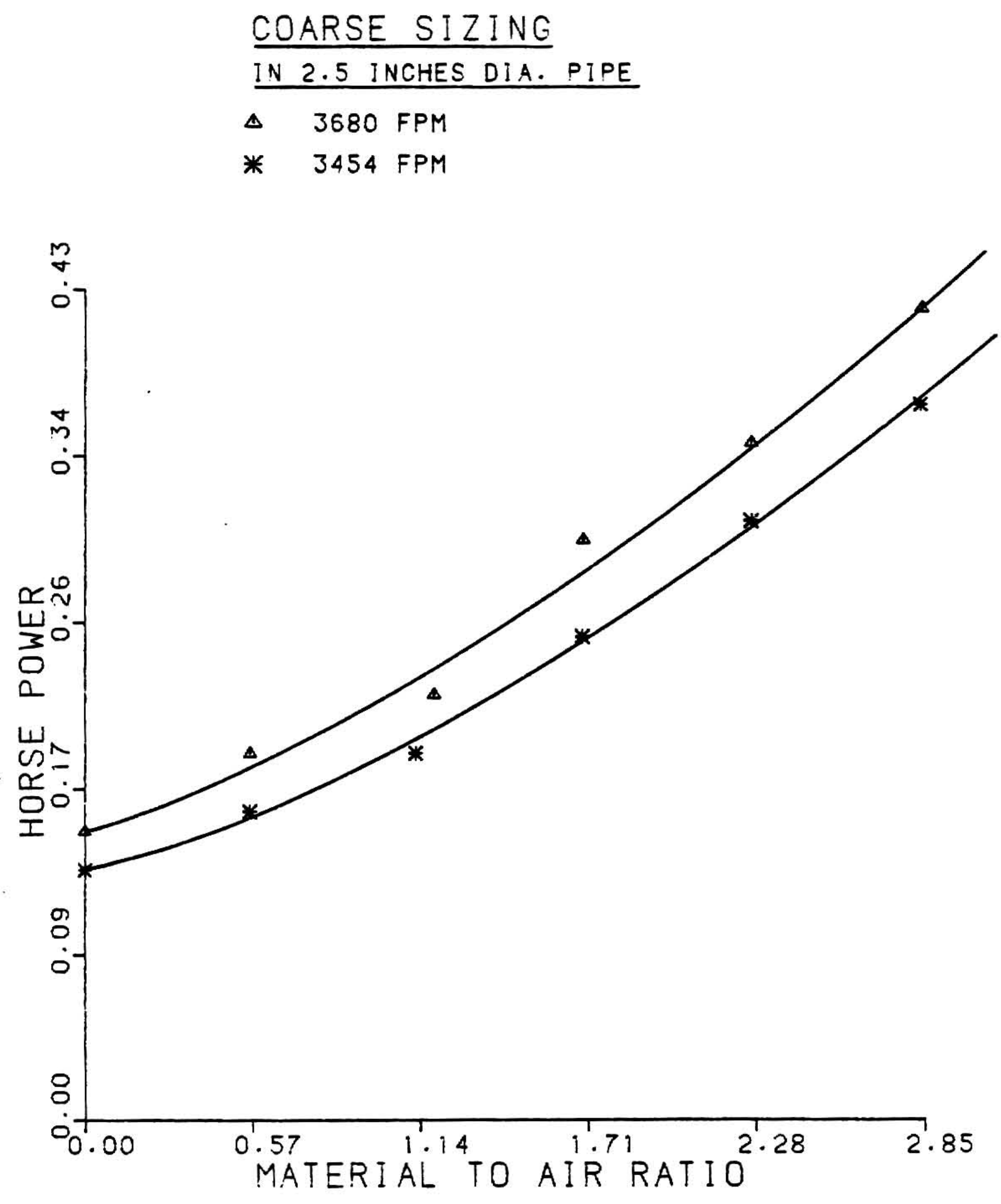

COARSE SIZING
IN 2.5 INCHES DIA. PIPE
3680 FPM
3454 FPM
HORSE POWER
0.00
0.09
0.17
0.26
0.34
0.43
0.00
0.57
1.14
1.71
2.28
2.85
MATERIAL TO AIR RATIO

fig (5c)

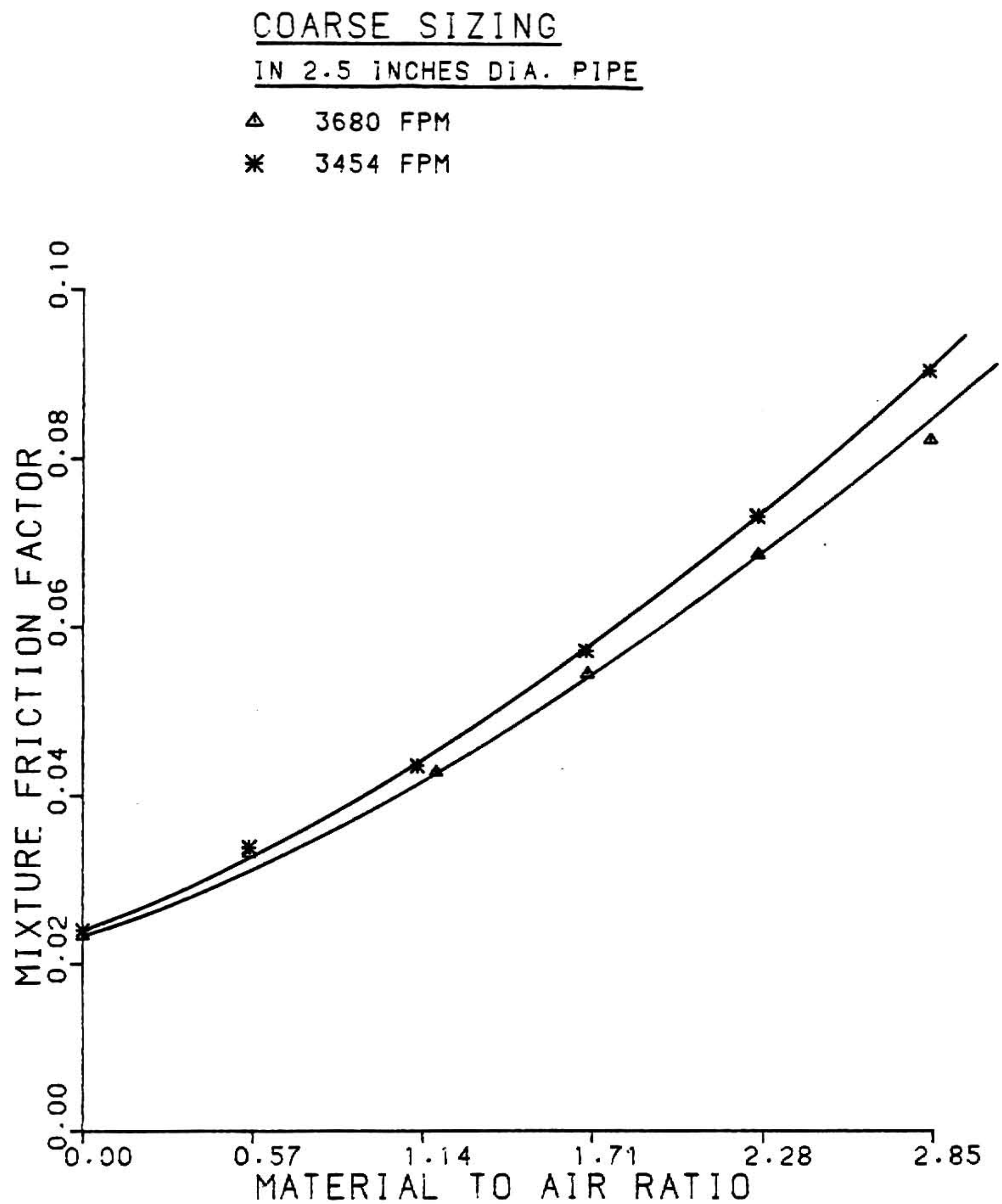
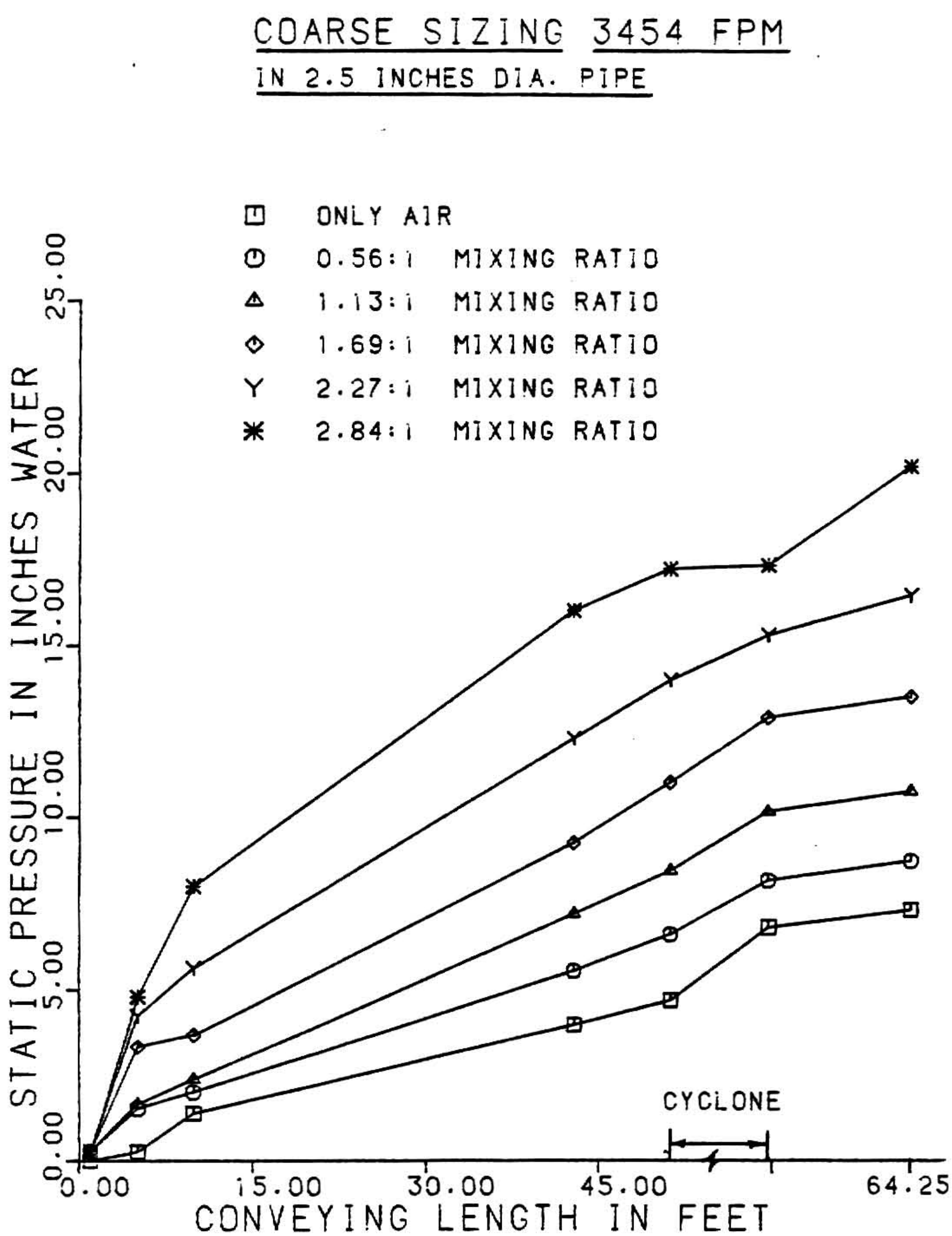
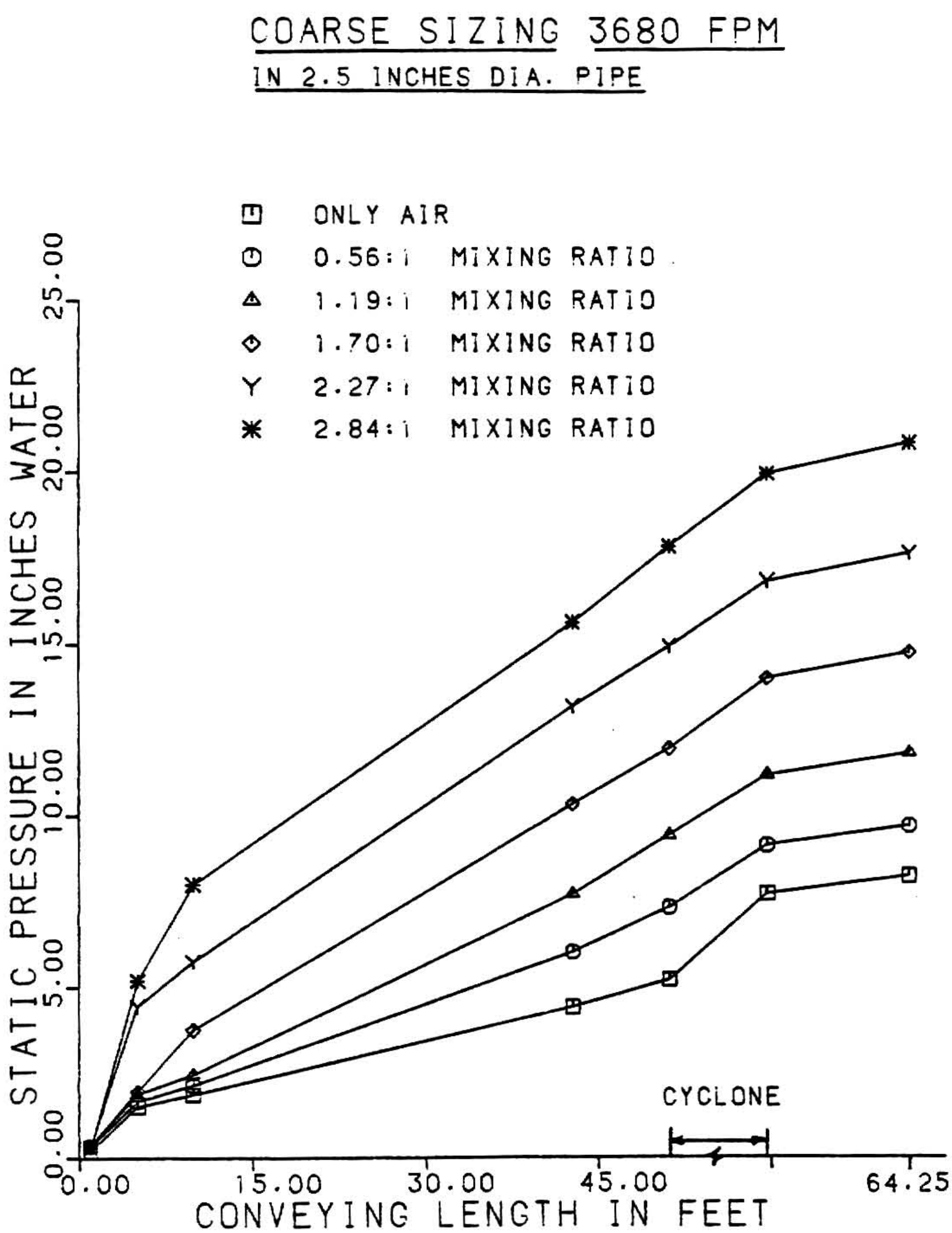

COARSE SIZING
IN 2.5 INCHES DIA. PIPE
△ 3680 FPM
✱ 3454 FPM
MIXTURE FRICTION FACTOR
0.00
0.02
0.04
0.06
0.08
0.10
0.00
0.57
1.14
1.71
2.28
2.85
MATERIAL TO AIR RATIO

fig (5d)


COARSE SIZING 3454 FPM
IN 2.5 INCHES DIA. PIPE
ONLY AIR
0.56:1 MIXING RATIO
1.13:1 MIXING RATIO
1.69:1 MIXING RATIO
2.27:1 MIXING RATIO
2.84:1 MIXING RATIO
STATIC PRESSURE IN INCHES WATER
0.00
5.00
10.00
15.00
20.00
25.00
CYCLONE
0.00
15.00
30.00
45.00
64.25
CONVEYING LENGTH IN FEET

fig(5e)


COARSE SIZING 3680 FPM
IN 2.5 INCHES DIA. PIPE
ONLY AIR
0.56:1 MIXING RATIO
1.19:1 MIXING RATIO
1.70:1 MIXING RATIO
2.27:1 MIXING RATIO
2.84:1 MIXING RATIO
STATIC PRESSURE IN INCHES WATER
0.00
5.00
10.00
15.00
20.00
25.00
CYCLONE
0.00
15.00
30.00
45.00
64.25
CONVEYING LENGTH IN FEET

the same load because of its very small particle size. It was again observed that the increase in specific pressure drop per unit increase in material to air ratio was less for high air velocity than it was for low air velocity (Fig. 6a and Table 9a).

More horsepower was required to convey at 3692 FPM air velocity than at 3459 FPM velocity (Fig. 6b and Table 9a). Mixture friction factors were small at 3692 FPM and large at 3459 FPM (Fig. 6c and Table 9a).

The static pressure requirements increased with increase in velocity and at approximately the same rate for all material to air ratios tested (Fig. 6d, 6e, and Table 9).

6 Middling

Tests were conducted at average conveying air velocities of 3678 FPM and 3453 FPM, respectively. The system was loaded up to 2.84:1 material to air ratio. The conveying was smooth and handled easily.

From Fig. 7a and Table 10a, it was noted that the specific pressure drops were related linearly with material to air ratios and specific pressure drop was lower 3678 FPM air velocity than at 3453 FPM air velocity for the same material to air ratio. This in comparison with coarse sizing and 1 Middling, where the relationship between specific pressure drop and material to air ratio is quadratic, brings out the major effect of bulk density in determining the pressure drops while particle size and number of particles/unit weight are comparable.

Horsepower requirement was high at 3678 FPM air velocity and low at 3453 FPM velocity (Fig. 7b and Table 10a). Smaller friction factors were encountered at 3678 FPM than at 3453 FPM (Fig. 7c and Table 10a).

As conveying air velocity was increased, static pressure drop along the conveying distance was increased. The rate of increase in pressure drops, at

TABLE 9. Data for Conveying of 1 Middling Stock

Material to air ratio	Static Pressure in Inches Water							Volume of air CFM	Velocity of air FPM	Velocity pressure inches water	Average velocity FPM
	Tap #1	Tap #2	Tap #3	Tap #4	Tap #5	Tap #6	Tap #7				
Air only	0.20	1.20	1.50	4.30	5.05	6.80	8.30	116.55	3710	0.86	
0.56:1	0.35	1.63	2.00	6.10	7.45	9.30	9.95	115.96	3690	0.85	
1.12:1	0.40	1.83	3.00	7.95	9.50	11.40	12.75	115.96	3690	0.85	3692
1.68:1	0.45	2.23	3.75	9.90	11.35	11.35	14.30	115.81	3687	0.85	
2.25:1	0.40	3.50	7.00	13.85	15.30	16.90	18.25	115.38	3673	0.84	
Air only	0.20	1.20	1.50	3.90	4.55	6.95	7.50	109.15	3474	0.75	
0.56:1	0.28	1.48	2.00	5.50	6.65	8.25	8.80	108.86	3465	0.75	
1.12:1	0.35	1.65	2.75	7.20	8.45	10.40	10.90	108.69	3460	0.75	3565
1.69:1	0.40	1.93	4.81	9.90	11.50	13.30	13.80	108.46	3452	0.74	
2.25:1	0.35	3.68	6.88	12.80	14.45	16.70	17.40	108.11	3441	0.74	

Relative humidity = 73.7%
Temperature = 75.5°F
Viscocity of air = 12.37×10^{-6} lb/foot sec.
Density of air = 0.0725 lb/cu.ft.

TABLE 9a. Calculated Data for Conveying of 1 Middling Stock

Feed rate lb/min	Material to air ratio	Specific pressure drop	Horsepower	Mixture friction factor	Average velocity FPM
0.00	0.00:1	1.00	0.15	0.0235	
4.71	0.56:1	1.58	0.19	0.0350	
9.43	1.12:1	2.06	0.24	0.0447	3692
14.13	1.68:1	2.51	0.28	0.0535	
18.85	2.25:1	3.45	0.36	0.0726	
0.00	0.00:1	1.00	0.13	0.0241	
4.42	0.56:1	1.55	0.16	0.0355	
8.84	1.12:1	2.03	0.20	0.0452	3459
13.25	1.69:1	2.83	0.26	0.0618	
17.67	2.25:1	3.61	0.33	0.0781	

fig (6a)

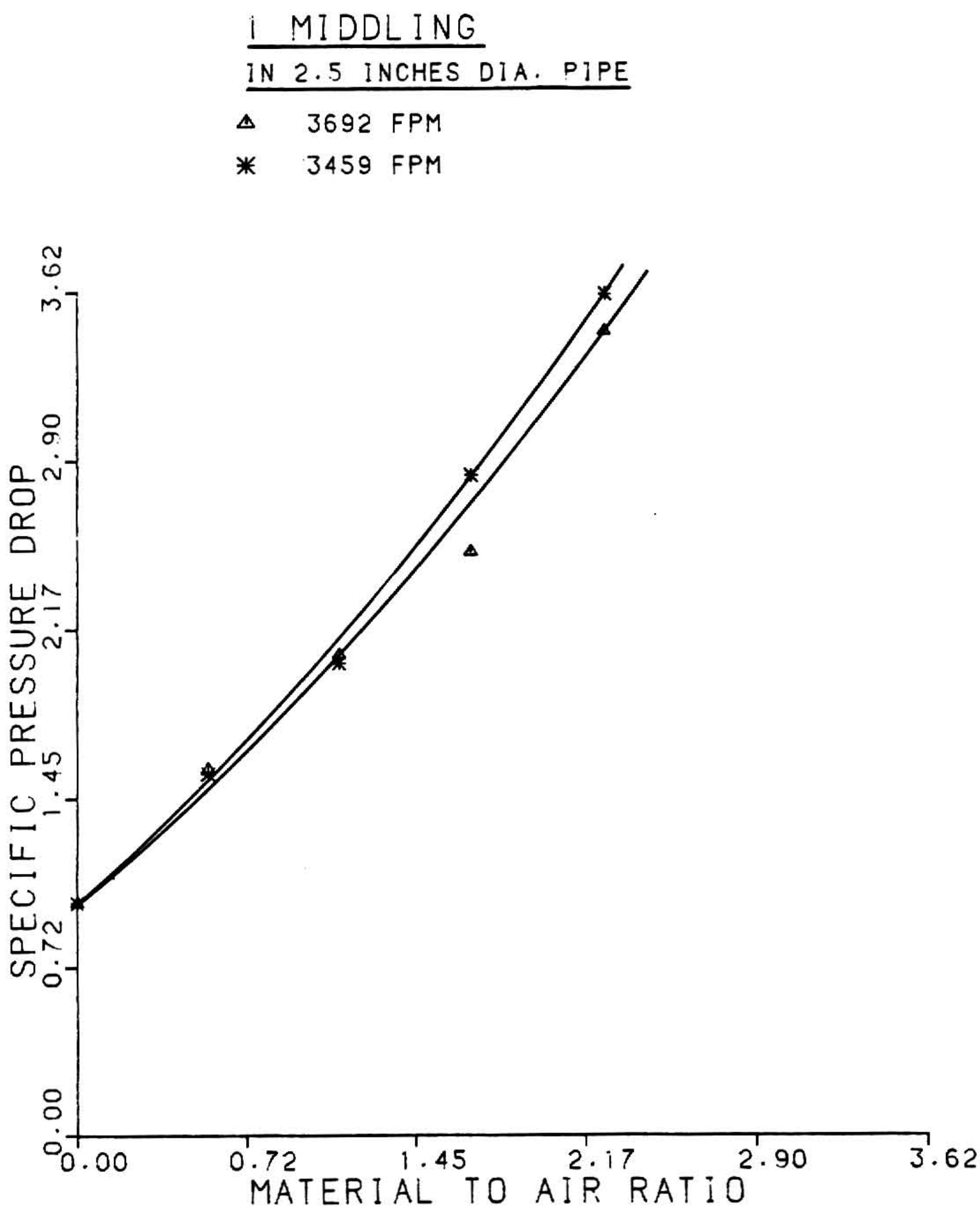

1 MIDDLING
IN 2.5 INCHES DIA. PIPE
3692 FPM
3459 FPM
SPECIFIC PRESSURE DROP
0.00
0.72
1.45
2.17
2.90
3.62
MATERIAL TO AIR RATIO

fig (6b)

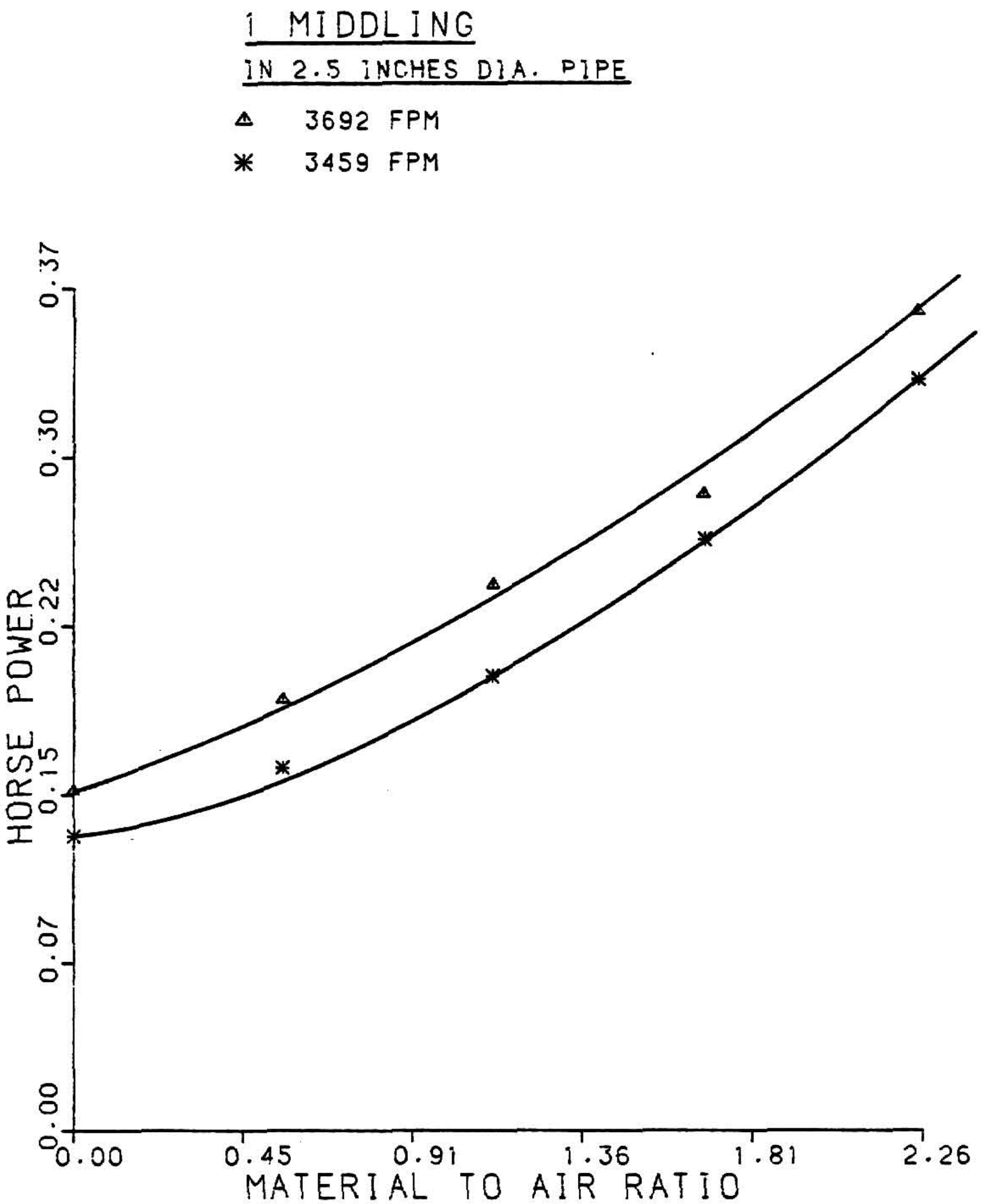

1 MIDDLING
IN 2.5 INCHES DIA. PIPE
3692 FPM
3459 FPM
HORSE POWER
0.00
0.07
0.15
0.22
0.30
0.37
0.00
0.45
0.91
1.36
1.81
2.26
MATERIAL TO AIR RATIO

fig (6c)

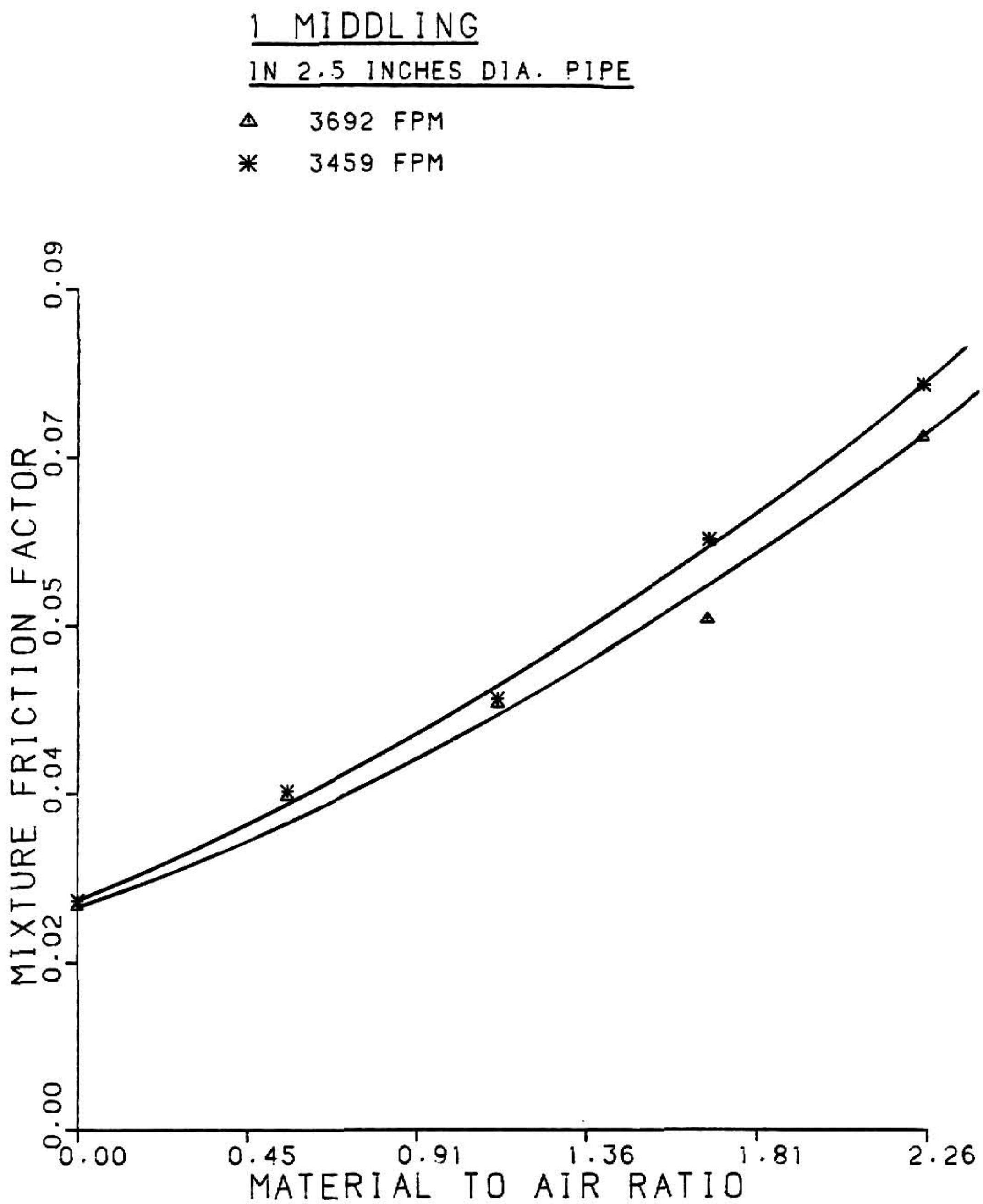

1 MIDDLING
IN 2.5 INCHES DIA. PIPE
3692 FPM
3459 FPM
MIXTURE FRICTION FACTOR
0.00
0.02
0.04
0.05
0.07
0.09
0.00
0.45
0.91
1.36
1.81
2.26
MATERIAL TO AIR RATIO

fig (6d)

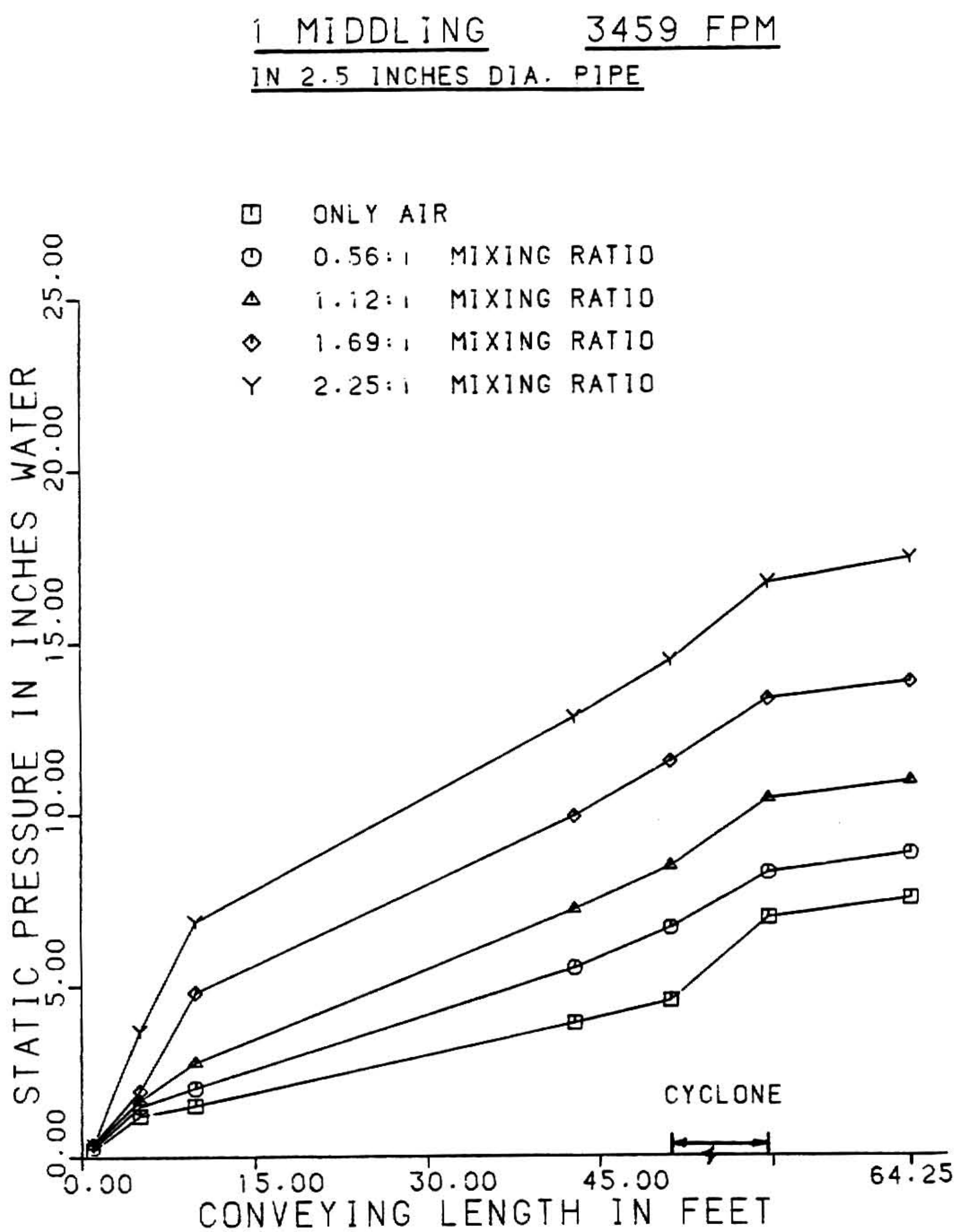

1 MIDDLING 3459 FPM
IN 2.5 INCHES DIA. PIPE
ONLY AIR
0.56:1 MIXING RATIO
1.12:1 MIXING RATIO
1.69:1 MIXING RATIO
2.25:1 MIXING RATIO
STATIC PRESSURE IN INCHES WATER
0.00
5.00
10.00
15.00
20.00
25.00
CYCLONE
0.00
15.00
30.00
45.00
64.25
CONVEYING LENGTH IN FEET

fig (6e)

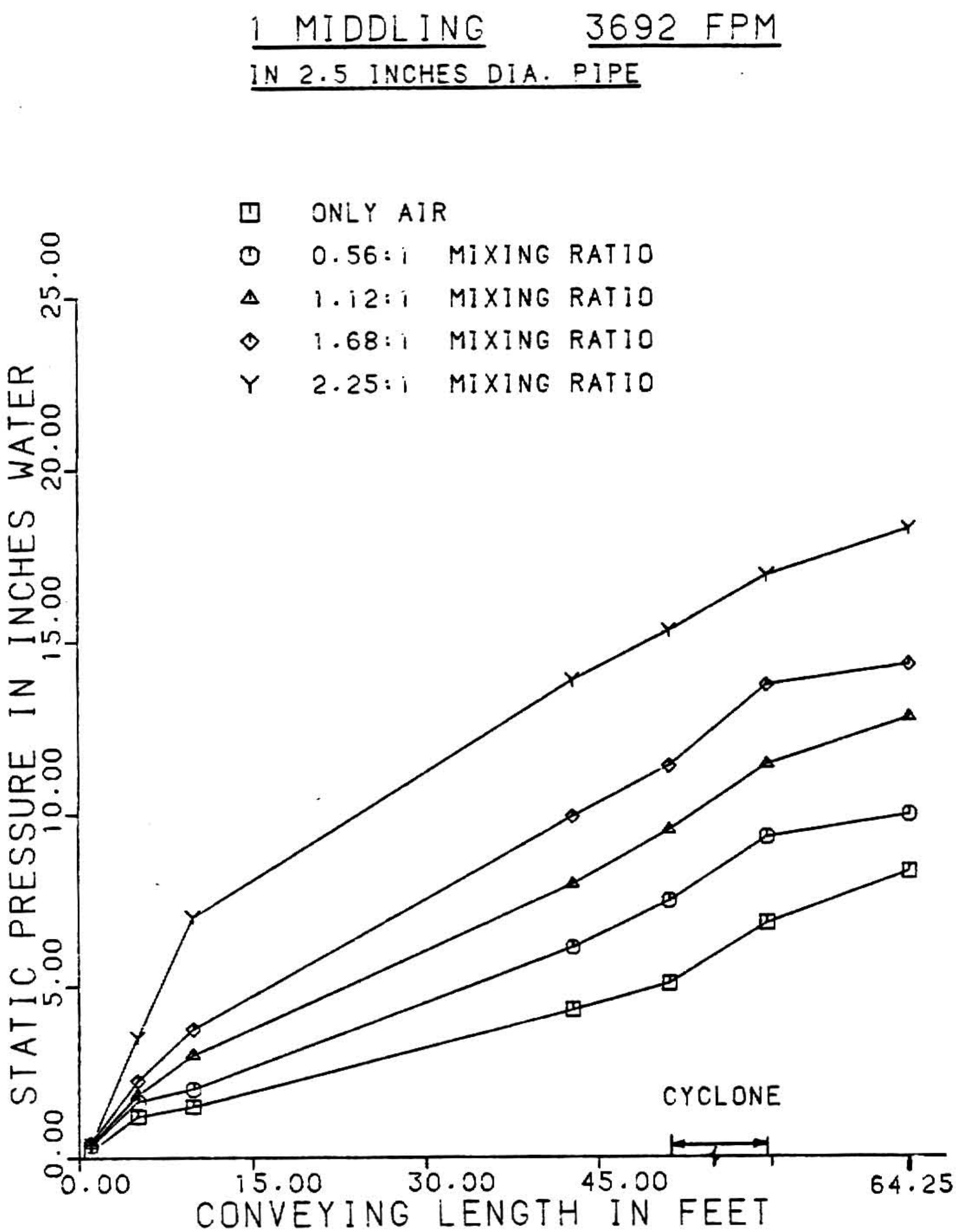

1 MIDDLING 3692 FPM
IN 2.5 INCHES DIA. PIPE
ONLY AIR
0.56:1 MIXING RATIO
1.12:1 MIXING RATIO
1.68:1 MIXING RATIO
2.25:1 MIXING RATIO
STATIC PRESSURE IN INCHES WATER
0.00
5.00
10.00
15.00
20.00
25.00
CYCLONE
0.00
15.00
30.00
45.00
64.25
CONVEYING LENGTH IN FEET

TABLE 10. Data for Conveying of 6 Middling Stock

Material to air ratio	Static Pressure in Inches Water Tap #1	Tap #2	Tap #3	Tap #4	Tap #5	Tap #6	Tap #7	Volume of air CFM	Velocity of air FPM	Velocity pressure inches water	Average velocity FPM
Air only	0.25	0.85	1.38	4.40	5.00	7.70	8.25	116.18	3698	0.85	
0.56:1	0.45	1.18	2.19	6.30	7.48	9.48	9.98	115.94	3690	0.85	
1.13:1	0.55	1.45	3.19	8.15	10.03	12.00	12.48	115.69	3683	0.85	3678
1.69:1	0.68	1.70	4.19	10.20	12.33	14.50	14.90	115.44	3675	0.84	
2.26:1	0.70	2.18	5.41	12.65	14.90	17.30	18.20	115.32	3671	0.84	
2.84:1	0.80	3.00	6.50	15.30	18.20	20.20	21.50	114.71	3651	0.83	
Air only	0.20	0.80	1.31	3.90	4.40	6.75	7.35	109.38	3482	0.76	
0.56:1	0.30	1.10	2.28	5.83	7.00	8.65	9.25	108.86	3465	0.75	
1.12:1	0.35	1.33	3.06	7.73	9.05	10.95	11.58	108.63	3458	0.75	3453
1.69:1	0.50	1.60	4.38	10.05	11.53	13.50	15.00	108.29	3447	0.74	
2.26:1	0.58	2.20	5.50	12.25	14.85	16.35	17.05	108.00	3438	0.74	
2.83:1	0.65	3.30	6.50	14.40	17.15	19.70	19.50	107.69	3428	0.73	

Relative humidity = 66.7%
Temperature = 77^{o}F
Viscocity of air = 12.39 X 10^{-6} lb/foot sec.
Density of air = 0.0724 lb/cu.ft.

TABLE 10a. Calculated Data for Conveying of 6 Middling Stock

Feed rate lb/min	Material to air ratio	Specific pressure drop	Horsepower	Mixture friction factor	Average velocity FPM
0.00	0.00:1	1.00	0.15	0.0234	
4.71	0.56:1	1.60	0.19	0.0342	
9.43	1.13:1	2.21	0.24	0.0474	3768
14.13	1.69:1	2.77	0.29	0.0585	
18.85	2.26:1	3.39	0.36	0.0709	
23.56	2.84:1	4.19	0.40	0.0875	
0.00	0.00:1	1.00	0.13	0.0233	
4.42	0.56:1	1.72	0.17	0.0374	
8.84	1.12:1	2.28	0.21	0.0485	3453
13.25	1.69:1	2.96	0.28	0.0622	
17.67	2.26:1	3.87	0.32	0.0806	
22.10	2.83:1	4.51	0.36	0.0936	

fig (7a)

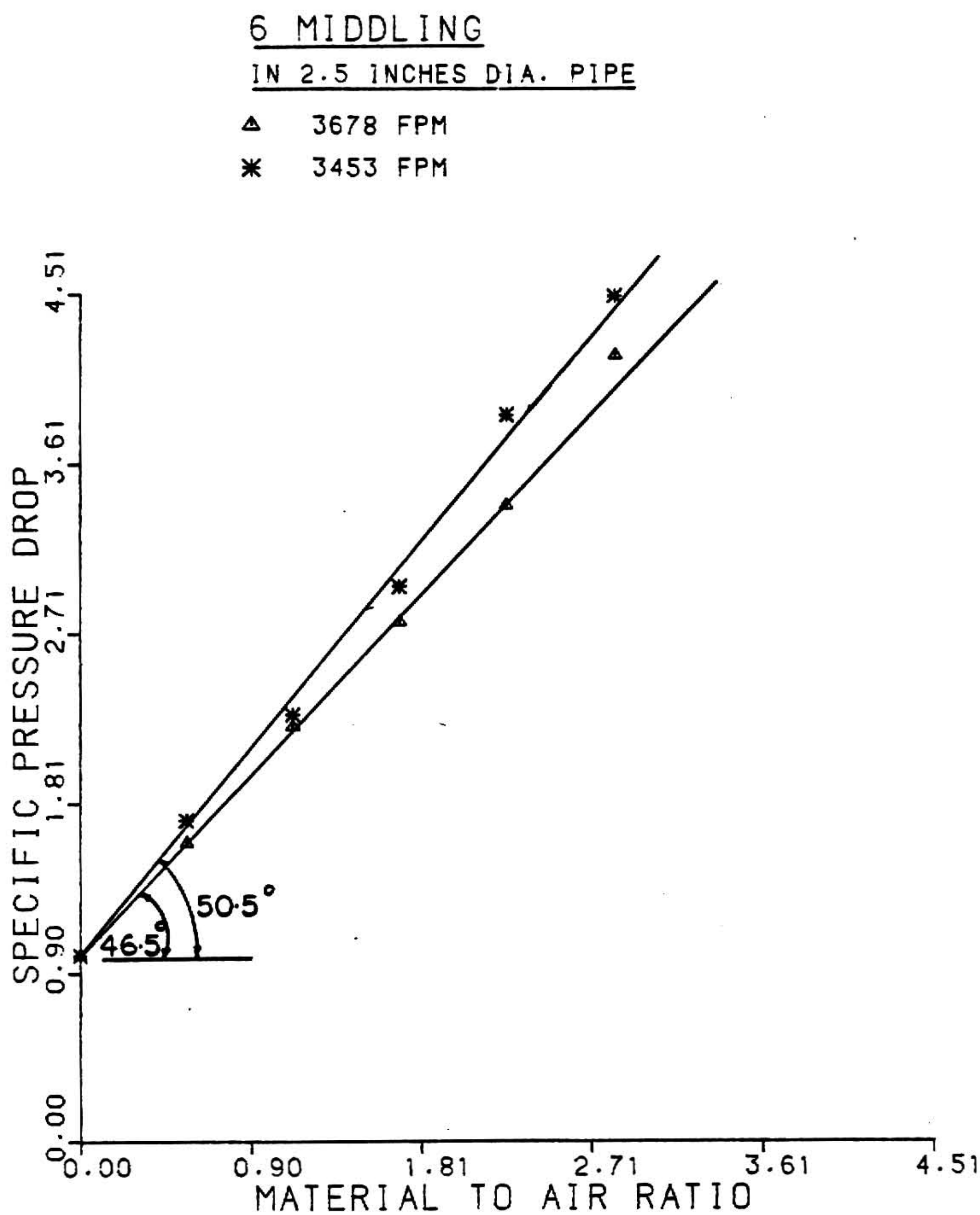

6 MIDDLING
IN 2.5 INCHES DIA. PIPE
△ 3678 FPM
✱ 3453 FPM
SPECIFIC PRESSURE DROP
0.00
0.90
1.81
2.71
3.61
4.51
50·5°
46·5°
0.00
0.90
1.81
2.71
3.61
4.51
MATERIAL TO AIR RATIO

fig (7b)

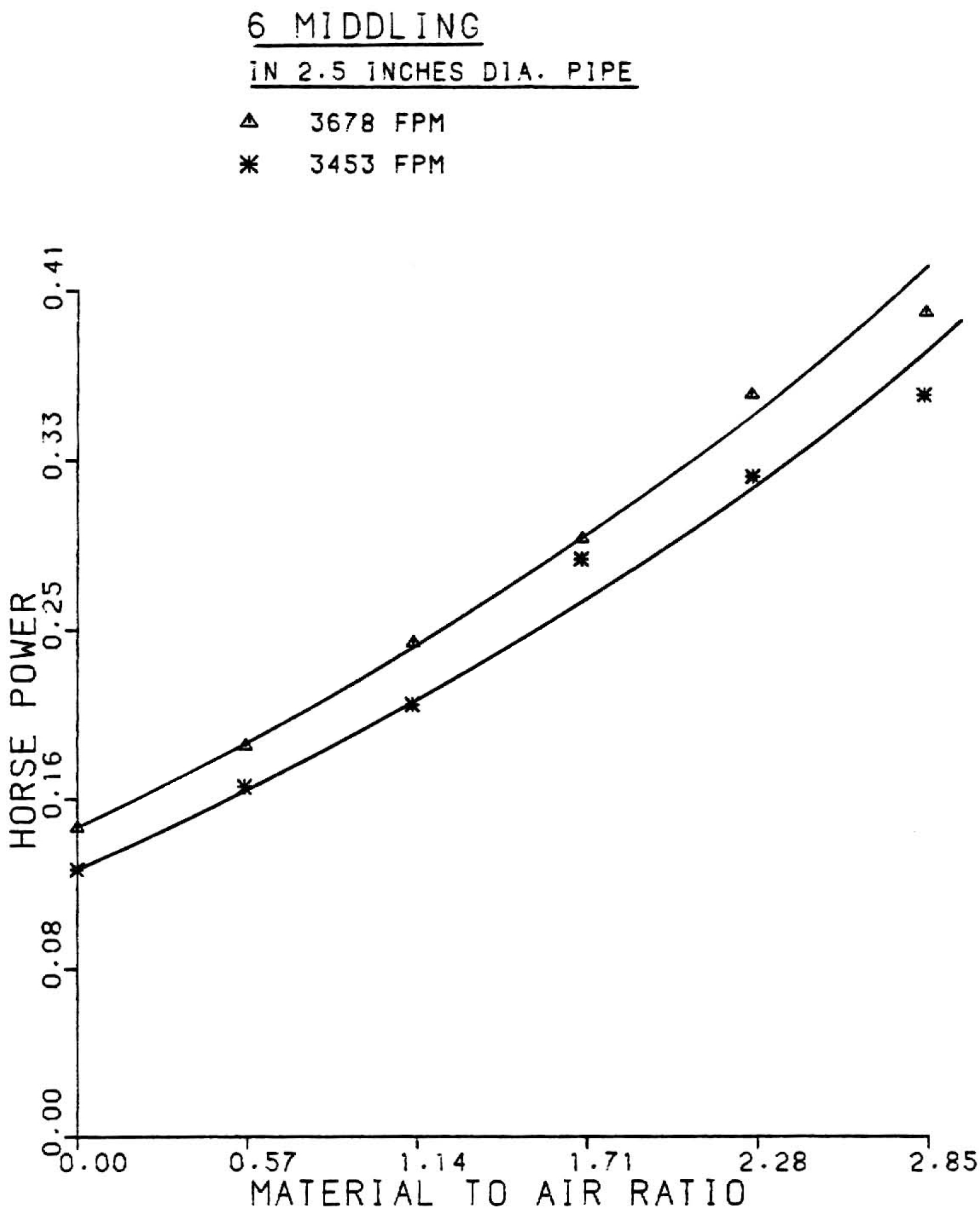

6 MIDDLING
IN 2.5 INCHES DIA. PIPE
3678 FPM
3453 FPM
HORSE POWER
0.00
0.08
0.16
0.25
0.33
0.41
0.00
0.57
1.14
1.71
2.28
2.85
MATERIAL TO AIR RATIO

fig (7c)

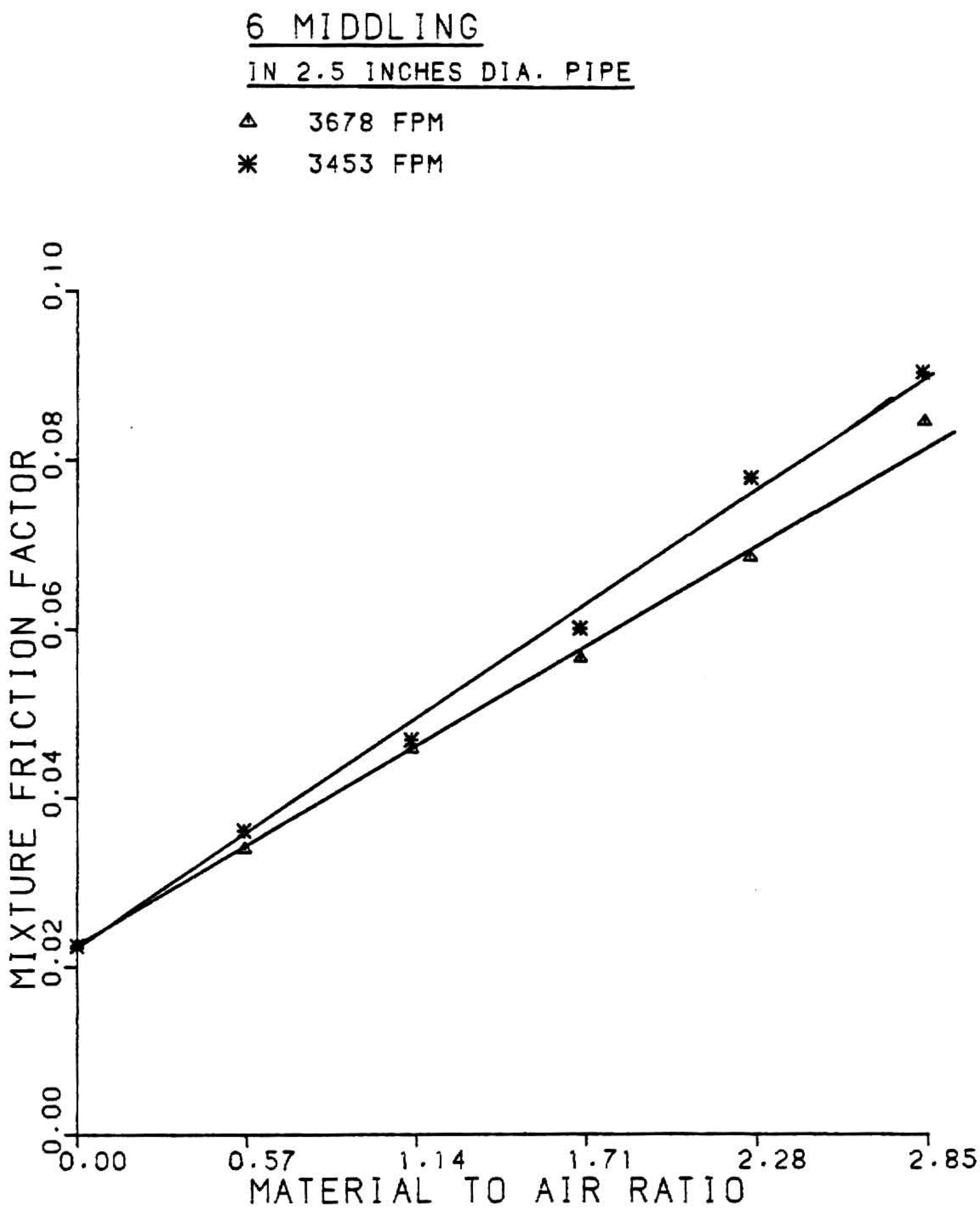

6 MIDDLING
IN 2.5 INCHES DIA. PIPE
△ 3678 FPM
✱ 3453 FPM
MIXTURE FRICTION FACTOR
0.00
0.02
0.04
0.06
0.08
0.10
0.00
0.57
1.14
1.71
2.28
2.85
MATERIAL TO AIR RATIO

fig (7d)

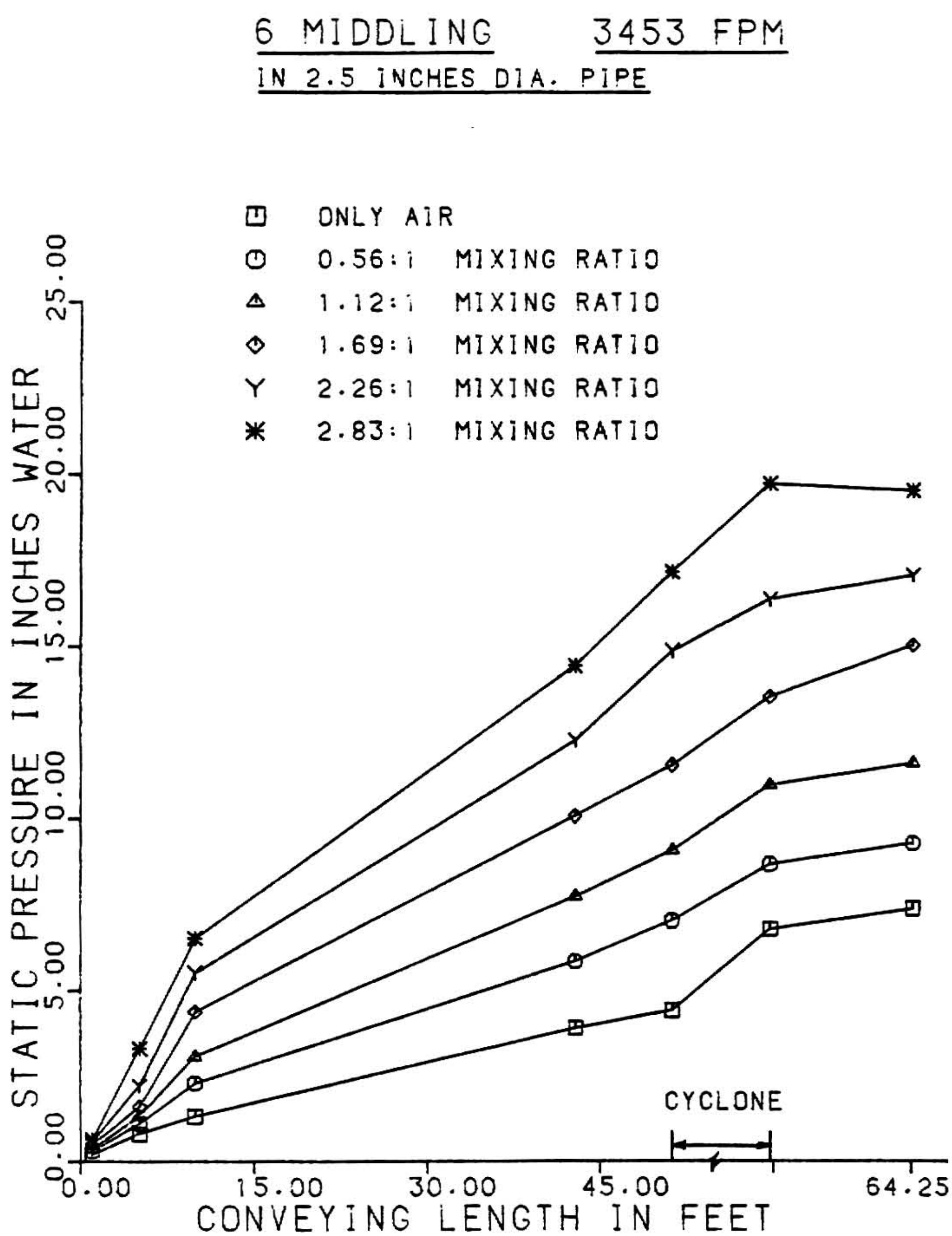
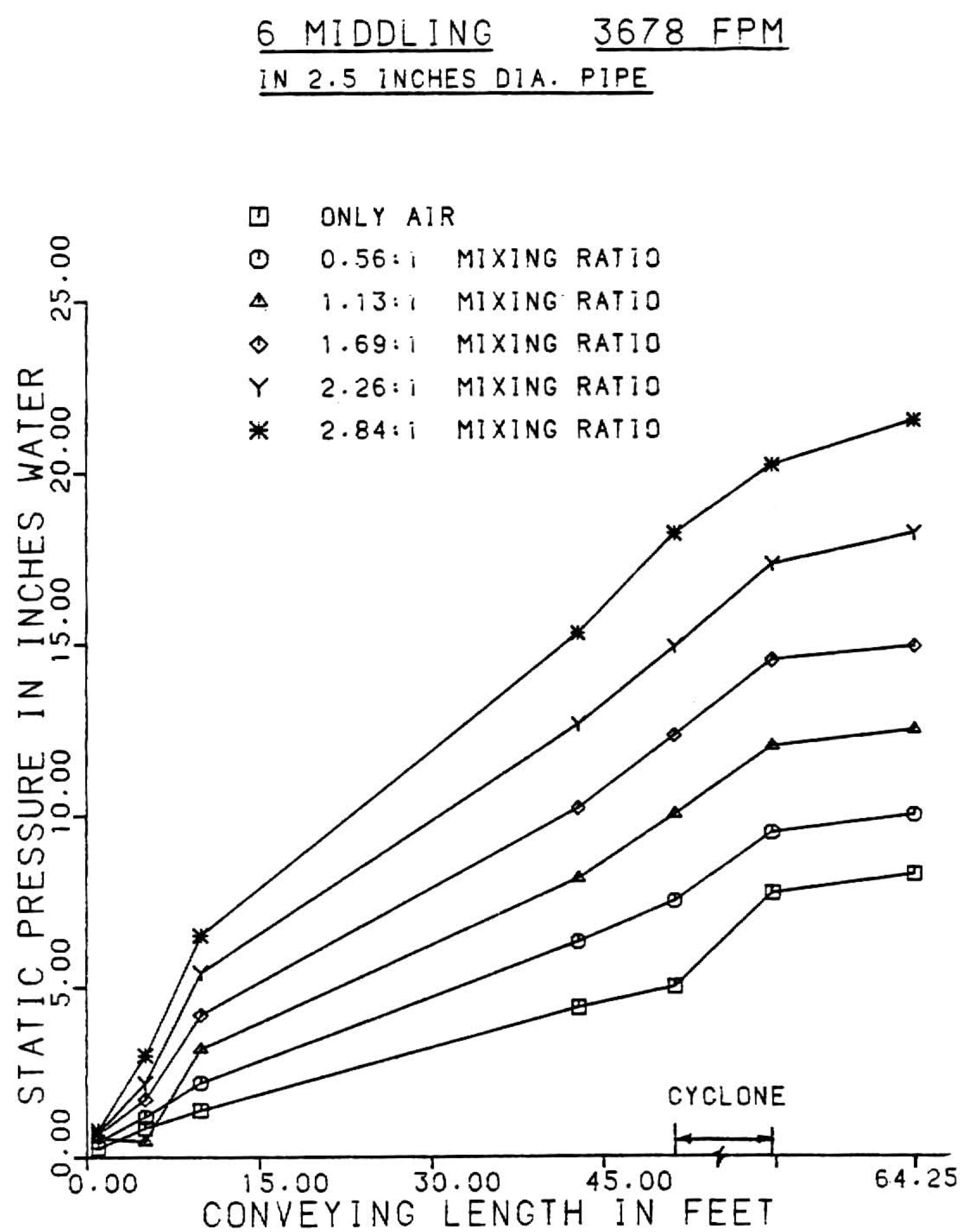

6 MIDDLING 3453 FPM
IN 2.5 INCHES DIA. PIPE
ONLY AIR
0.56:1 MIXING RATIO
1.12:1 MIXING RATIO
1.69:1 MIXING RATIO
2.26:1 MIXING RATIO
2.83:1 MIXING RATIO
STATIC PRESSURE IN INCHES WATER
0.00
5.00
10.00
15.00
20.00
25.00
CYCLONE
0.00
15.00
30.00
45.00
64.25
CONVEYING LENGTH IN FEET

fig (7e)


6 MIDDLING 3678 FPM
IN 2.5 INCHES DIA. PIPE
ONLY AIR
0.56:1 MIXING RATIO
1.13:1 MIXING RATIO
1.69:1 MIXING RATIO
2.26:1 MIXING RATIO
2.84:1 MIXING RATIO
STATIC PRESSURE IN INCHES WATER
0.00
5.00
10.00
15.00
20.00
25.00
CYCLONE
0.00
15.00
30.00
45.00
64.25
CONVEYING LENGTH IN FEET

both conveying velocities, for all material to air ratios tested, was approximately the same (Fig. 7d, 7e, and Table 10).

1 Tailing

The tests were conducted at average conveying air velocities of 3695 FPM and 3475 FPM, respectively. The system is loaded up to 2.83:1 material to air ratio at 3695 FPM and only up to 1.68:1 material to air ratio at 3475 FPM. In the later case even at 1.68:1 ratio conveying was unsteady and started to surge. This indicates that 3475 FPM was not a suitable air velocity to convey 1 Tailing stock up to good loading ratios.

Fig. 8a and Table 11a shows that specific pressure drop beared linear relationship with material to air ratio at both conveying air velocities. Pressure drops were lower at 3695 FPM air velocity than at 3475 FPM air velocity for the same material to air ratio. Horsepower required was more at 3695 FPM velocity than at 3475 FPM (Fig. 8b and Table 11a). Mixture friction factors were smaller at 3695 FPM than at 3475 FPM air velocity (Fig. 8c and Table 11a). Figures 8d, 8e and Table 11 indicated that static pressure drop increased with increase in conveying air velocity. At each material to air ratio, pressure drop increased by the same amount for both conveying air velocities.

FLOUR

Tests were conducted at average conveying air velocities of 3696 FPM and 3512 FPM, respectively. The system was loaded up to 2.82:1 material to air ratio.

It was found that the relationship between specific pressure drop and material to air ratio was linear (Fig. 9a and Table 12a), and that specific pressure drop increased with increase in conveying air velocity. This was in contrast to other more granular material, but was in confirmation with results

TABLE 11. Data for Conveying of 1 Tailing Stock

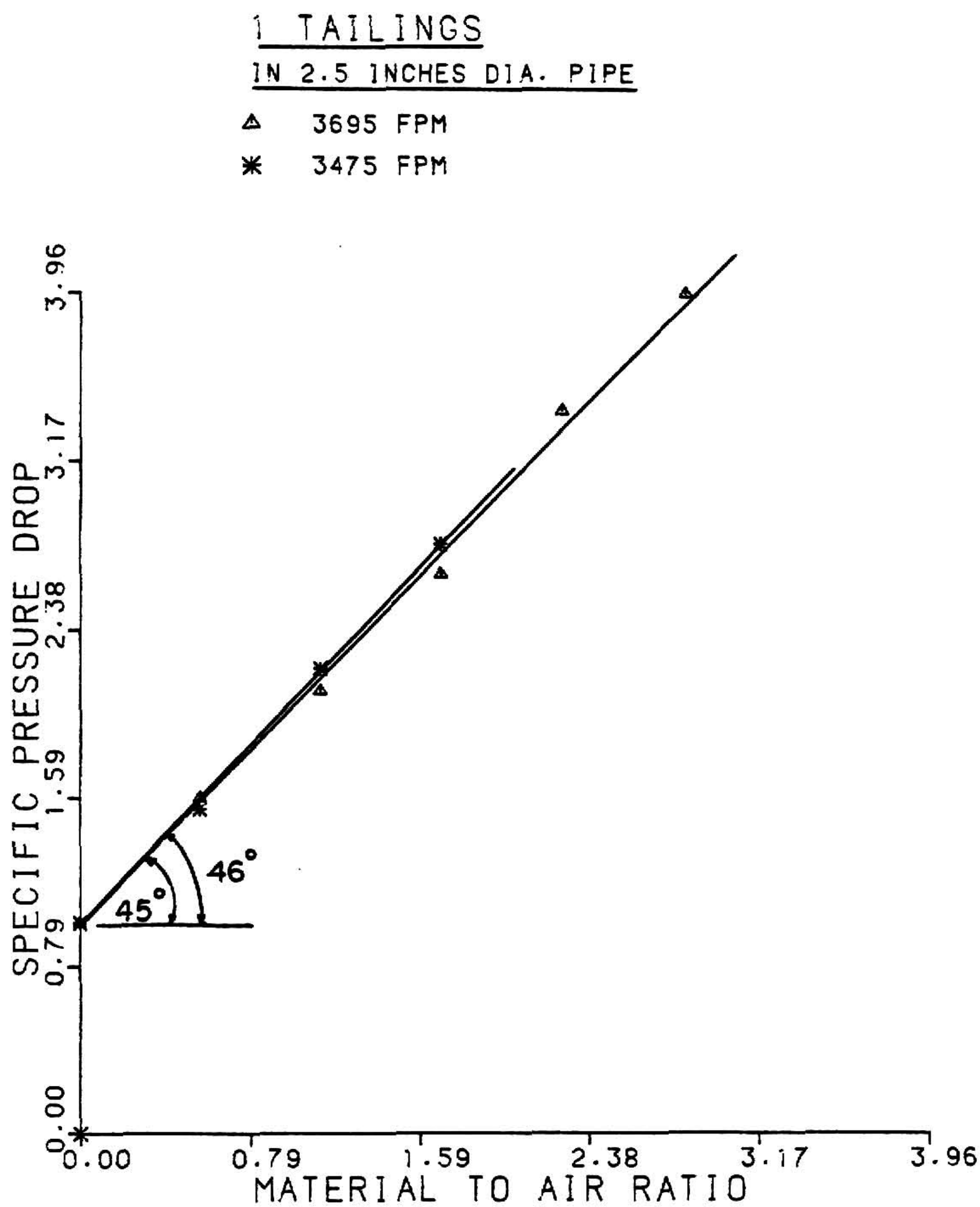
Material to air ratio	Static Pressure in Inches Water							Volume of air CFM	Velocity of air FPM	Velocity pressure inches water	Average velocity FPM
	Tap #1	Tap #2	Tap #3	Tap #4	Tap #5	Tap #6	Tap #7				
Air only	0.35	1.10	1.63	4.40	5.05	7.60	8.20	116.70	3714	0.86	
0.56:1	0.45	1.55	2.25	6.25	7.50	9.50	10.10	116.50	3708	0.86	
1.12:1	0.50	1.75	2.88	8.05	9.60	11.60	12.40	116.30	3701	0.85	3695
1.68:1	0.45	2.10	4.00	10.05	11.90	14.00	15.10	116.20	3698	0.85	
2.25:1	0.55	2.40	5.16	12.55	15.40	17.00	17.50	115.80	3687	0.85	
2.83:1	0.55	2.60	6.13	14.80	17.40	19.60	20.10	115.10	3664	0.84	
Air only	0.25	1.00	1.50	4.10	4.70	6.90	7.50	109.26	3478	0.76	
0.56:1	0.35	1.40	2.00	5.80	6.80	8.85	9.15	109.38	3482	0.76	
1.12:1	0.35	1.55	3.50	7.70	9.40	11.10	11.40	109.03	3471	0.75	3475
1.68:1	0.40	2.00	4.44	10.15	11.70	13.15	13.55	108.92	3467	0.75	
2.25:1			Choked								
2.83:1			Choked								

Relative humidity = 71.1%
Temperature = 77°F
Viscocity of air = 12.39×10^{-6} lb/foot sec.
Density of air = 0.0723 lb/cu.ft.

TABLE 11a. Calculated Data for Conveying of 1 Tailing Stock

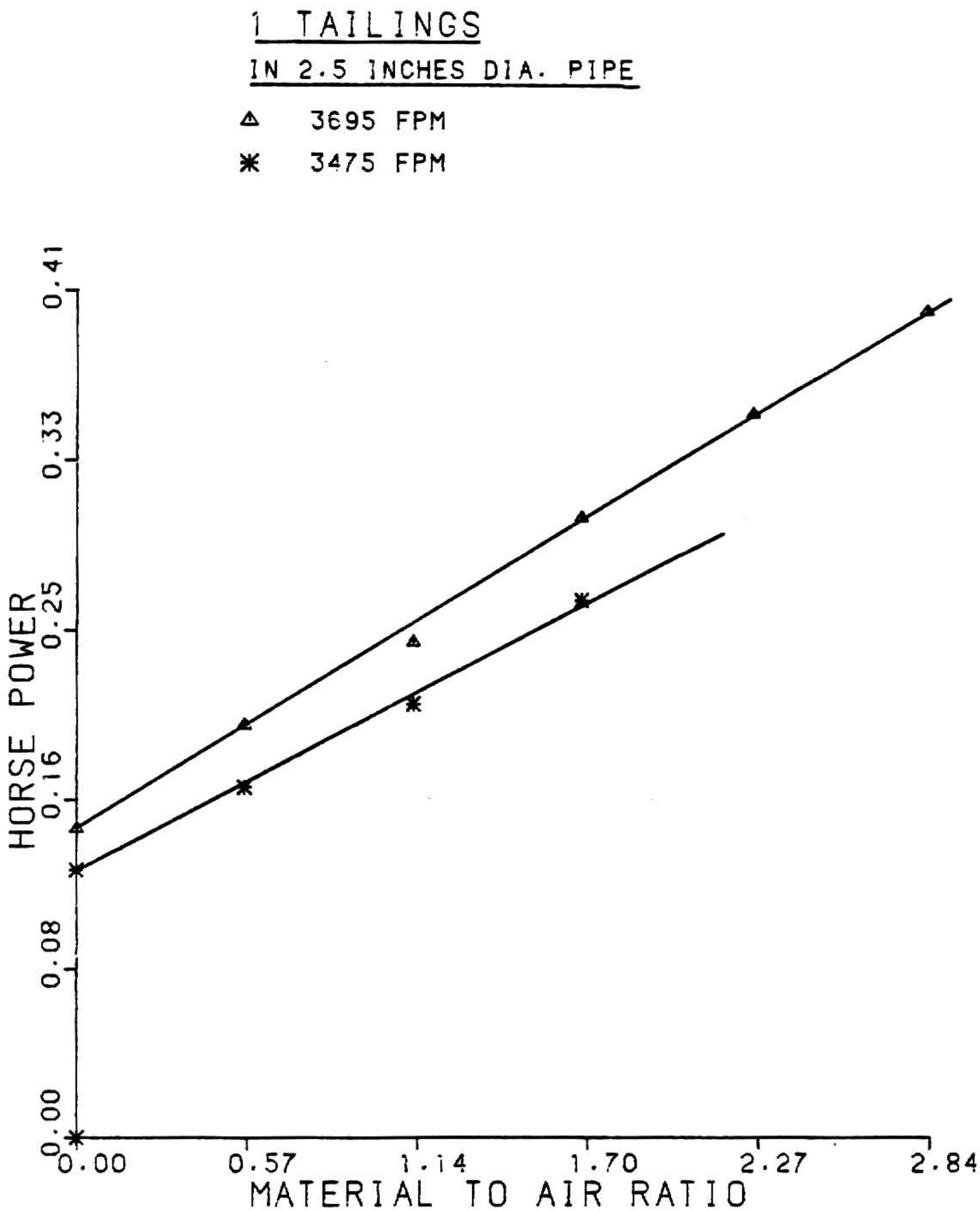
Feed Rate lb/min	Material to air ratio	Specific pressure drop	Horsepower	Mixture friction factor	Average velocity FPM
0.00	0.00:1	1.00	0.15	0.0235	
4.71	0.56:1	1.59	0.20	0.0350	
9.43	1.12:1	2.09	0.24	0.0450	3695
14.13	1.68:1	2.64	0.30	0.0559	
18.85	2.25:1	3.40	0.35	0.0727	
23.56	2.83:1	3.95	0.40	0.0832	
0.00	0.00:1	1.00	0.13	0.0249	
4.42	0.56:1	1.53	0.17	0.0360	3475
8.84	1.12:1	2.19	0.21	0.0500	
13.25	1.68:1	2.78	0.26	0.0625	

fig (8a)

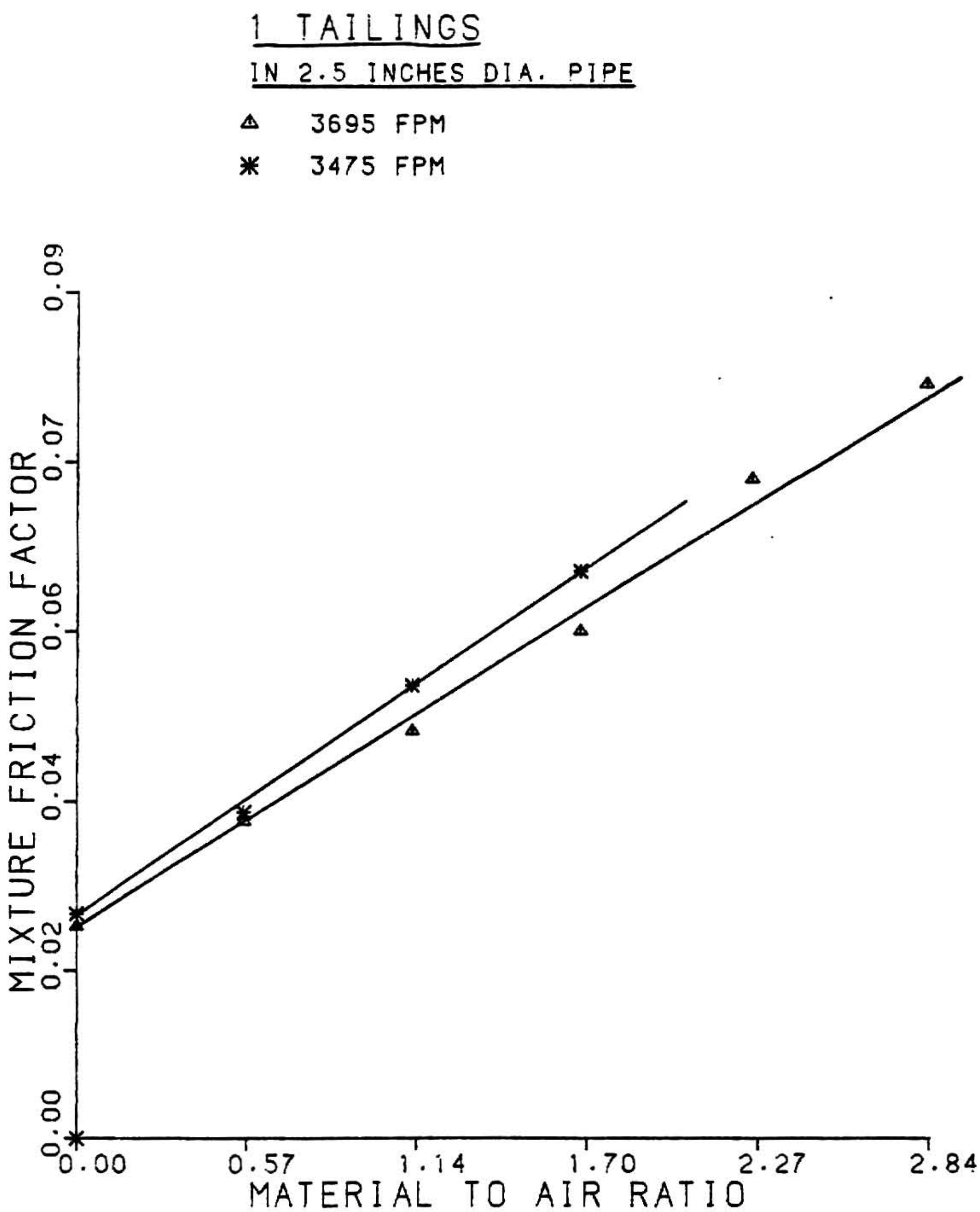


1 TAILINGS
IN 2.5 INCHES DIA. PIPE
3695 FPM
3475 FPM
SPECIFIC PRESSURE DROP
0.00
0.79
1.59
2.38
3.17
3.96
45°
46°
0.00
0.79
1.59
2.38
3.17
3.96
MATERIAL TO AIR RATIO

fig (8b)


1 TAILINGS
IN 2.5 INCHES DIA. PIPE
△ 3695 FPM
✱ 3475 FPM
HORSE POWER
0.00
0.08
0.16
0.25
0.33
0.41
0.00
0.57
1.14
1.70
2.27
2.84
MATERIAL TO AIR RATIO

fig(8c)


1 TAILINGS
IN 2.5 INCHES DIA. PIPE
3695 FPM
3475 FPM
MIXTURE FRICTION FACTOR
0.00
0.02
0.04
0.06
0.07
0.09
0.00
0.57
1.14
1.70
2.27
2.84
MATERIAL TO AIR RATIO

fig(8d)

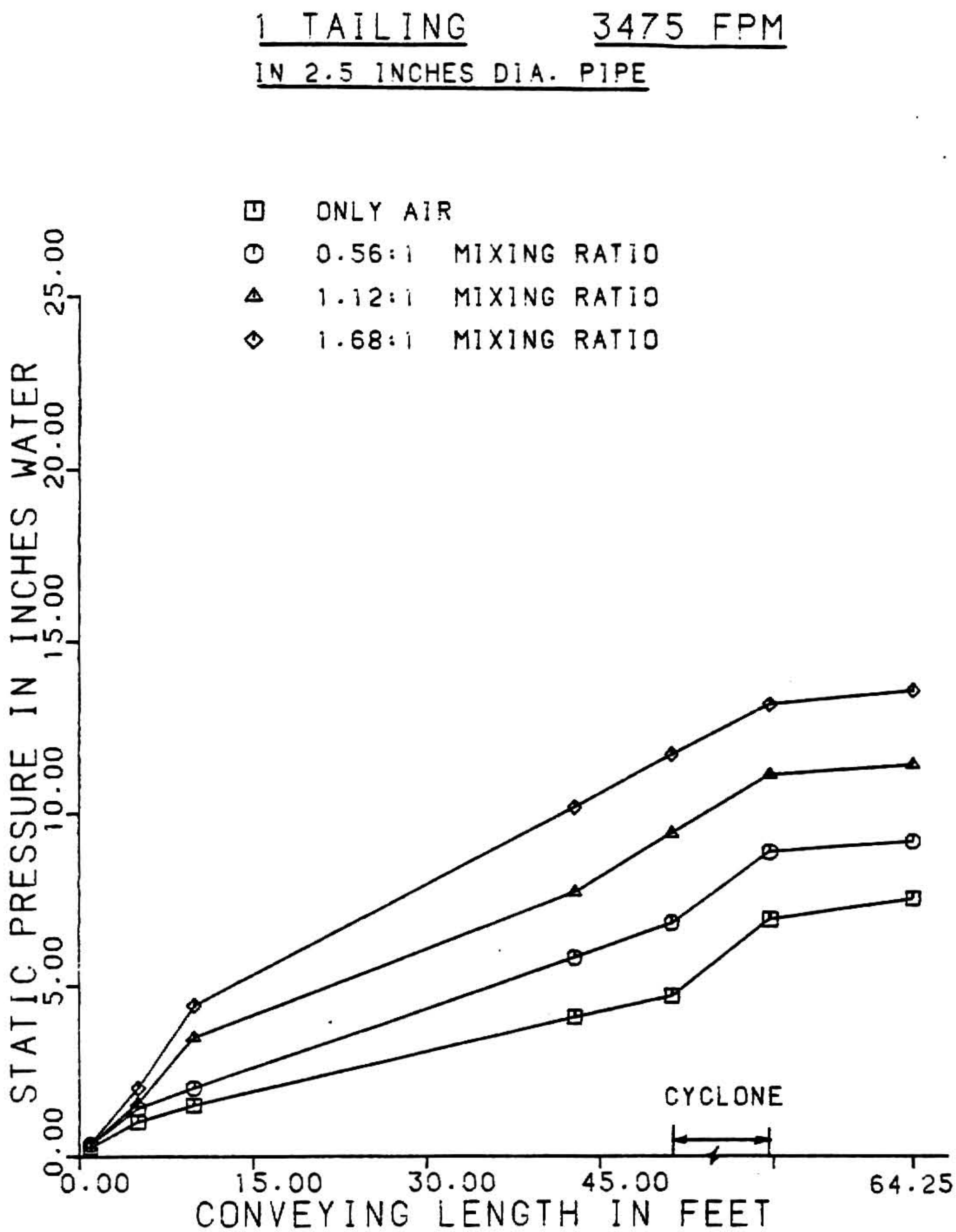

1 TAILING 3475 FPM
IN 2.5 INCHES DIA. PIPE
ONLY AIR
0.56:1 MIXING RATIO
1.12:1 MIXING RATIO
1.68:1 MIXING RATIO
STATIC PRESSURE IN INCHES WATER
0.00
5.00
10.00
15.00
20.00
25.00
CYCLONE
0.00
15.00
30.00
45.00
64.25
CONVEYING LENGTH IN FEET

fig (8e)

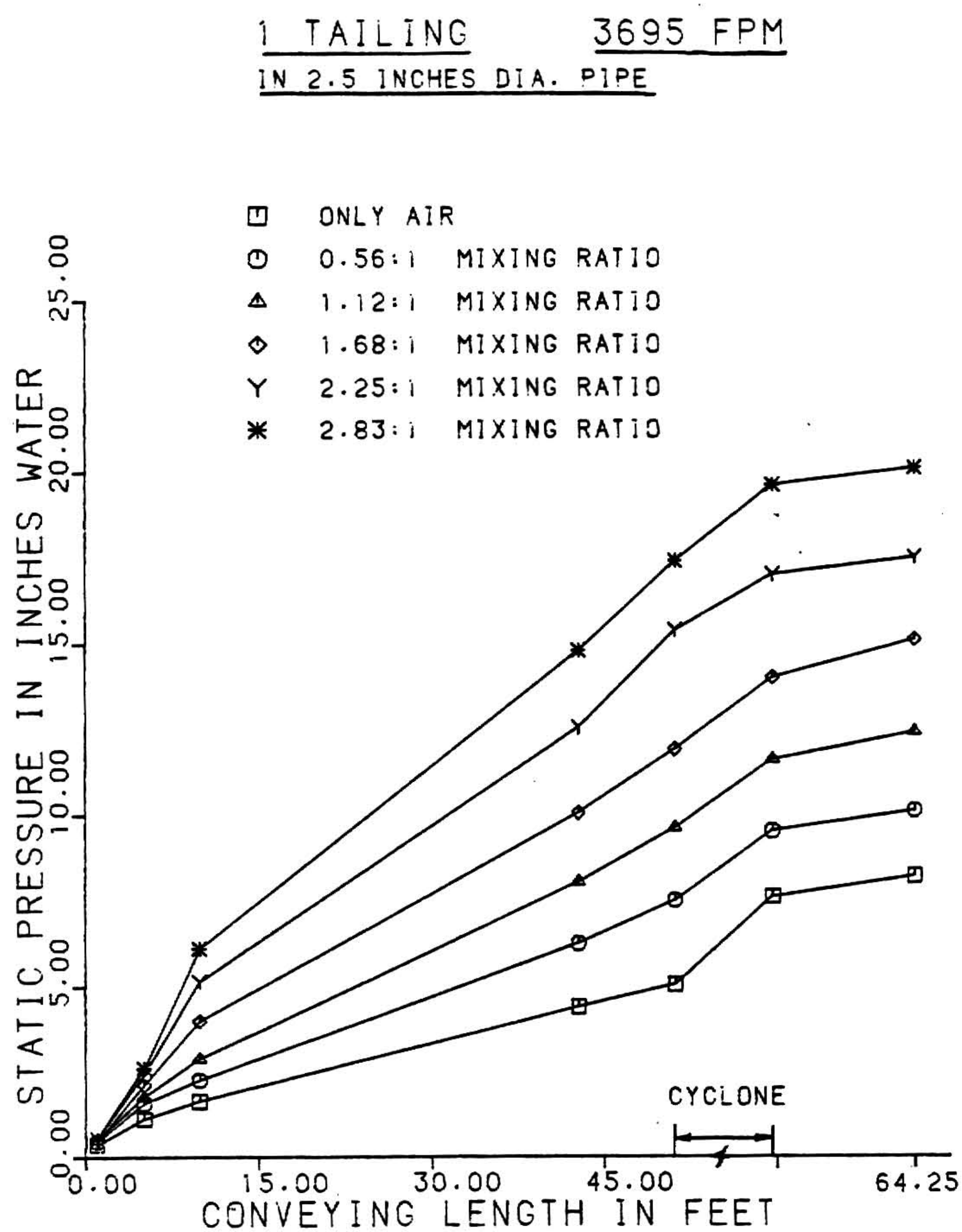

1 TAILING 3695 FPM
IN 2.5 INCHES DIA. PIPE
ONLY AIR
0.56:1 MIXING RATIO
1.12:1 MIXING RATIO
1.68:1 MIXING RATIO
2.25:1 MIXING RATIO
2.83:1 MIXING RATIO
STATIC PRESSURE IN INCHES WATER
0.00
5.00
10.00
15.00
20.00
25.00
CYCLONE
0.00
15.00
30.00
45.00
64.25
CONVEYING LENGTH IN FEET

TABLE 12. Data for Conveying of Flour

Material to air ratio	Static Pressure in Inches Water							Volume of air CFM	Velocity of air FPM	Velocity pressure inches water	Average velocity FPM
	Tap #1	Tap #2	Tap #3	Tap #4	Tap #5	Tap #6	Tap #7				
Air only	0.28	1.25	1.81	4.05	5.00	7.75	8.30	116.83	3719	0.86	
1.12:1	0.65	2.25	2.69	7.40	9.10	11.55	12.00	116.32	3703	0.86	
1.69:1	0.80	2.58	3.50	9.28	11.40	13.60	14.00	116.03	3693	0.85	3696
2.25:1	0.85	2.63	4.75	11.30	13.75	15.85	16.30	115.77	3685	0.85	
2.81:1	0.80	2.80	5.75	13.70	16.00	17.65	18.50	115.57	3679	0.84	
Air only	0.30	1.50	1.78	4.03	4.73	7.30	7.90	113.36	3608	0.81	
1.10:1	0.60	2.30	2.69	6.80	8.65	10.50	10.85	109.40	3476	0.75	
1.67:1	0.60	2.30	4.07	8.80	10.68	12.95	13.25	110.78	3540	0.78	3512
2.24:1	0.70	2.90	4.81	10.85	12.85	14.70	14.70	109.46	3484	0.76	
2.80:1	0.75	3.50	5.56	13.15	14.55	16.95	17.50	108.40	3451	0.74	

Relative humidity = 64%
Temperature = $78^{o}F$
Viscocity of air = 12.41×10^{-6} lb/foot sec.
Density of air = 0.0723 lb/cu.ft.

TABLE 12a. Calculated Data for Conveying of Flour

Feed rate lb/min	Material to air ratio	Specific pressure drop	Horsepower	Mixture friction factor	Average velocity FPM
0.00	0.00:1	1.00	0.15	0.0232	
9.43	1.12:1	2.00	0.23	0.0426	
14.14	1.69:1	2.56	0.28	0.0537	3696
18.86	2.25:1	3.13	0.33	0.0650	
23.57	2.81:1	3.68	0.38	0.0759	
0.00	0.00:1	1.00	0.14	0.0233	
8.80	1.10:1	2.03	0.20	0.0460	
13.20	1.67:1	2.55	0.25	0.0547	3512
17.60	2.24:1	3.10	0.28	0.0680	
22.0	2.80:1	3.56	0.34	0.0784	

fig (9a)

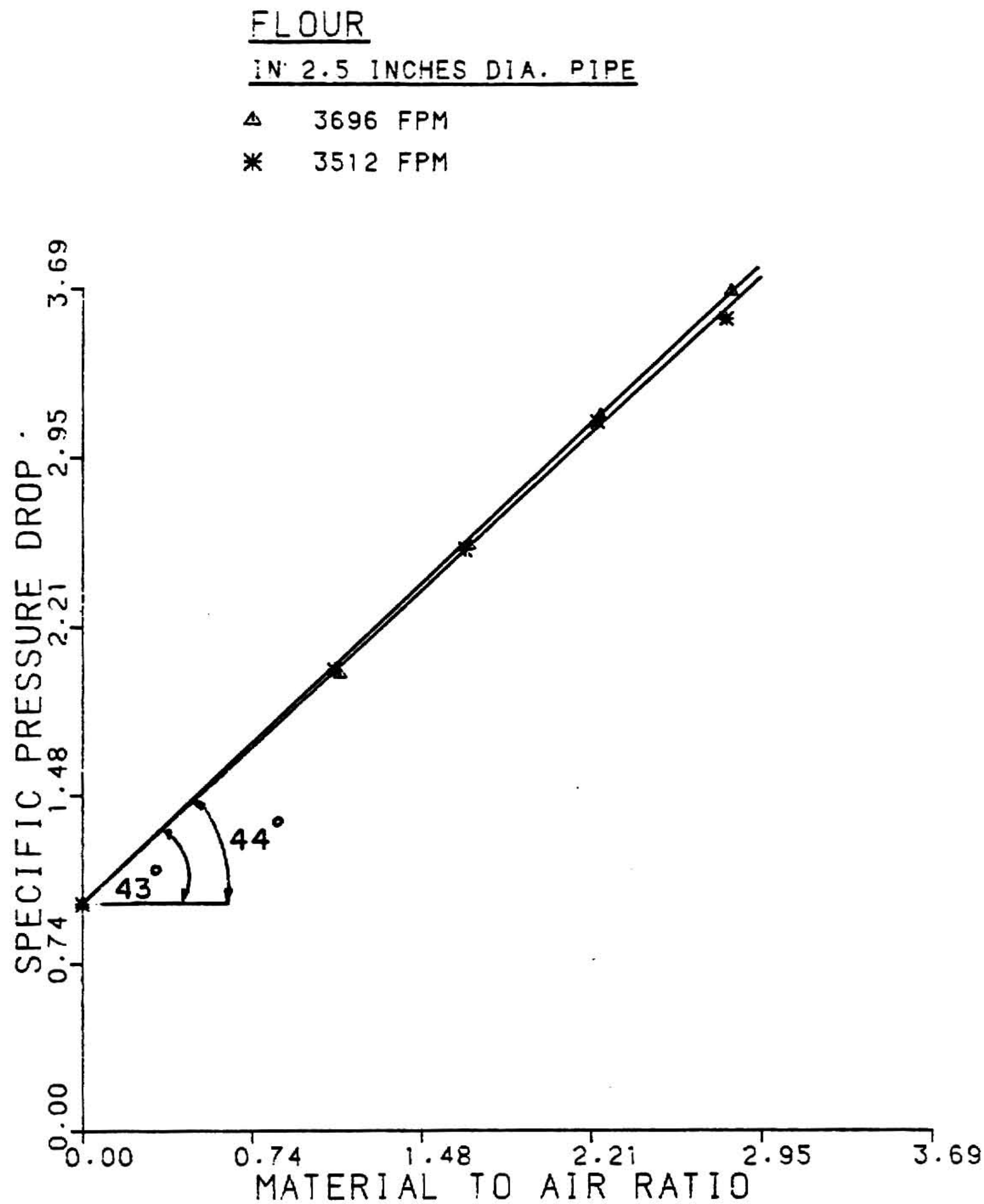
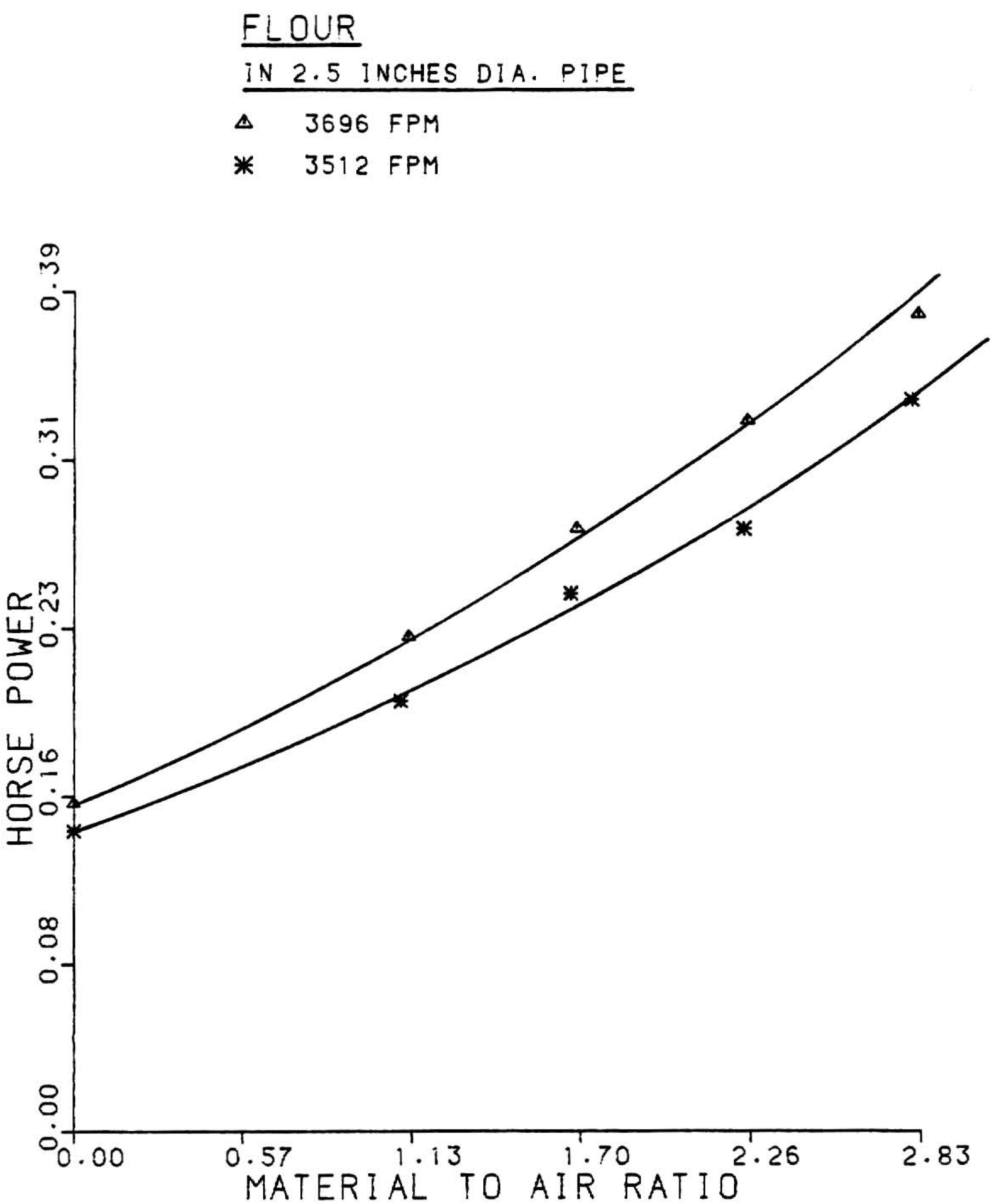
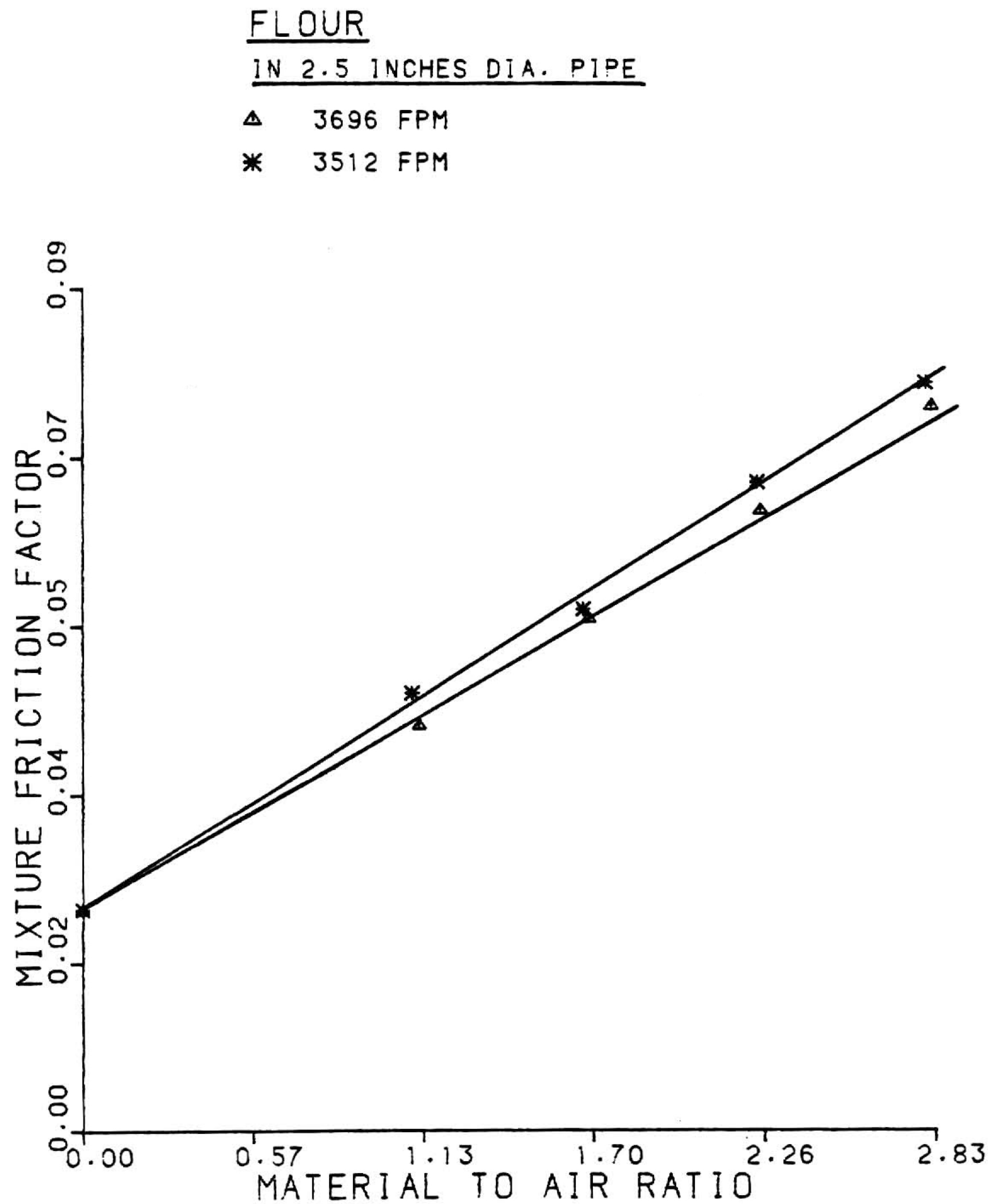

FLOUR
IN 2.5 INCHES DIA. PIPE
△ 3696 FPM
✱ 3512 FPM
SPECIFIC PRESSURE DROP
0.00
0.74
1.48
2.21
2.95
3.69
43°
44°
0.00
0.74
1.48
2.21
2.95
3.69
MATERIAL TO AIR RATIO

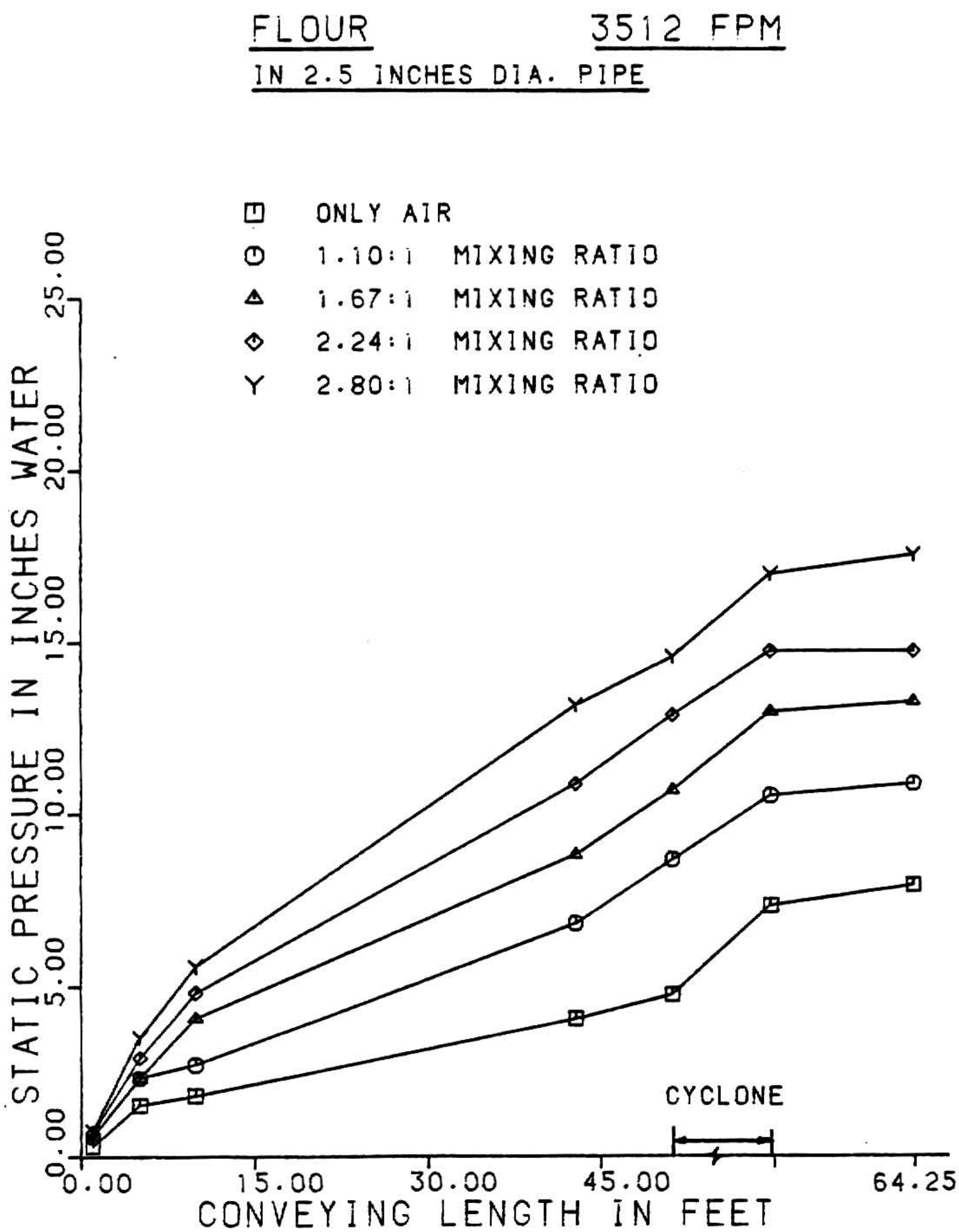
fig (9b)


FLOUR
IN 2.5 INCHES DIA. PIPE
△ 3696 FPM
✱ 3512 FPM
HORSE POWER
0.00
0.08
0.16
0.23
0.31
0.39
0.00
0.57
1.13
1.70
2.26
2.83
MATERIAL TO AIR RATIO

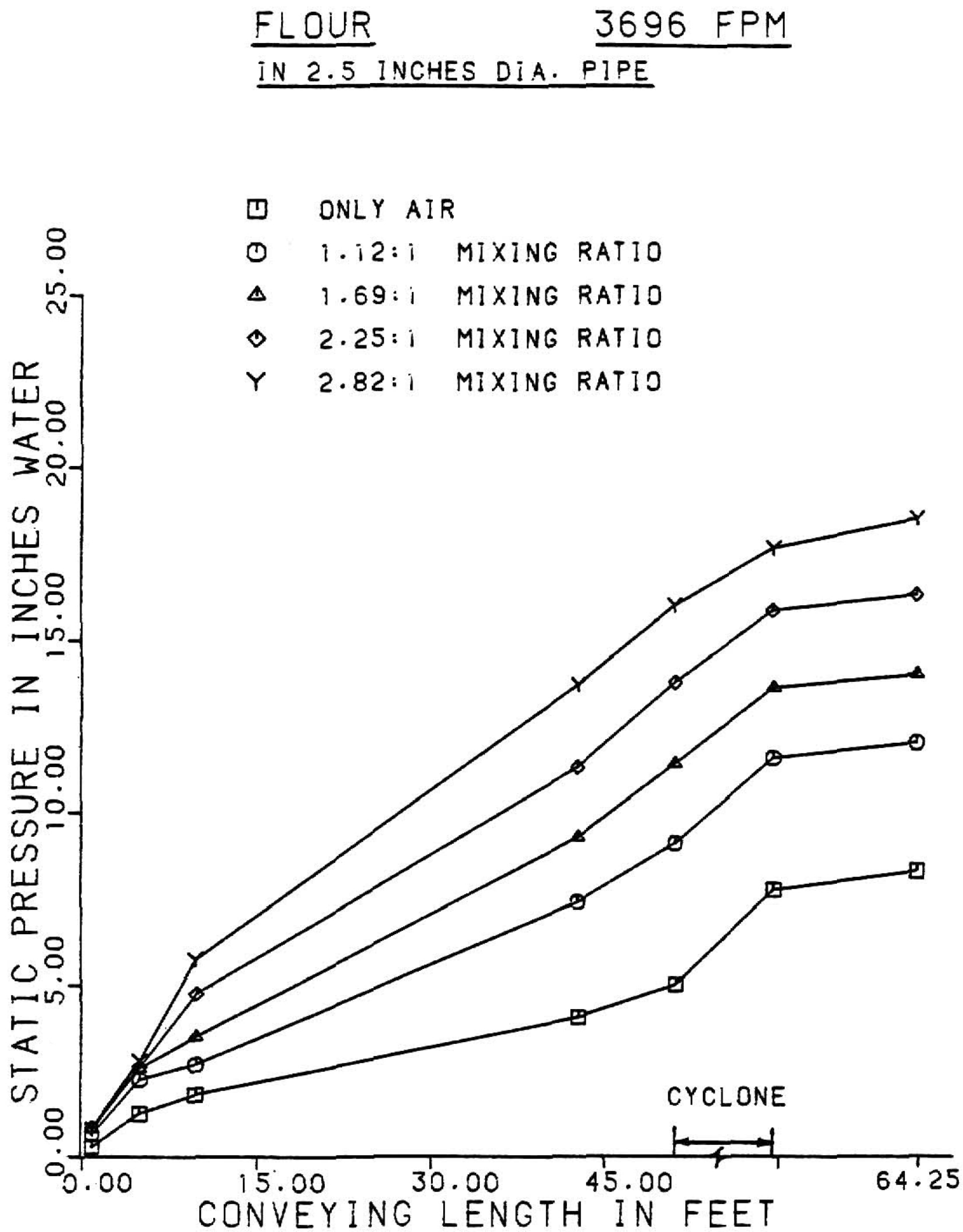
fig(9c)


FLOUR
IN 2.5 INCHES DIA. PIPE
△ 3696 FPM
✱ 3512 FPM
MIXTURE FRICTION FACTOR
0.00
0.02
0.04
0.05
0.07
0.09
0.00
0.57
1.13
1.70
2.26
2.83
MATERIAL TO AIR RATIO

fig(9d)


FLOUR 3512 FPM
IN 2.5 INCHES DIA. PIPE
ONLY AIR
1.10:1 MIXING RATIO
1.67:1 MIXING RATIO
2.24:1 MIXING RATIO
2.80:1 MIXING RATIO
STATIC PRESSURE IN INCHES WATER
0.00
5.00
10.00
15.00
20.00
25.00
CYCLONE
0.00
15.00
30.00
45.00
64.25
CONVEYING LENGTH IN FEET

fig(9e)


FLOUR 3696 FPM
IN 2.5 INCHES DIA. PIPE
ONLY AIR
1.12:1 MIXING RATIO
1.69:1 MIXING RATIO
2.25:1 MIXING RATIO
2.82:1 MIXING RATIO
STATIC PRESSURE IN INCHES WATER
0.00
5.00
10.00
15.00
20.00
25.00
CYCLONE
0.00
15.00
30.00
45.00
64.25
CONVEYING LENGTH IN FEET

published by Karlsruhe Technical high school on fine materials and as referred to by Barth (5a). Horsepower requirements were higher at 3696 FPM air velocity than at 3512 FPM (Fig. 9b and Table 12a). Mixture friction factors were smaller at 3696 FPM and larger at 3512 FPM (Fig. 9c and Table 12a).

Static pressure drop along the conveying distance was high at higher velocity and follow the same trend observed in earlier stocks. Rate of increase in static pressure drops was approximately the same at both conveying velocities for all the material to air ratios considered (Fig. 9d, 9e and Table 12).

BRAN

Tests were conducted at average conveying air velocities of 3224 FPM and 3032 FPM, respectively. The system was loaded up to 2.3:1 material to air ratio at 3225 FPM air velocity and only up to 2.1:1 material to air ratio at 3032 FPM. Difficulties were encountered in maintaining the feed rate. The air lock used couldn't handle heavier loads due to low bulk density and high volume of stock.

Linear relationship was observed between material to air ratio and specific pressure drop at both conveying air velocities (Fig. 10a and Table 13a). As in the case of first break stock, specific pressure drops were higher at high conveying air velocity. This may be due to the large particle size (Bran - 1439μ, IBK-1194μ) and resultant large surface area which increased the drag on the particle. This drag should be increasing with increase in air velocity causing higher pressure drops.

As observed in other cases, the horsepower required was more at high velocity (Fig. 10b and Table 13b). Mixture friction factors were smaller at 3032 FPM than at 3032 FPM (Fig. 10c and Table 13b). The drop in static

TABLE 13. Data for Conveying of Bran

Material to air ratio	Static Pressure in Inches Water Tap #1	Tap #2	Tap #3	Tap #4	Tap #5	Tap #6	Tap #7	Volume of air CFM	Velocity of air FPM	Velocity pressure inches water	Average velocity FPM
Air only	0.33	1.18	1.28	3.28	3.90	5.80	6.25	101.86	3242	0.66	
1.15:1	0.65	1.80	2.28	6.00	7.30	8.55	9.05	101.27	3223	0.65	3225
1.72:1	0.75	1.93	2.63	7.25	8.80	10.30	10.60	101.11	3218	0.65	
2.30:1	0.68	2.10	3.56	8.95	10.65	12.00	12.58	101.00	3215	0.64	
Air only	0.33	1.05	1.25	3.05	3.55	4.75	5.60	95.83	3050	0.58	
1.05:1	0.50	1.55	2.00	5.80	6.40	7.40	7.90	94.97	3033	0.57	
1.57:1	0.58	1.60	2.44	6.40	7.60	8.90	9.30	94.92	3021	0.57	3032
2.10:1	0.50	1.78	3.00	7.78	9.05	10.60	11.00	95.02	3025	0.57	

Relative humidity = 62%
Temperature = $83^{o}F$
Viscocity of air = 12.50×10^{-6} lb/foot sec
Density of air = 0.0710 lb/cu.ft.

TABLE 13a. Calculated Data for Conveying of Bran

Feed Rate lb/min	Material to air ratio	Specific pressure drop	Horsepower	Mixture friction factor	Average velocity FPM
0.00	0.00:1	1.00	0.10	0.0243	
8.25	1.15:1	2.05	0.15	0.0460	
12.38	1.72:1	2.51	0.19	0.0556	3225
16.50	2.30:1	3.09	0.23	0.0674	
0.00	0.00:1	1.00	0.085	0.0250	
7.07	1.05:1	1.96	0.13	0.0455	
10.61	1.57:1	2.37	0.16	0.0545	3032
14.14	2.10:1	2.86	0.18	0.6470	

fig (10a)

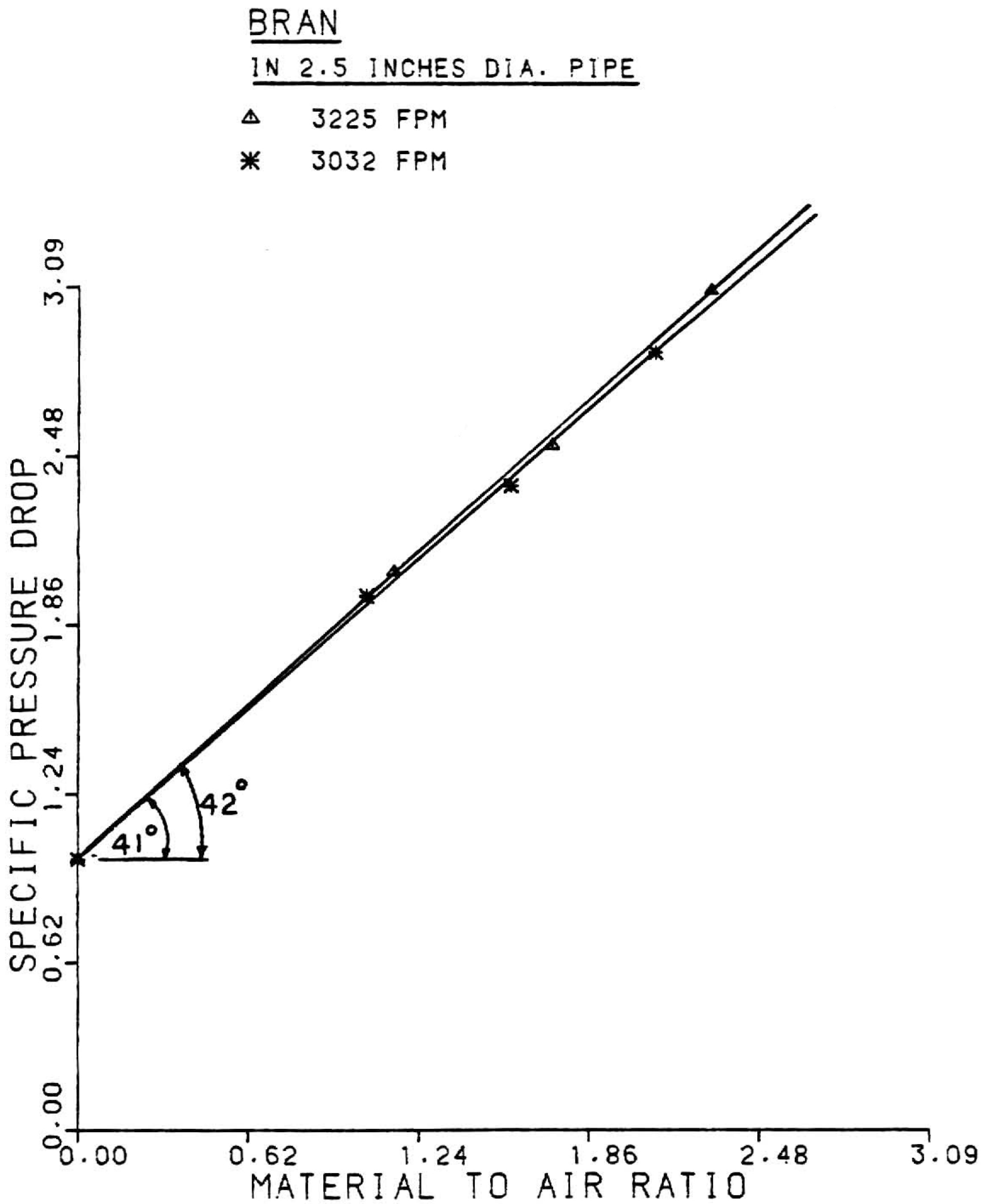
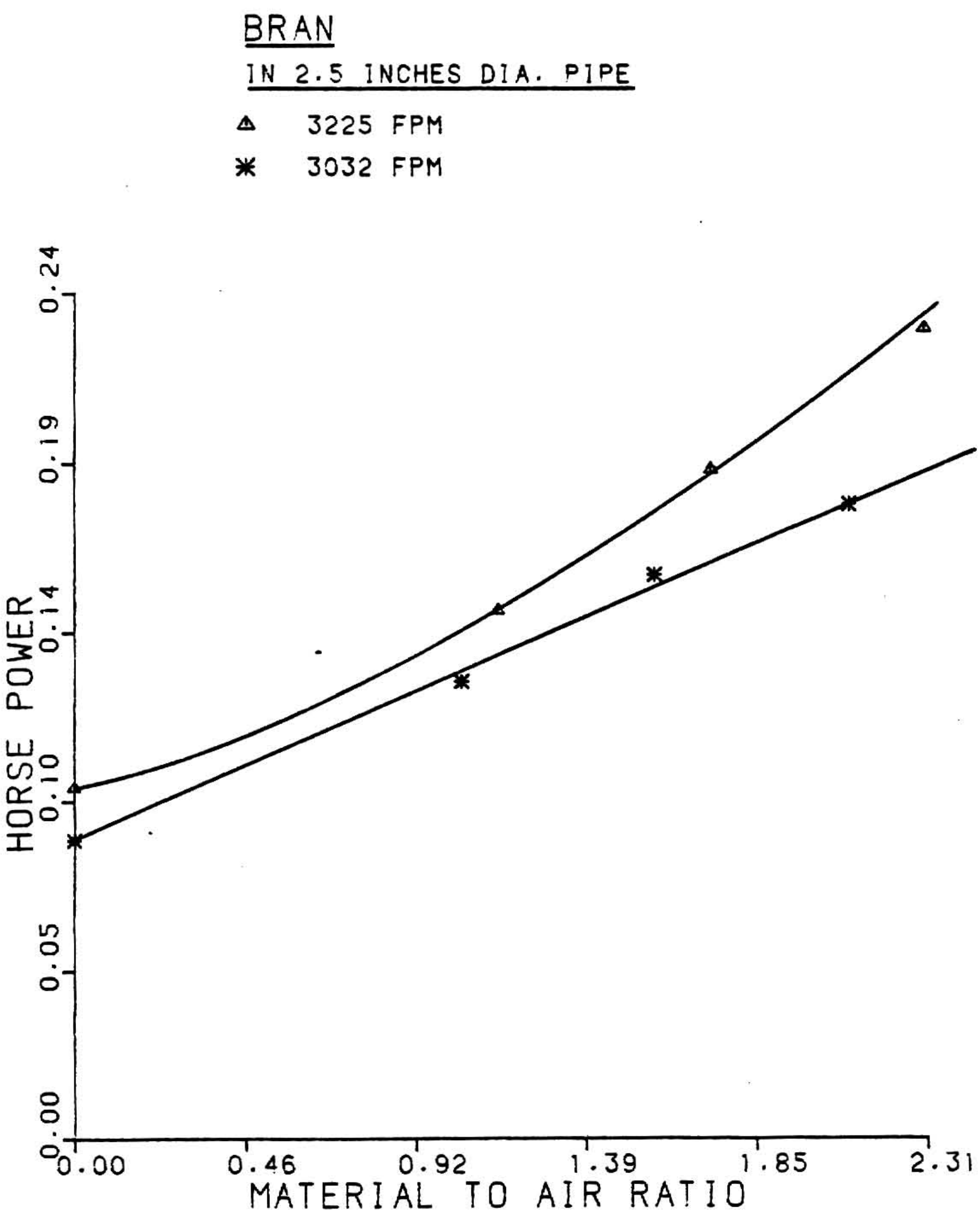

BRAN
IN 2.5 INCHES DIA. PIPE
△ 3225 FPM
✳ 3032 FPM
41°
42°
SPECIFIC PRESSURE DROP
0.00
0.62
1.24
1.86
2.48
3.09
MATERIAL TO AIR RATIO

fig (10b)


BRAN
IN 2.5 INCHES DIA. PIPE
△ 3225 FPM
✱ 3032 FPM
HORSE POWER
0.00
0.05
0.10
0.14
0.19
0.24
0.00
0.46
0.92
1.39
1.85
2.31
MATERIAL TO AIR RATIO

fig(10c)

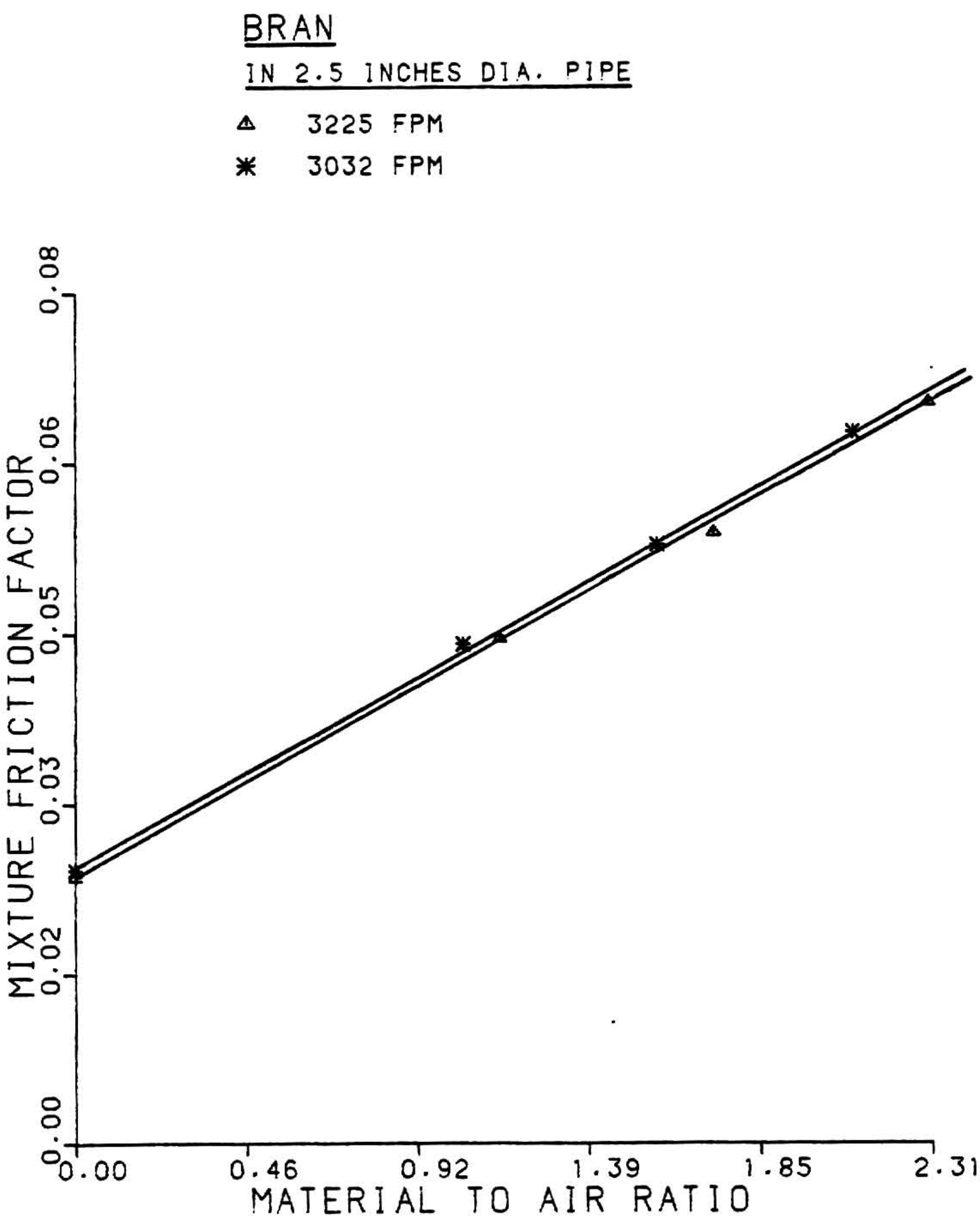

BRAN
IN 2.5 INCHES DIA. PIPE
3225 FPM
3032 FPM
MIXTURE FRICTION FACTOR
0.00
0.02
0.03
0.05
0.06
0.08
0.00
0.46
0.92
1.39
1.85
2.31
MATERIAL TO AIR RATIO

fig (10d)

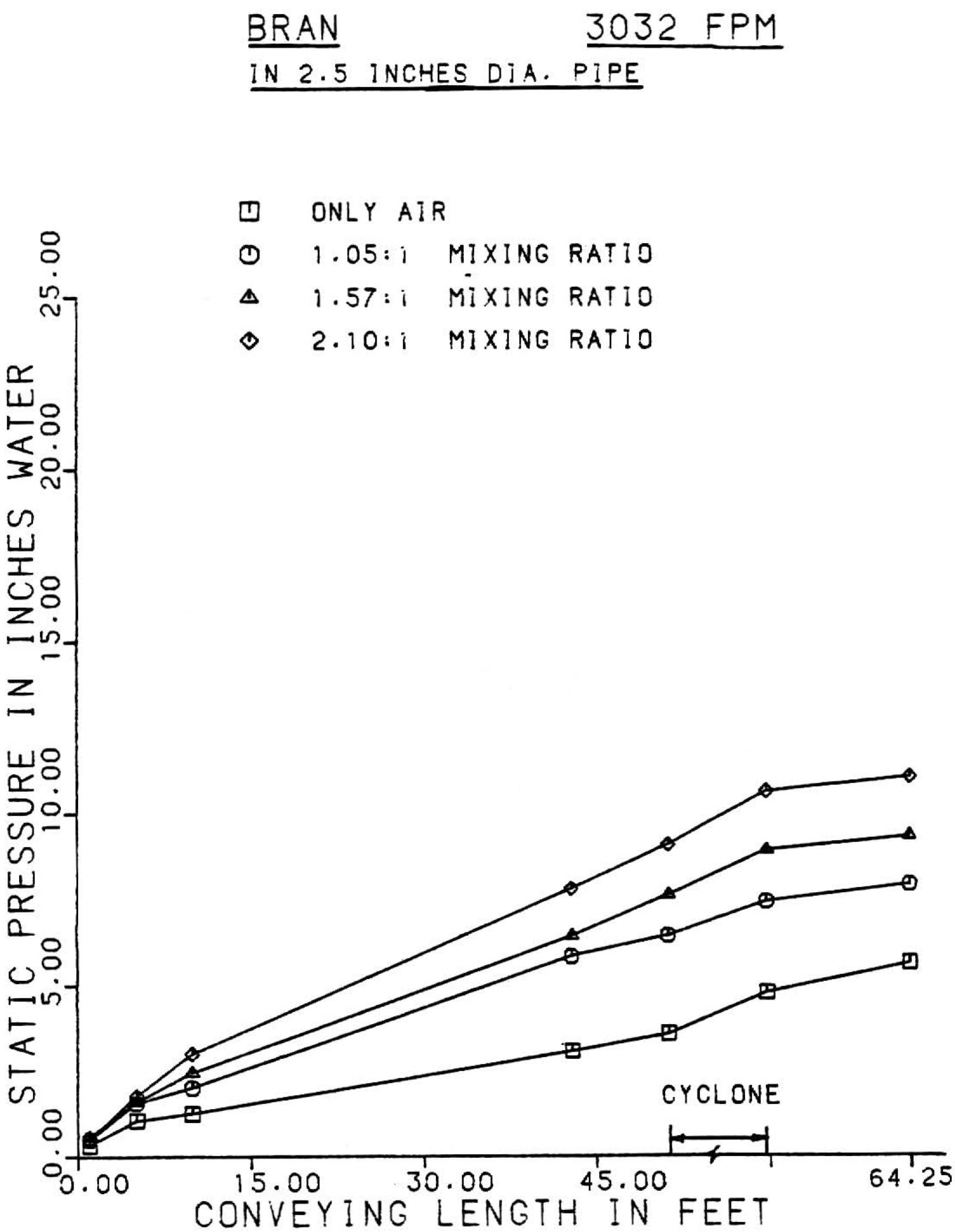
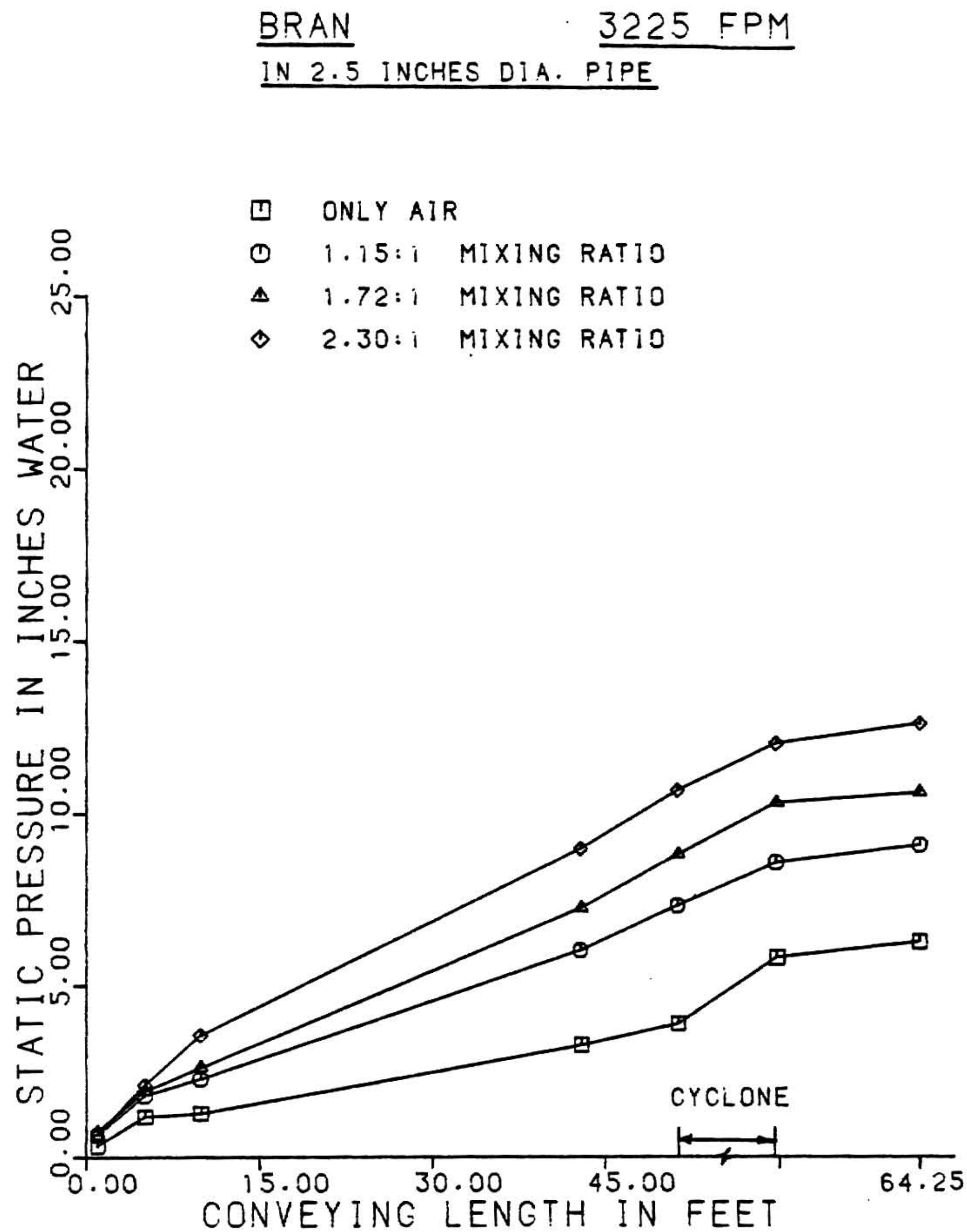

BRAN
3032 FPM
IN 2.5 INCHES DIA. PIPE
ONLY AIR
1.05:1 MIXING RATIO
1.57:1 MIXING RATIO
2.10:1 MIXING RATIO
STATIC PRESSURE IN INCHES WATER
0.00
5.00
10.00
15.00
20.00
25.00
CYCLONE
0.00
15.00
30.00
45.00
64.25
CONVEYING LENGTH IN FEET

fig (10e)


BRAN
3225 FPM
IN 2.5 INCHES DIA. PIPE
ONLY AIR
1.15:1 MIXING RATIO
1.72:1 MIXING RATIO
2.30:1 MIXING RATIO
STATIC PRESSURE IN INCHES WATER
0.00
5.00
10.00
15.00
20.00
25.00
CYCLONE
0.00
15.00
30.00
45.00
64.25
CONVEYING LENGTH IN FEET

pressure increased with increase in velocity of air and by the same amount for both conveying velocities at all material to air ratios tested (Fig. 10d, 10e, and Table 13).

CONCLUSIONS

Even with the very limited scope of the present investigation it is evident that specific pressure drops encountered while conveying milled stocks pneumatically were related linearly with material to air ratios of up to 3:1, which is the range ususally used in flour mill pneumatics. The conveying air velocities had great influence on this relationship. Conveying velocities were in turn dependent on bulk density, particle size and shape of the material conveyed. For conveying wheat, air velocities of 4200 FPM or higher seem to be practical, while for first break, air velocities of 3950 FPM or higher suffice. While conveying air velocity of 3500 FPM was enough to convey stocks like 6 Middling, 1 Tailing and flour, fourth break requires at least 3700 FPM air velocity to have trouble free operation at a respectable loading. For coarse sizing and 1 Middling, 4000 FPM seems to be a safe conveying air velocity. For bran, 3000 FPM air velocity is satisfactory.

A greater part of the horsepower required to convey material pneumatically was contributed by the air horsepower. While moving air consumed 75 to 80% of total horsepower only 20 to 25% was consumed for actually moving the stock. By carefully controlling the air quantities used, i.e. if the conveying air velocities were selected with restraint, keeping in mind safe, trouble free operation but at the same time not overdesigning the system, power consumption could be effectively controlled.

Mixture friction factors were smaller for conveying stocks at higher conveying air velocities than at lower air velocities.

Static pressure drop for conveying air alone increased with the distance conveyed, and increased corresponding to increases in conveying air velocity and increases in the amount of stock conveyed.

While conveying only air, the static pressure drops across elbows, and the vertical run of the lift and cyclone were linearly related to the velocity head. Static pressure drop at entrance was quadratically related to velocity head.

Terminal velocities of stocks were related to and influenced mainly by their bulk density, particle size and shape.

OBSERVATIONS MADE DURING RESEARCH

While the rotameter has proved to be convenient instrument for measuring air volumes, it has been found that a 3" rotamer requires approximately 20" water gauge pressure just to make it operational. This additional pressure drop has to be taken into consideration while designing the system and the blower has to be selected accordingly.

The blower used should have only appropriate capacity suitable for the experiments. Too big a blower, as used in the present investigations, caused unnecessary calculations to creep into the observations. Throttling of the blower to bring down the volume of air handled, generated heat which made the observations noted from the direct reading rotameter apparent as these observations have to be corrected for temperature and pressure. If the rotameter is standardized for the conditions which may prevail during experiments, the readings could be directly noted and would be more accurate.

The capacity of air lock and cyclone were not sufficient to handle at the high loadings, stocks such as fourth break and bran which have low bulk density and high volume.

The belt feeder used for these experiments was not able to feed the low bulk density materials like fourth break, bran and also first break stock with enough accuracy. A gravimetric feeder capable of giving repeatable feed rates by weight would have been more suitable.

Because of the long vertical fall the stock takes from the feeder on fourth floor to the pickup on second floor, it accelerates to a great speed and causes turbulence at the entrance of the pneumatic lift. It became necessary that a speed reducing arrangement be incorporated into the down grade pipe just before the pickup to make the entrance of stock into the lift smoother, and causing a lesser pressure drop.

SUGGESTIONS FOR FUTURE WORK

It is necessary to refine the experimental technique for any future experiments of this nature.

1. The design of the lift should accommodate the isolation of static pressure drop across the horizontal run, i.e. there should be enough horizontal run between the pickup and the first elbow to give steady flow in the horizontal run.
2. Horizontal length of the lift pipe should take care of initial acceleration of stock and the stock should be conveyed at equillibrium velocity before entering the elbow.
3. It is desirable to have facility to measure the dispersed bulk density of stock while being conveyed. Dispersed bulk density is more appropriate for use in the calculations.
4. Instrumentation to measure solids velocity if available would be excellent and would help in correlating the results obtained.
5. Selection of blower to suit the capacity required for the investigation is very important.
6. Rotameter for measuring air volumes should be standardized to suit the experimental conditions of temperature and pressure or vice versa for more convenience.
7. Experiments should be conducted using a whole range of lift pipe diameters ranging from 2 inches to 4.5 inches with at least ½" increments.
8. Experiments should be designed to use better range of conveying air velocities than the present investigation. Velocities should range from velocity lesser than the lower limit used in the present tests up to 4500 FPM. At least tests should be done at four different velocities having good spread between them.

9. Finally, it would be a better idea to build the experimental rig in a single floor incorporating all the enumerated features for reasons of ease and convenience to the researcher.
10. Care should be taken to eliminate the influence of atmospheric conditions on the air used in the experiments.

GLOSSARY OF TERMS

a - radius of particle in centimeters or feet

D - Internal diameter of pipe in centimeters or feet

Δl, L - equivalent length of the pipe line in centimeters or feet

g - acceleration due to gravity in cm/sec^2 or $feet/sec^2$

G - Mass flow rate of solids in kg/sec or lb/sec

P - Static pressure in the system in centimeters or inches water gauge

Q - Quantity of air in m^3/min or cubic feet/minute

fm or λm - mixture friction factor

K - conversion factor = 0.1921317

V - terminal velocity in cm/sec or feet/sec

Va - velocity of air in cm/sec or feet/sec

Vs - velocity of solids in cm/sec or feet/sec

ρs, σ - density of solid particle = Gm/cm^3 or lb/ft^3

ρ - density of fluid in Cm/cm^3 of lb/ft^3

ρa - density of air in Gm/cm^3 of lb/ft^3

ν - kinematic viscocity of fluid in CGS or FPS units

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VITA

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He is a member of the following professional organizations:

Association of Operative Millers, and

American Association of Cereal Chemists.

APPENDIX

METHOD OF CALCULATING FLOUR MILL PNEUMATICS USING SPECIFIC PRESSURE DROP APPROACH

Step-1 Maximum loads per minute coming to all streams are estimated - (Gs) lb/min.

Step-2 Conveying velocities for various stocks are determined - (Va) ft/sec (based on experience gained during the research).

Step-3 Suitable material to air ratios are then fixed - (μ).

Step-4 Air volumes are then calculated for each lift - (Q) cu. ft./min.

Air volume = $\frac{Gs}{\mu} \times \frac{1}{\int a}$ $\int a$ = Air density-lb/cu. ft.

Step-5 Pipe inner diameter is calculated from air volume - d inches.

$d = \sqrt{\frac{Q}{Va} \times \frac{4}{\pi}}$ Va is in feet per min.

Step-6 Slopes of static pressure drop vs. material to air ratio - Plots are measured for all materials. Angles are noted α

Step-7 For the present μ values, specific pressure drops H are calculated:

$H = 1 + \mu \tan \alpha$

Step-8 Reynold's number for flows in each lift are calculated:

Reynold's number - $Re = \frac{Va\ d \int a}{\propto a}$

Va = air velocity in ft/sec, d = diameter inner of pipe in ft.

$\int a$ = air density in lb/cu. ft., $\propto a$ = viscocity in lb/ft. sec.

Step-9 Using Moody's formula, pipe friction factor - (fa) are calculated:

$$fa = 0.0055 \left(1 + \left\{20000 \times \frac{\varepsilon}{d} + \frac{10^6}{Re}\right\}^{1/3}\right)$$

ε = roughness factor = 0.000005 for drawn pipes

Step-10 Equivalent length of lift pipe is calculated: (Horizontal length + vertical length + equivalent straight pipe length of elbows) - L in ft.

Step-11 Dynamic pressure of velocity head is calculated:

$$= \frac{Va^2 \rho a}{2g} \times 0.1921317 \text{ "}H_2O$$

where g = acceleration due to gravity, 32.1740 ft/sec^2

Step-12 Static pressure drop in the lift pipe up to cyclone is calculated using formula:

$$\text{Static pressure drop} = fa \times \frac{Va^2 \rho a}{2g} \times H \times \frac{L}{d} \times 0.1921317 \text{ "}H_2O$$

Step-13 Pressure drop across cyclone is added to this value to get the total static pressure across each lift.

The maximum static pressure drop calculated among these lifts together with the back pressure due to filter and the connecting ducts will determine the static pressure requirements of the blower. Air volume generated by the blower could be calculated by summing up the air volume requirements of all lifts. Usually when specifying the blower, 10 to 20% capacity is added for safety reasons.

CALCULATION OF FLOUR MILL PNEUMATICS

Capacity of mill ∿ 32.5 tons of wheat/24 hours
(480 cwt of flour/24 hours)

Air temperature = 70°F
Air density = 0.075 lb/cu ft.
Air viscocity = 12.16×10^{-6} lb/ft. sec.

Characteristics of the pneumatics	Pre. Bk.	1Bk	2Bk	3Bk	4Bk	5Bk	1,2,3 Bk red	Coar. siz.	Fine Siz.	1M	2M	3M	4M	5M	6M	1T	2Q	Flour	Suction	B.D. S.D.
Max. Expected Load-Gs in the Stream lb/min	45.0000	44.1000	31.8000	20.7000	11.0000	11.2000	9.8000	9.8000	12.9000	10.8000	12.6000	9.3000	5.6000	7.0000	4.1000	5.5000	1.7000	33.6000	0.8000	2.3000
Conveying velocity V ft/sec	75.0000	70.0000	70.0000	70.0000	61.7000	61.7000	61.7000	61.7000	61.7000	61.7000	61.7000	61.7000	61.7000	61.7000	61.7000	61.7000	61.7000	61.7000	61.7000	61.7000
Inner Dia. of Conveying Pipe - d Inches	2.9000	2.9000	2.9000	2.6500	2.4000	2.4000	2.4000	2.4000	2.4000	2.4000	2.4000	2.4000	1.9000	1.9000	1.9000	1.9000	1.9000	2.9000	1.9000	1.9000
Volume of air, Q cu. ft/min	206.4000	192.7000	192.7000	160.9000	116.2000	116.2000	116.2000	116.2000	116.2000	116.2000	116.2000	116.2000	72.9000	72.9000	72.9000	72.9000	72.9000	169.8000	72.9000	72.9000
Slope of sp. pr. drop plot-α-degrees	36.0000	41.0000	41.0000	41.0000	28.0000	28.0000	46.5000	46.5000	46.5000	45.0000	45.0000	45.0000	46.5000	46.5000	46.5000	45.0000	44.0000	44.0000	44.0000	42.0000
Material to air ratio μ	2.9100	3.0500	2.2000	1.7200	1.2600	1.2800	1.1300	1.1300	1.4800	1.2400	1.4500	1.0700	1.0300	1.2800	0.7600	1.0000	0.3000	2.6400	0.1500	0.4200
Specific pressure drop, H (1 + μ tan α)	3.1100	3.6500	2.9100	2.5000	1.6700	1.6800	2.1900	2.1900	2.5500	2.4500	2.4500	2.0700	2.0800	7.3500	1.8000	2.0000	1.2900	3.5500	1.1400	1.3700
Equivalent length of conveying pipe-ft. L	65.0000	65.0000	65.0000	65.0000	65.0000	65.0000	65.0000	65.0000	65.0000	65.0000	65.0000	65.0000	65.0000	65.0000	65.0000	65.0000	65.0000	65.0000	65.0000	65.0000
Dynamic pressure of velocity head - "H_2O	1.2600	1.1000	1.1000	1.1000	0.8500	0.8500	0.8500	0.8500	0.8500	0.8500	0.8500	0.8500	0.8500	0.8500	0.8500	0.8500	0.8500	0.8500	0.8500	0.8500
Pipe friction factor fa	0.0170	0.0173	0.0173	0.0177	0.0186	0.0186	0.0186	0.0186	0.0186	0.0186	0.0186	0.0186	0.0197	0.0197	0.0197	0.0197	0.0197	0.0178	0.0197	0.0197
Reynolds number Re	111791.0000	104338.0000	104338.0000	95343.0000	76110.0000	76110.0000	76110.0000	76110.0000	76110.0000	76110.0000	76110.0000	60254.0000	60254.0000	60254.0000	60254.0000	60254.0000	60254.0000	91967.0000	60254.0000	60654.0000
Estimated static pressure drop up to cyclone "H_2O	18.0900	18.6800	14.8900	14.3300	8.5800	8.6300	11.2500	11.2500	13.1000	11.500	12.5800	10.6400	14.3000	16.1500	12.3700	13.7500	8.8700	14.4500	7.8400	9.4100
Pressure drop across cyclone "H_2O	2.0000	2.0000	2.0000	2.0000	1.5000	1.5000	2.0000	2.0000	2.0000	1.7500	1.7500	1.7500	1.7500	2.0000	2.0000	2.0000	2.0000	2.2500	2.2500	1.5000
Total static pressure drop "H_2O	20.0900	20.6800	16.8900	16.3300	10.0800	10.1300	13.2500	13.2500	15.1000	11.2500	14.3300	12.3900	16.0500	18.1500	14.3700	15.7500	10.8700	16.6900	10.0900	10.9100

Maximum static pressure demand = 20.68" H_2O

Back pressure in system (filter and connecting ducts) = 3.32" H_2O

Static pressure requirement of the blower = 20.68 + 3.32 = 24" H_2O

Air volume used by the blower = 2162 cu. ft/min.

PNEUMATIC CONVEYING OF FLOUR MILL STOCKS

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ABSTRACT

Pneumatic conveying is a widely used method of transport for granular and pulvarized materials, in a great range of industries all over the world. There are a host of emperical formulas developed for use in chemical and other industries. Despite a great amount of research already done, a universal approach for the design of a pneumatic system is not yet developed, mainly due to unlimited variety of materials that could be conveyed, vary widely in their characteristics.

Information on pneumatic conveying of milled stocks of a flour mill is scarce and hard to get. The objective of this investigation is to generate information about pneumatic conveying of milled stocks and to observe any definite trends in the relationships between the variables of the experiments.

The following materials are used for the tests: tempered hard red winter wheat, bran and flour from Kansas State University pilot mill. First break, fourth break, coarse sizing, 1 Middling, 6th middling and 1 Tailing stocks, after they passed thru the grinding rolls, were collected from ADM milling company at Salina, Kansas. Experiments are conducted on the experimental lift built for this purpose using the negative pressure system.

While conveying only air, it is found that static pressure drop across the lift components like elbows, vertical run and cyclone is linearly related with velocity head. Terminal velocities of the test materials are related to and influenced by bulk density and particle size and shape.

The experimental data, when analyzed indicates that for all materials except coarse sizing and 1 Middling, at the conveying air velocities considered specific pressure drop is linearly related to material to air ratio. Specific pressure drops decrease with increase in conveying velocity for

all test materials except first break, bran and flour for first break, flour and bran specific pressure drops increased with increase in conveying air velocities. More horsepower is needed at higher conveying air velocities. Mixture friction factors are smaller at higher conveying air velocities than at lower air velocities.