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DEVELOPMENT OF PNEUMATIC ASSISTED FERTILIZER APPLICATOR

by

(C) RAKESH KUMAR AERON

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

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FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled "Development of Pneumatic Assisted Fertilizer Applicator" submitted by Rakesh Kumar Aeron in partial fulfillment of the requirements for the degree of Master of Science.

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ABSTRACT

The objective of the thesis was to investigate the feasibility of using penumatic power for the application of fertilizer to the soil and to suggest a design procedure for a pneumatic assisted fertilizer applicator. The design of such an applicator has been based upon the anhydrous ammonia applicator. To achieve the objective, two possible alternatives namely, medium-air pressure, and low-pressure high volume systems were investigated. Both of these systems require pneumatic conveying of fertilizers and the art of conveying lies in an intimacy with which rheological properties of the fertilizer under consideration are known. Therefore the rheological properties of ammonium sulphate and urea, specifically density, particle size, and angle of repose were established. The medium-air pressure system did not prove to be successful due to technical difficulties encountered in integrating with the available equipment for fertilizer application.

The information required for the low pressure-high volume conveying system was obtained from actual tests performed on the ammonium sulphate and urea in an experimental air-duct. The air duct designed for the development of a pneumatic assisted fertilizer applicator was considered as a hydraulic model, and the procedure for acquisition of design data was based on an energy analysis that accounts for all energy losses that may exist in the proposed system. The air-duct was set-up to find the optimum air velocity that will carry a certain amount of fertilizer without causing blockage. Velocity profiles were observed at various air volumes and fertilizer throughputs, and compared against the basic velocity profile of air in the duct. Based on this comparison, values for velocity, pressure, and pipe size can be calculated as per

recommended design procedures based on similitude studies.

For multiple point distribution of the fertilizer from the central conveying duct, the feasibility of using concentric mitre bends was also investigated. Due to non-homogeneous dispersion of fertilizer particles in the conveying duct these bends gave irregular distribution.

The design suggested offers a possibility of pneumatic assisted fertilizer application to the soil. However, before a prototype could be attempted detailed investigations are needed for a number of mechanical components.

ACKNOWLEDGEMENTS

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CHAPTER 1

INTRODUCTION

The proper use of commercial fertilizer is of vital importance to present and future farmers of the world. The use of commercial fertilizers is the most important means yet known to man or science that will provide an abundance of economically produced food for feeding an ever increasing population and at the same time maintain the fertility level of soils.

1.1 The Problem

The conventional grain drill which is designed to place fertilizer with the seed is not satisfactory when high rates of fertilizers are used. These drills at present utilize the principle of gravity flow. The inherent disadvantage of this system, however, is the frequent stoppage of fertilizer flow in the conveying tubes; and in addition, places fertilizer in contact with seed causing problems associated with germination and seedling injury.

The broadcasting of fertilizers has always presented a problem regarding uniformity of application. Most spreaders available on the market to-day do not spread the fertilizer uniformly. The uniformity of distribution varies with the design and mechanical refinement of the distributor and with the flowability of the fertilizer. Cyclical impulses of metering systems are the principal cause of irregular distribution of fe ili r.

Most of e p es nt day equipment, while doing al at slow travel rates, is of f nd to be unsatisfactory with modern tractor field speeds. This does not necessarily mean that speed of travel is to be a governing condition. However, sound economics together with modern farm management calls for equipment that is balanced as far as possible with modern tractors.

1.2 The Objective

The objective of this thesis was to develop suitable mechanical equipment designed to place precise amounts of fertilizer a definite distance from the seed; thus optimizing the availability of nutrients to plants.

To fulfill the above objective, a study was conducted to investigate the feasibility of using pneumatic power in the application of fertilizer to soil. In theory, the method offers a possibility of fertilizer application in the field with increased efficiency and less labour.

1.3 Methodology

The investigations for developing a pneumatic assisted fertilizer applicator were carried out in two phases:

1. Pneumatic conveying of fertilizer.
2. Use of pneumatic power for fertilizer application to the soil.

In this thesis, the first phase was investigated extensively and background data was collected for the design of pneumatic fertilizer applicators. The study was conducted:

1. To establish the air delivery of the experimental set-up.
2. To standardize the basic velocity profile in the experimental duct.

3. To study the drop in air velocity after fluidization of fertilizer particles, in the air stream.
4. To establish rheological properties of fertilizers used.

1.4 Results

The results of these tests were correlated with Reynolds number. The Reynolds number is defined as the ratio of inertial to viscous forces. In flows which are limited by rigid flow boundaries, the Reynolds number provides dynamic similitude between prototype and model. Expressing the results with Reynolds number describes the experiment in its entirety and based on this, a design appraoch for air requirements of the pneumatic fertilizer applicator prototype has been suggested.

CHAPTER 2

LITERATURE REVIEW

A review of literature has been done under the following headings:-

2.1 The need for fertilizer placement machinery.

2.2 Application of pneumatics in agriculture.

2.3 Pneumatic conveying.

2.4 Model study.

2.1 The Need for Fertilizer Placement Machinery

McVickar (1963) reviewing the early history of fertilizers reported that in 1842, Sir John Lawes, an Englishman, developed and patented the process for making superphosphate. This was the beginning of the chemical fertilizer industry in the world. McVickar further wrote, "the fertilizer industry represents the most important advance ever made towards providing plenty of food for the people of the earth". Since the introduction of fertilizer to agriculture, the goal has been to design a machine which will distribute fertilizer evenly on the ground. Mehring and Cummings (1930) reported that the first machine for broadcasting fertilizer was offered to the public in 1848. At present many different types of distributors are in use, and most seeders and planters, as well as several makes of cultivators and transporting machines, may be purchased equipped with fertilizer attachments. How fertilizer is applied to the crop is just as important as using the proper analysis or correct amount. Smith (1948) emphasizing the need for localized placement of fertilizer quoted the following statement, which was adopted by the National Joint Committee on Fertilizer Application in 1947:

> *"Contact of fertilizer with the seed, except when fertilizer is used in very small amounts, tends to depress and delay germination and may even prevent it. The recommended fertilizer placement is 2 to 3 inches to the side of the row and 3 to 4 inches below the soil surface".*

McVickar (1963) lists three reasons for localized placement:

1. Restricted contact of fertilizer with soil lessens fixation of phosphorus and potash.

2. The plant food is placed within easy reach of the roots; thus the possibility of injurious concentration is minimized if placement is accurately controlled, and in the case of light applications, the effect of fertilizers are not diluted by mixing with a large volume of soil.

3. Fertilizer placed in bands along the row does not furnish nutrients to weeds growing between the rows.

Several research workers Prummel (1957), Lawton and Davis (1960), Hulburt et al (1962), Sherrell et al (1964), and Westselaar et al (1972) emphasized the need for correct placement with respect to various crop and soil conditions. Walker (1957) writing in an article says, "It is the response of economic plants, however, that reveals to us most readily the success of fertilization methods. For this reason the specific needs of the plant have a great influence on the specifications for fertilizer placement".

From time to time various research workers have designed fertilizer machinery for specific placement requirements. The National Joint Committee on Fertilizer application (1956) published a directory of 96 special fertilizer application machines. In this report the subcommittee on machinery for research reported that some fertilizer placement experiments have contained serious errors due to inaccurate and irregular performance of placement equipment. Further the report said that such occurrences definitely point up the importance of effective and reliable placement equipment. As expressed by Shaw (1956), "fertilizer prescriptions would be based on a clear understanding of nutrients, and the plant's ability to make use of them. A single application of fertilizer will provide sufficient nutrition throughout a plants life". The last sentence of this quote is of interest to engineers. A single application for complete crop fertilization would require an increase in the density of materials, as well as improved methods of placement. If the dry fertilizers available to-day can be pelletized into particles having a uniform size and shape, then more accurate placement of fertilizer is possible by mechanical methods.

The need for more efficient machines to accurately place fertilizer is the most urgent need for modern agriculture. The large amounts of fertilizers used annually pose labour problems for the manufacturer, dealer and farmer, both as to storage and field placement. Fall application of nitrogenous fertilizers eases the problem of storage and transportation for manufacturers. Nyborg et al (1977) in discussing fall application of nitrogen said that urea or ammonium sulphate gave approximately one quarter more uptake of N over calcium nitrate, when these fertilizers were applied in the fall. The authors further suggested that when the urea was applied in the fall but banded, the yield of barley increased eight percent. The problem of placement must therefore be considered in relation to the type of material, applicators used, and time of application.

2.2 Application of Pneumatics in Agriculture

Rollins (1973) stated that compressed air is widely used in farm equipment and for farm operations in most of the primary and auxiliary agricultural activities. There are many compressed air applications around the farm, such as materials handling, pumping and primary processing. As reported by Woodely (1964) the pneumatic system has several distinct advantages, like flexibility, safety, inherent cleanliness of system, etc. Because of this, pneumatic systems have found wide use in agriculture. Some of the applications include pruning and spraying trees, dusting insecticides and fungicides, handling rice hulls, picking raw cotton, etc. Some more recent applications of pneumatic systems are in the area of seeding and fertilizing equipment. Andersson (1977) states that machines using pneumatic systems for fertilizer spreading and seeding were introduced in Sweden over 20 years ago. At present two Swedish* manufacturers are producing commerical fertilizer applicators which broadcast fertilizer using pneumatic power.

At the beginning of this decade, one major manufacturer of agricultural machinery, International Harvester Company, introduced into the market the 400 cyclo planter; which uses the pneumatic system for seeding. Braunbeck and Wilkinson (1975) reporting on this machine stated that the primary advantage the pneumatic planter has over the grain drill, is that the cyclo planter can plant both row crops and small grains. Lys... (1975) described the machine developed by a

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*YSTA, Ystad G... Mek. Verkstads AB -S-27100 YSTAD - Sweden.
AB Skurup-Verk... Department ...ck, S-202 10 Malmö - Sweden.

Saskatchewan farmer. This machine, when mounted on a cultivator or discer, carries the seed and fertilizer in an air current through a cluster of pipes. In designing newer machines one has to meet the exact operating requirement of present and future needs. Olsson (1970), stated that modern grain drills can be operated at speeds up to 9 miles per hour. Lee and Karkanis (1965) writing about the effect of speed on delivery rate indicated that at higher speeds of operation the agitator has more effect upon the flow of fertilizer than at low speeds where the flow is more dependent on the flow characteristics of the fertilizer. Therefore, newer machines should be more efficient at higher speeds than any machine offered to-date.

In this thesis an approach has been suggested for the design of a machine for agricultural fertilizer application. The design has been based upon the anhydrous ammonia applicator. McVickar et al (1966) while investigating the development of the anhydrous ammonia applicator wrote that this equipment was introduced around 1942 for direct injection of ammonia into soil. The basic unit consists of a tank, metering device, distribution manifold, and a heavy duty cultivator type unit with a tube down the back of the shank and blade through which liquid ammonia is conveyed. As the liquid ammonia has sufficient pressure, there are no problems encountered while being conveyed from the tank to the blades of the injector knives. In the proposed design the trailing bulk-wagon will transport the fertilizer which will be pneumatically conveyed to the cultivator unit for field placement.

2.3 Pneumatic Conveying

Stoess (1970) defines pneumatic conveying, as the art of transporting dry bulk materials through a pipeline by either a negative or positive pressure air stream. Kraus (1968) and Andersson (1977) state that the published information on the design of pneumatic systems is meagre.

The following brief review of experimental work in the field of pneumatic conveying will provide background information. The early investigations in this field involved the determination of terminal velocities of various materials of particular particle sizes falling vertically through air. Similar investigations were made to determine the variations in resistance to motion of spheres of various sizes and densities immersed in various fluids. Further experimental work was devoted to determination of the minimum floatation velocity of various materials. Floatation velocity is defined as that upward air-stream velocity which would hold the material suspended without motion up or down.

Kraus (1968) states that the first extensive investigation of the complete pneumatic conveying system was made by Gasterstädt on a wheat conveying unit set up in the Machine Laboratory of the Technical High School in Dresden, Germany. Gasterstädt's graph (Figure 2.1) for specific pressure drop versus the mixture ratio (weight of material to weight of air) shows, that, for constant air velocity, the specific pressure drop is a linear function of the mixture ratio. More recent experiments in solids flow techniques show that, for a specific material, a given solids mass-flow rate can be maintained in a horizontal conveying line. Kraus also refers to a graph (Figure 2.2) based on the experience of the former B.F. Sturtervant Co. in conveying such items as cereals, wood blocks, chips, sawdust, beans,

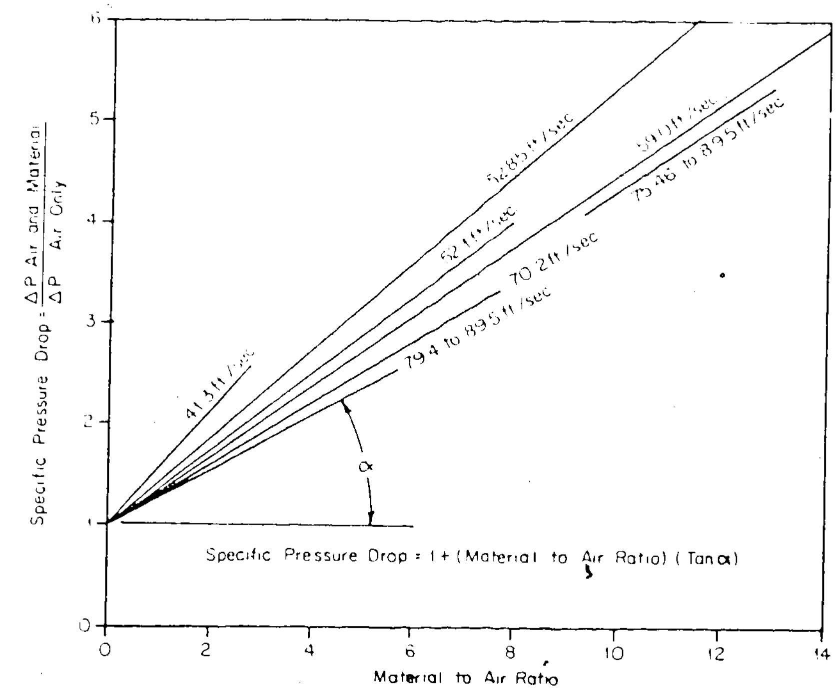

Fig. 2.1 GASTERSTÄDT'S TEST RESULTS FOR CONVEYING WHEAT.

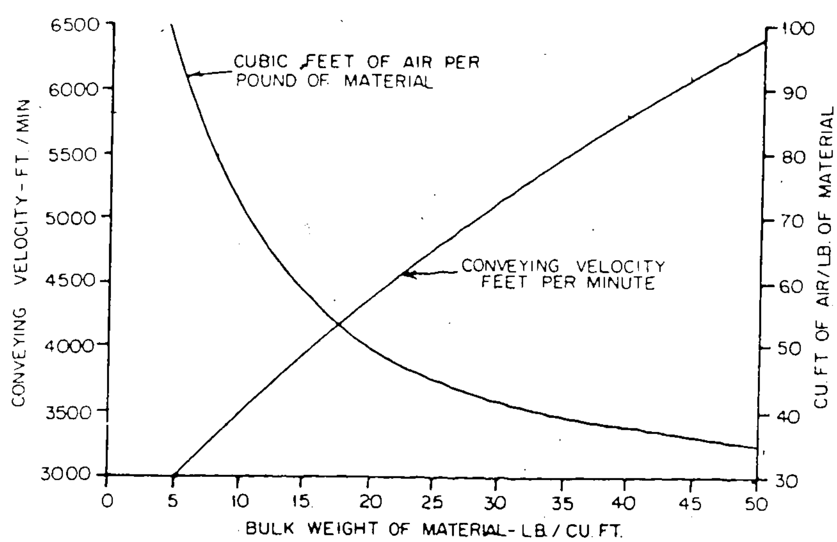

Fig. 2.2 AVERAGE VELOCITIES AND AIR VOLUMES FOR CONVEYING MATERIALS.

cotton etc. Kraus, further suggests that the design procedures seem to be straight forward, however, the information required to design the system must be obtained by actual test on a specific material, not by the selection of design factors from tabulated data or graphs relating to other materials.

Stoess (1970) refers to Table 2.1 (abridged) in which various type of conveyors applicable to many known materials are listed. This table indicates that available information on fertilizer conveying systems is meagre. Therefore for design purposes one has to work from basics. The usual and logical procedure is to follow an energy analysis that accounts for the loss of all conceivable forms of energy that may exist in a proposed system. The above approach has been followed in the thesis. Calculations for energy losses have been done by following well known methods of experimental hydraulics, and an analysis of energy losses is presented for a proposed pneumatic fertilizer applicator.

2.4 Model Study

The model designed for the development of a pneumatic assisted fertilizer applicator can be considered as a hydraulic model. A hydraulic model is a precision device for the experimental investigation of a hydromechanical phenomenon, and can give reliable information only if its scales are determined according to certain definite rules. Yalin (1971) writes that a small scale reproduction of a physical phenomenon can be a scientifically valid model only if a certain set of its measureable characteristics are related to their counterparts in

Table 2.1 Abridged table of system type according to known material for the design of pneumatic conveyors

Materials	Type of System						
	Vacuum	Low-Pressure	Medium-Pressure	High-Pressure	Vacuum-Pressure	Air-Activated	Closed Circuit
Alum	x	x					
Bentonite	x	x	x	x	x	x	
Cement, Portland			x	x		x	
Cereals	x	x					
Coal, Pulverized			x	x			
Coffee beans	x	x					
Detergent powders	x	x	x			x	
Feldspar	x		x			x	
Fertilizers	?	?	?	?	?	?	?
Grain, whole	x	x					
Lime, hydrated	x	x	x	x	x	x	x
Ores, pulverized			x	x		x	
Starch	x	x	x		x	x	

Reference: Pneumatic Conveying by H.A. Stoess, 1970 the actual phenomenon, or prototype, by certain constant proportions* which satisfy definite mathematical conditions. In the model study investigated in this thesis, the fertilizer was conveyed in the duct and sufficient data collected for scale-up. Streeter and Wylie (1975) state that in pipe flow, viscous and inertial forces are the only ones of consequence; hence, when geometric similitude is observed, the same Reynolds number in model and prototype provides dynamic similitude.

In other words, inertial force (IF) and viscous force (VF) in model and prototype should be multiples of the scale ratio λ i.e.,

$$(VF)_P + (IF)_P = \lambda[(VF)_M + (IF)_M] \qquad \ldots(1)$$

where subscript P and M denote prototype or model in consideration. Scale ratio for viscous forces is:

$$\frac{(VF)_P}{(VF)_M} = \lambda \qquad \ldots(2)$$

similarly scale ratio for inertial forces is:

$$\frac{(IF)_P}{(IF)_M} = \lambda \qquad \ldots(3)$$

Equating 2 and 3

$$\frac{(VF)_P}{(VF)_M} = \lambda = \frac{(IF)_P}{(IF)_M} \qquad \ldots(4)$$

Viscous force $VF = \mu V/L^2$

where μ is dynamic viscosity
V is velocity
L^2 is area;

Inertial force IF = mass x acceleration

or $\rho V^2/L$

*These constant proportions are referred to as scales, whereas the mathematical conditions which must be satisfied by the scales are called the criteria of similarity.

where ρ is density,

V^2/L is acceleration.

Substituting the values of viscous and inertial force in equation 4,

$$\frac{(\mu V/L^2)_P}{(\mu V/L^2)_M} = \frac{(\rho V^2/L)_P}{(\rho V^2/L)_M}$$

or $[(\mu V/L^2).(L/\rho V^2)]_P = [(\mu V/L^2).(L/\rho V^2)]_M$

or $(VL/\nu)_P = (VL/\nu)_M$, where ν= kinematic viscosity = $\frac{\mu}{\rho}$

i.e. Reynolds number in prototype = Reynolds number in model.

Scale relations between prototype and model could be determined by the Reynolds number R, and by the geometry and is given by the equation:

$$\lambda\rho \cdot \lambda V \cdot \lambda L \cdot \lambda\mu^{-1} = 1 \qquad \ldots(5)$$

In this equation μ, ρ, and L possess independent dimensions, therefore the scales $\lambda\mu$, $\lambda\rho$, and λ_L could be chosen freely. However, if the model operates with the prototype fluid, i.e.

$\lambda\mu = 1$; and $\lambda\rho = 1$.

Accordingly equation 5 reduces into;-

$$\lambda_V = \frac{1}{\lambda_L}$$

or the velocity scale ratio is inversely proportional to length ratio, i.e. the smaller the model the higher are the model velocities.

The committee of the Hydraulic Division on Hydraulic Research of the American Society of Civil Engineers (ASCE) prepared a manual for the orderly presentation of facts on hydraulic models in 1942. Further detailed treatment, of this subject, has also been undertaken by Yalin (1971), and Streeter and Wylie (1975).

CHAPTER 3

EXPERIMENTAL SET-UP

3.1 Preliminary Field Studies

Construction of equipment for preliminary testing for placement of nitrogenous fertilizers commenced in May 1976. The heavy-duty cultivator was chosen as the primary unit for mounting of the fertilizer placement equipment. The reason for selecting a cultivator was simple. As this equipment is commonly used by farmers for tillage, and if some suitable fertilizing equipment is integrated with a cultivator, the greatest savings can be obtained in labour and materials.

Two Spierco* fertilizer hoppers of width six and seven feet were mounted on the cultivator. These hoppers had oscillating-bottom fertilizer feed mechanisms which constantly agitated the fertilizer thus preventing bridging. The rate of application of fertilizer was adjusted by loosening one wingnut, moving the pointer to the desired rate number of the calibrated wheel and then retightening the nut. The cultivator had a working width of 13 feet and was equipped with 13 chisel points which were mounted on spring-cushioned steel shanks. Boots for fertilizer placement were carefully designed so that they did not interfere with the basic operation of the cultivator. The boots were mounted behind the chisel points. Test runs were conducted during the fall of 1976. The fertilizer hoppers, mounting and boots used for this test are shown in Figure 3.1. The equipment worked well at low application rates of fertilizers; however, the inherent disadvantage of gravity flow, i.e., plugging of conveying tubes, became apparent at

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*Spierco Industries Ltd. 727 - 42 Ave. S.E., Calgary, Alberta, Canada.

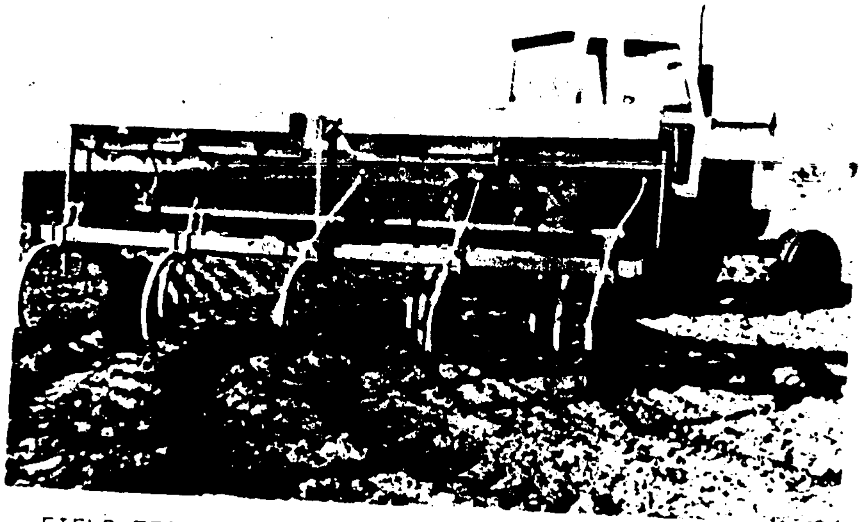

Fig. 3.1a FIELD TESTING OF FERTILIZER BANDING EQUIPMENT

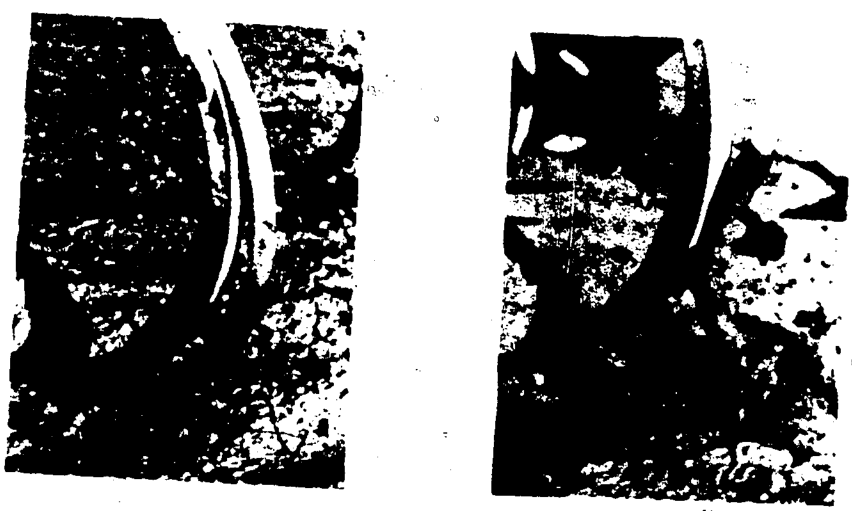

Fig. 3.1b SOME OF THE BOOTS TESTED FOR FERTILIZER BANDING

higher application rates. Some mechanical refinement to the system was needed to prevent plugging of the conveying tubes so that fertilizer application could proceed without interruption. A pneumatic system offers flexibility and safety, therefore, the possibility of such a system for fertilizer application was investigated.

3.1 Preliminary Work on Pneumatic System

In an attempt to prevent plugging of fertilizer conveying tubes, a medium air pressure system was investigated. The medium pressure system is categorized as such by the air pressure requirement, 15 to 45 psig. Air at a pressure of 30 psig was injected into the conveying tubes by nozzles. In the conventional fertilizer applicators the fertilizer particles move because of the force of gravity acting on them. In this system the particles were given an additional velocity by the velocity of air injected through nozzles into the conveying tubes. However, because of limitations in size and space in the fertilizer conveying tubes, the method did not work well. The details of the medium pressure system used are shown in Figure 3.2.

3.2 Objectives of Test Set-up

As stated previously published information on the design of pneumatic fertilizer conveying system is meagre and theory cannot cover all the practical complications. Therefore, a model study was thought to be the best systematic approach.

The objectives of the model study were to:

i. determine the quantity of air to convey one pound of the material;

ii. determine the air conveying velocity;

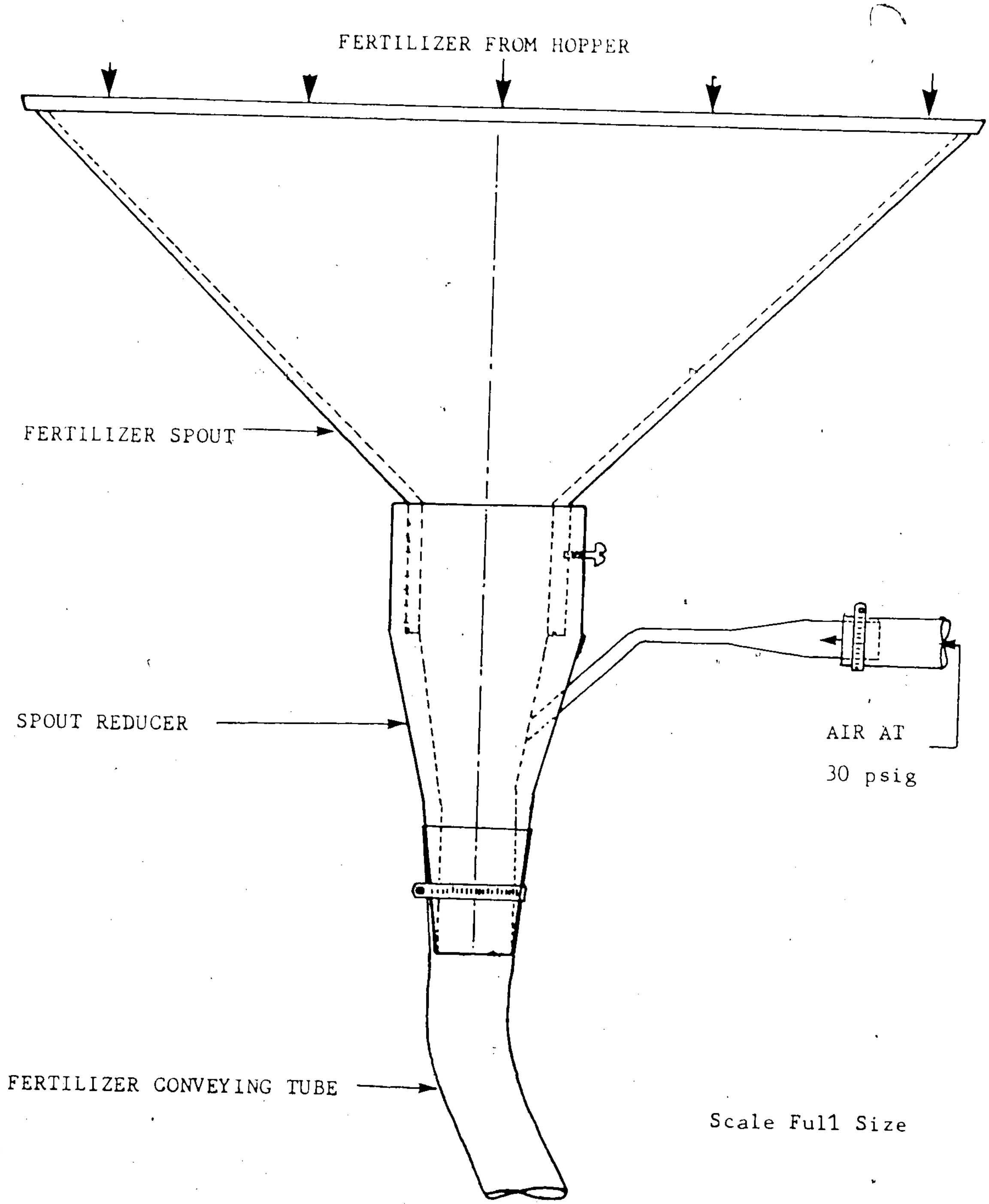

Fig. 3.2 MEDIUM AIR PRESSURE SYSTEM FOR FERTILIZER PLACEMENT

iii. select a pipe size on the basis of the air flow and air velocity;

iv. summarize all energy losses due to air flow;

v. determine the input power required.

The aim was to collect sufficient data for scale-up when conveying fertilizer at the maximum possible air-to-material ratio and the lowest air velocity that will ensure complete clean-out of the pipe line without settling of fertilizer within the horizontal section of the conveying line.

3.2.1 Test Set-Up

An air duct was set-up to provide the required data. The duct was a drawn tubing of clear transparent plexiglass with 0.25 in. wall thickness. The inside diameter of the duct was 2.5 in. The general set-up of the test duct is illustrated in Figure 3.3 while Figure 3.4 gives dimensions of the test set-up. To supply air to the duct two "Canadian Blower* 2E type" fans arranged in series were joined to the duct. Figure 3.5 illustrates the coupling of fans. The fans at their highest operating range gave a total pressure of 2.5 in. water at 2875 r.p.m. The fans were operated in a speed range of 2875 to 1225 r.p.m. Different operating speeds were obtained by an arrangement of V-belt driven stepped pulleys. Obviously, some slippage losses are unavoidable and in the experiment were assumed to be negligible.

3.2.2 Flow Straightener

To eliminate the whirl before the pitot tube traverse an egg-

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*Canadian Blower/Canada Pumps Ltd., Kitchener, Ontario, Canada.

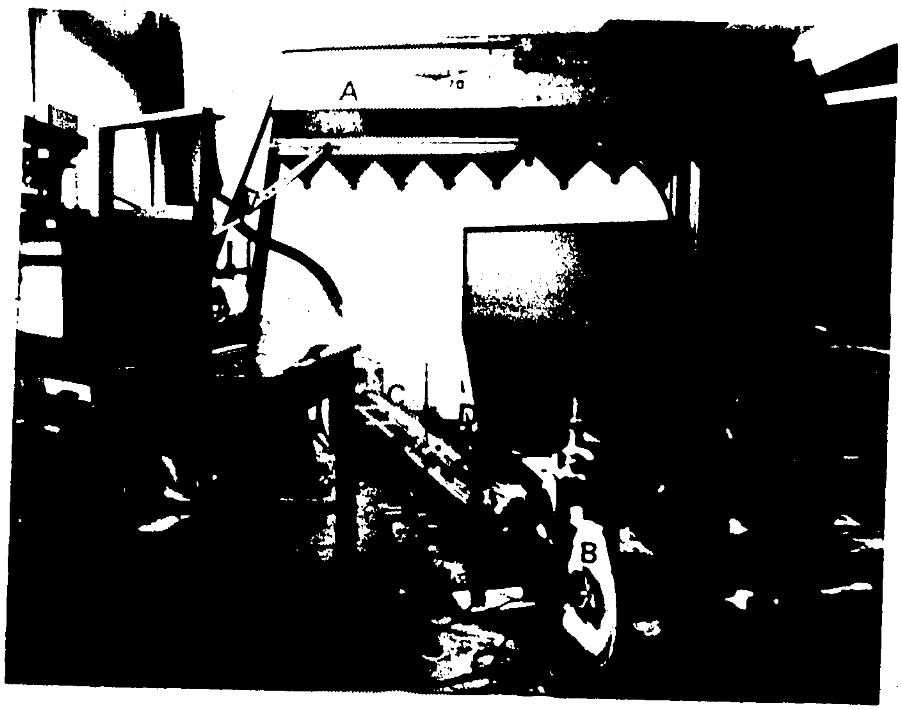


Fig. 3.3 GENERAL SET-UP OF THE EQUIPMENT

A: FERTILIZER HOPPER

B: RADIAL PADDLE BLOWER FANS

C: PLEXIGLASS DUCT

D: FERTILIZER FEEDER

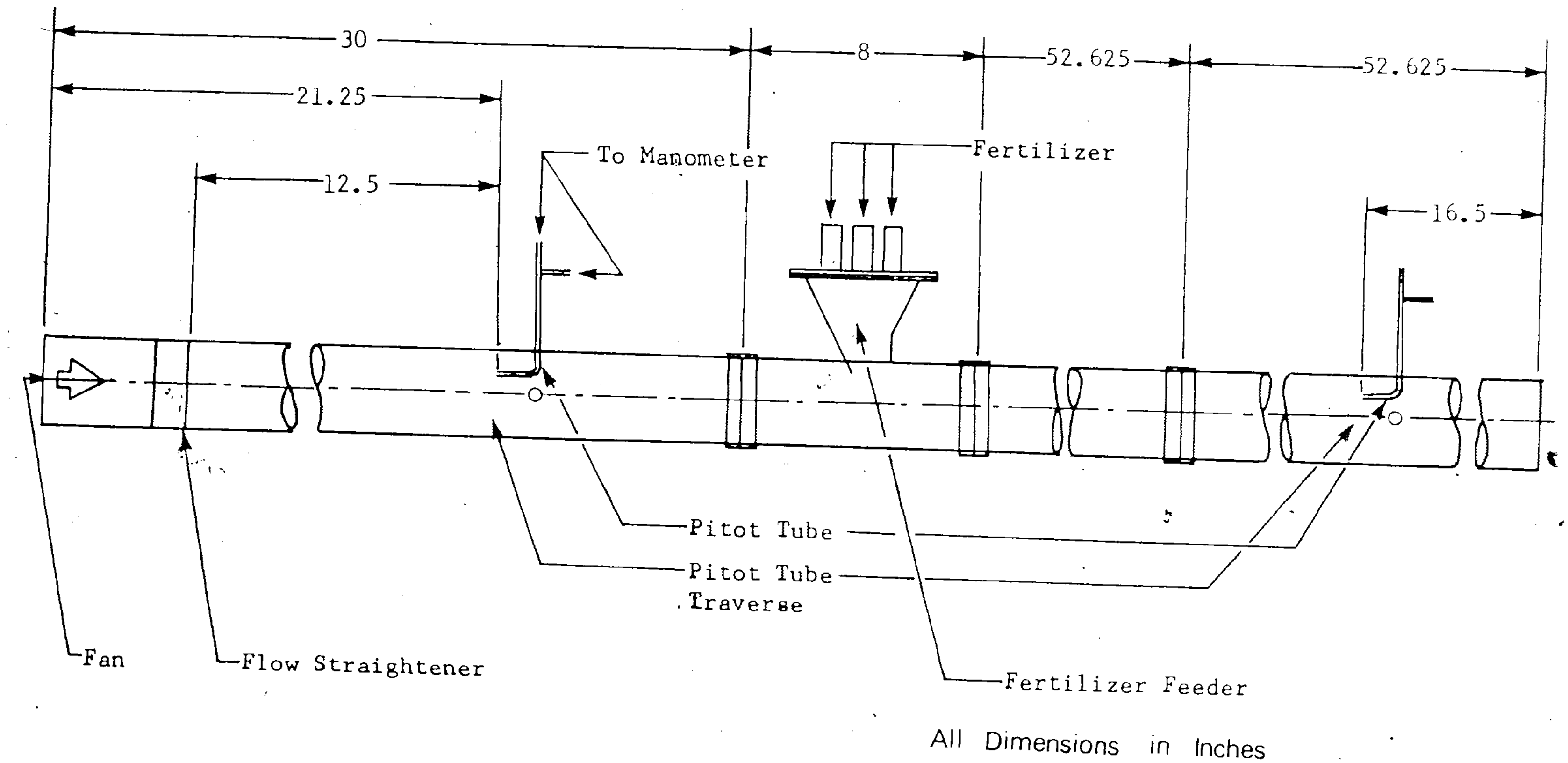


Fig. 3.4 DUCT SETUP FOR FERTILIZER CONVEYING

Fig. 3.5 SERIES FAN SYSTEM USED IN TEST SET-UP

A: RADIAL PADDLE BLOWER FANS

B: FLOW STRAIGHTENER

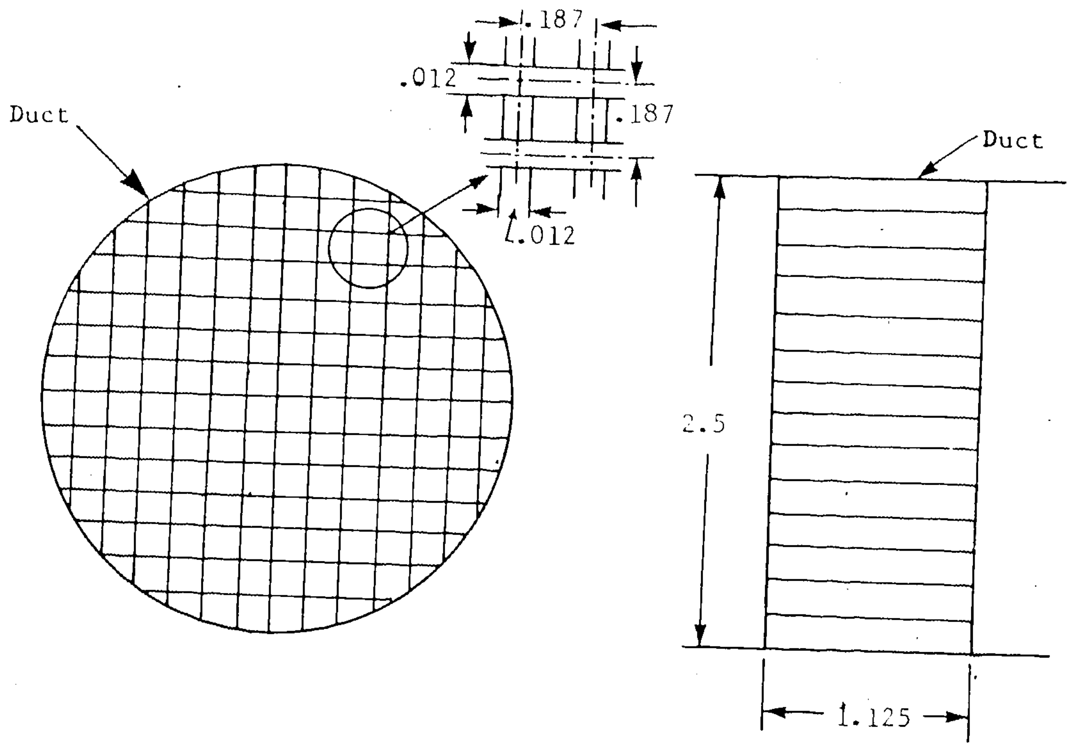
crate type of flow straightener was installed as per American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRE) Standard No. 51-75. The flow straightener was located between 5 and 5.25 duct diameters upstream of the plane of the pitot tube traverse. The straightener installed had standard dimensions as per ASHRAE Standard No. 51-75. Details of the straightener are shown in Figure 3.6.

3.2.3 Pressure Measuring Station

As per ASHRAE Standard No. 51-75 the upstream pressure measuring station as shown in Figure 3.7 was located at a distance of 8.5 duct diameters from the upstream end. The downstream pressure measuring station was located 39 duct diameters from the upstream pressure measuring station. This station was used to establish the friction of the duct and fertilizer feeder. The location of the downstream pressure measuring station changed from 39 duct diameters to 42.2 duct diameters when the fertilizer feeder was installed in the duct. Only the upstream pressure measuring station was used when observations with fertilizer flowing in the duct were being recorded.

3.2.4 Pitot Tube Traverse

The velocity of the air stream is not uniform across the cross section of a duct. Friction slows the air moving close to the walls, so the velocity is greater in the center of duct. To obtain the average velocity and velocity profile in the duct, a series of velocity pressure readings were obtained by the tangential method as discussed by Ower and Pankhurst (1966). The duct was divided into 5 zones of equal area by concentric circles of radii, as shown in Figure 3.8. Twenty readings along two perpendicular diameters were observed and recorded. Actual velocities for each area were calculated from individual pressure



All Dimensions in Inches

Fig. 3.6 FLOW STRAIGHTENER

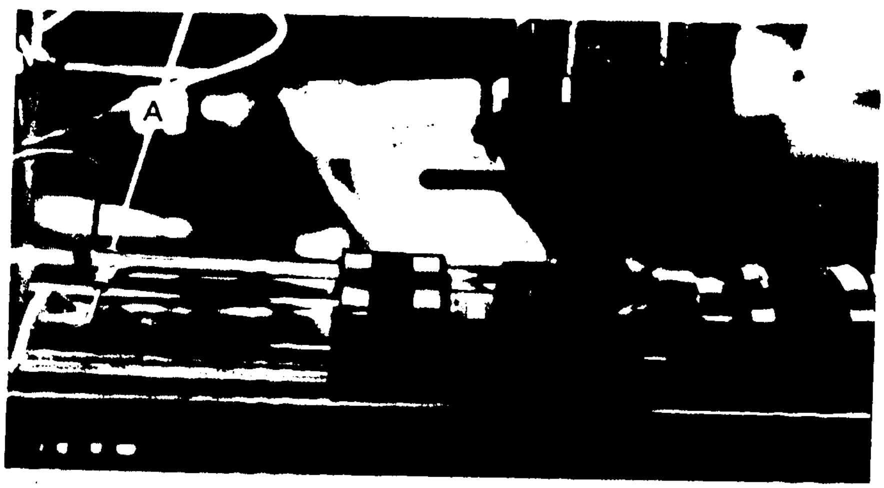
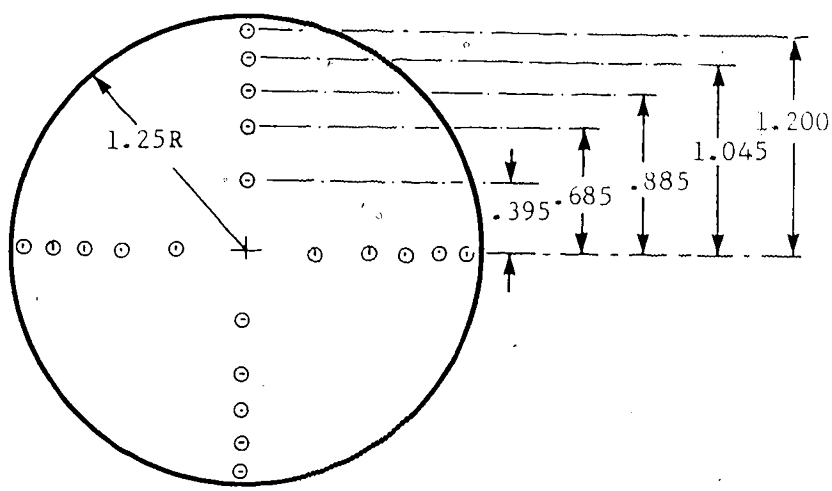


Fig. 3.7 UPSTREAM PRESSURE MEASURING STATION

A: PITOT TUBE

B: STATIC PRESSURE TAP

C: FERTILIZER FEEDER



All Dimensions in Inches

Fig. 3.8 TRAVERSE POINTS IN DUCT

readings.

3.2.5 Fertilizer Feeder

A venturi type stationary feeder was used in this experiment. The design and details of this type of feeder are illustrated in Figure 3.9. This type of feeder is suitable for positive pressure systems. The entry of fertilizers through this feeder is shown in a series of photographs in Figures 5.12, and 5.13 (Chapter 5).

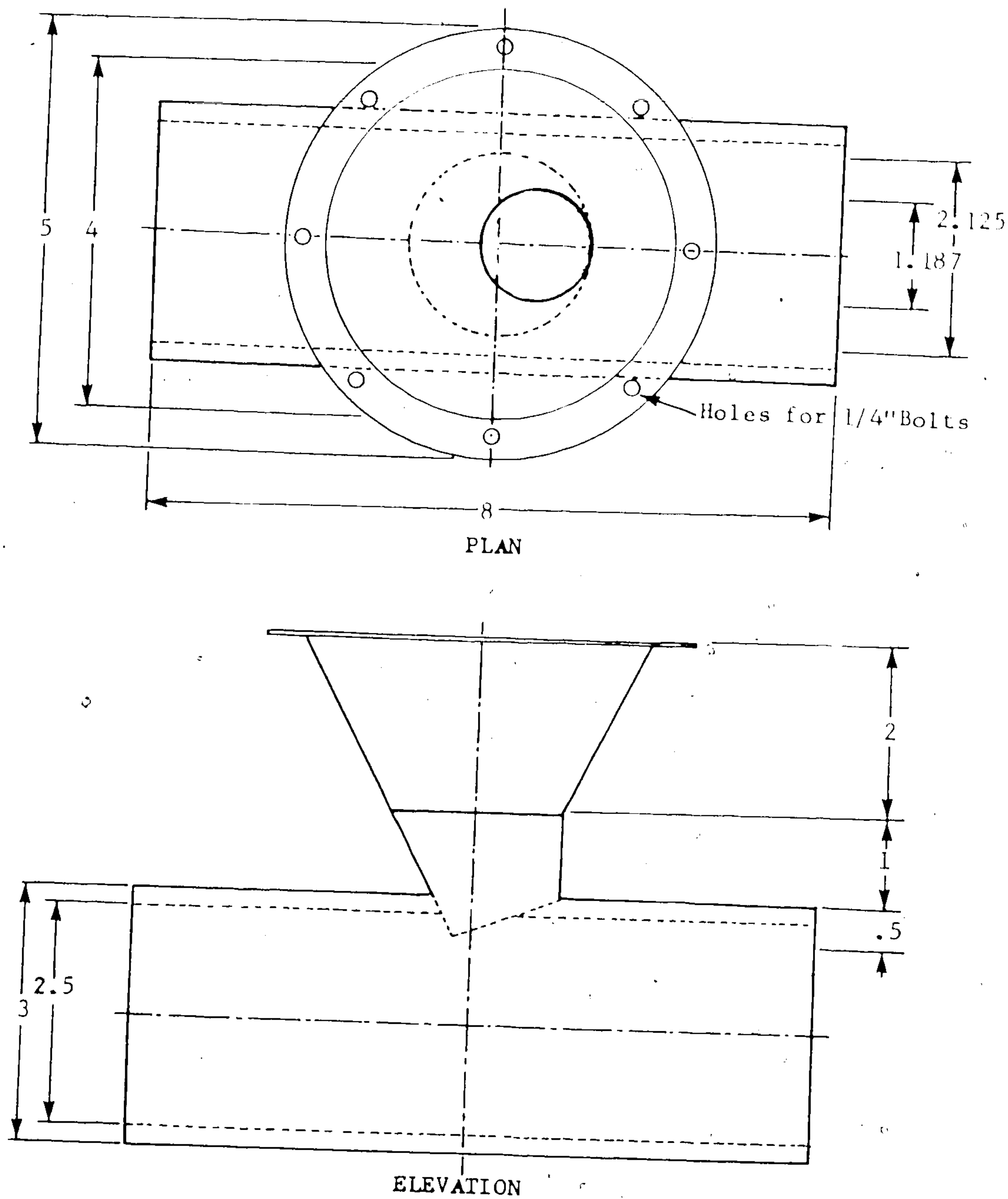
3.2.6 Mitre Bends

The intended purpose for using these right angled mitre bends (90° elbow) was to design a simple, accurate and effective fertilizer metering device which could distribute fertilizer evenly to all spouts. Therefore three concentric bends were placed at the end of the conveying tube or duct. The area of concentric bends facing the air flow were equal. The details and dimensions of these concentric mitre bends are shown in Figure 3.10.

3.2.7 Test Procedure

The test procedure followed is described in the following paragraphs:

i. To establish the basic fan characteristics, the fans were operated at pre-determined speeds. A complete pitot tube traverse was observed and recorded by operating the fan at 2875 r.p.m. The pitot tube measurements were obtained at both upstream and downstream measuring stations. The velocity profile obtained at this speed was the basic profile for the experiment. As there was no change in flow conditions the velocity profile at other speeds was assumed to be of the same shape. To cover the working range of the experiment, the air volume, pressure, and power required by the system were also measured at various speeds. The average velocity was computed from the observations of the pitot tube traverse at a fan speed of 2875 r.p.m. The manometric reading of the velocity pressure was calculated from the average velocity after adjusting for the differences in the densities of air between the two observations i.e., observed and calculated. The pitot



All Dimensions in Inches

Fig. 3.9 VENTURI TYPE FEEDER

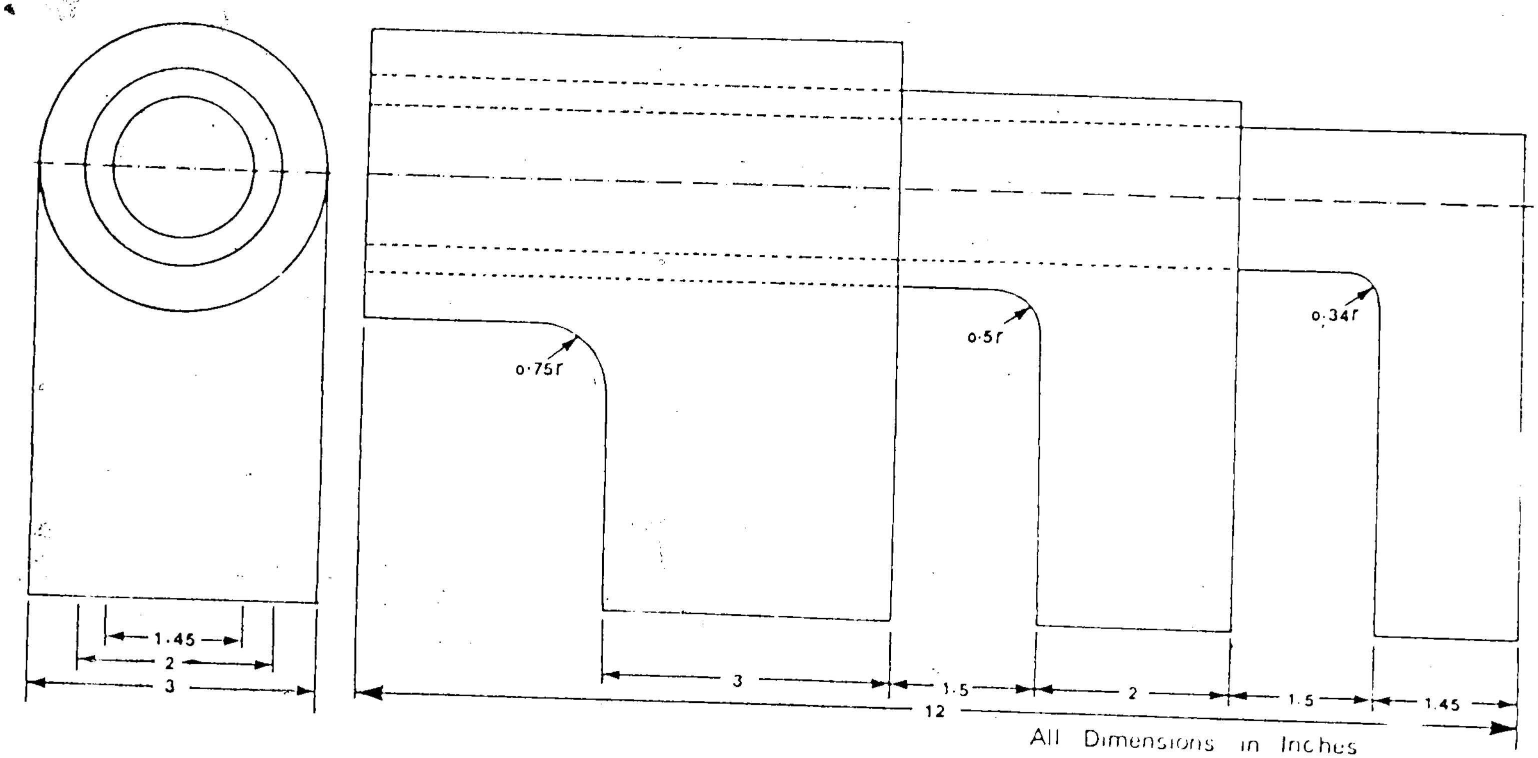


Fig. 3.10 MITRE BENDS FOR FERTILIZER DISTRIBUTION

tube was then positioned in the duct to give this velocity pressure measurement on the manometer. Test runs on other speeds of the fan to obtain average flow conditions in the duct were obtained from this position of the pitot tube. Appendix A contains details of computations performed on observations, while Appendix B contains observations and computations for fan performance characteristics.

ii. The fertilizer feeder was installed in the duct. Test runs were again conducted to establish the change in the basic velo ty profile obtained earlier. Complete pitot tube tra es were recorded at 1225 and 2875 r.p.m. The velocity profiles between these operating speeds were assumed to follow the same pattern. The observations for the fertilizer feeder test run are given in Appendix C.

iii. The pitot tube from the downstream measuring station was removed. This was done to prevent plugging of the pitot tube with fertilizer.

iv. Fertilizer was introduced into the duct through the fertilizer feeder. The three conveying tubes connected at the bottom of the hopper conveyed the fertilizer from the hopper to the fertilizer feeder. The driving mechanism for the fertilizer metering device consisted of a 1725 r.p.m. motor and gear-train which drove the flexible power cable. This cable provided power to the metering device. The metering device was operated at 333 r.p.m. which is approximately equivalent to a field speed of four miles per hour. Three settings on the calibrated fertilizer metering wheel were selected to obtain varying rates in the duct. These settings gave a delivery rate of 1.19, 3.05, 6.33 lb/min of ammonium sulphate, and 0.89, 1.84, 4.09 lb/min of urea. Test runs to obtain velocity profiles were conducted at three speeds for both ammonium sulphate and urea. Appendix D contains observations and calculations for flow conditions while the fertilizer was being conveyed.

v. To study the distribution pattern of particles within the duct, a 16mm movie camera was operated at 64 frames per second. A four inch by seven inch paper with a grid one inch square was used to record the pattern and distribution on film.

vi. Mitre bends were fixed to the duct. Observations without fertilizer flow were recorded first to establish the friction loss and drop in velocity. These observations are given in Appendix E. Later fertilizer was introduced into the stream of air, the bend divided the fertilizer into three fractions, and these fractions were weighed and recorded.

3.3 Properties of Fertilizers

Urea and ammonium sulphate were selected to establish the pneumatic conveying characteristics. These fertilizers were selected because they represent a range of specific weight from lightest to heaviest among nitrogenous fertilizers. Urea is a synthetic organic nitrogenous fertilizer and is made by combining liquid ammonia and liquid carbon dioxide at very high temperatures and pressures. The product in final form is prilled and contains 46 per cent nitrogen. On the other hand ammonium sulphate contains 21 per cent nitrogen. In addition to nitrogen, ammonium sulphate contains about 24 per cent sulphur, one of the secondary plant-food elements. Ammonium sulphate is less susceptible to caking than other nitrogenous fertilizers, because of less affinity for moisture.

Rheological properties like particle size, repose angle and loose specific weight have a direct bearing on pneumatic conveying. The method followed to determine these properties is given below.

3.3.1 Particle size analysis

Fineness of fertilizer affects the uniformity with which it will flow in a pneumatic conveying system. In lieu of any standard method for finding the particle size of fertilizers, the procedure suggested by Henderson and Perry (1976) for feed grains was used. A 250 gram sample of fertilizer was weighed and shaken in the Ro-Tap machine for five minutes. The fertilizer fractions retained on prescribed Tyler screens were weighed and recorded (Appendix F).

3.3.2 Angle of Repose

The kinetic angle of repose of any substance is the angle with the horizontal at which the substance will form, when poured into a pile. The tangent of this angle is a measure of the resistance to flow and is called the kinetic coefficient of friction. The angle of repose was measured by slowly pouring approximately a gallon of fertilizer through a funnel into a pile upon a level surface. The angle was then determined by simple trigonometry (Appendix F).

3.3.3 Loose Specific Weight

This is the weight per unit volume of fertilizer after it is poured gently into a container of known volume. A measuring cylinder of 250 milliliters was gently filled with fertilizer. The measuring cylinder was weighed, an allowance made for tare and the density computed. Appendix F contains the test values thus obtained.

CHAPTER 4

INSTRUMENTATION

The following measurements were obtained during the experiment:

i. Barometric pressure.

ii. Dry and wet bulb temperatures of air.

iii. Static pressures at plane of traverse.

iv. Velocity pressures at plane of traverse.

v. Fan speed.

vi. Electric motor power input.

The instruments used and methods of measurement are described in the following paragraphs:

4.1 The Pitot Tube

Air pressures in the duct were measured with a pitot tube similar in construction as per ASHRAE Standard 51-75. The pitot tube is a combination of an inner impact tube fastened concentrically inside a second tube of slightly larger diameter which receives static pressure input from radial sensing holes around the tip. The air space between inner and outer tubes permit transfer of pressure from the sensing holes to the static pressure connection. When the inner impact tube (total pressure tube) is connected to the manometer, velocity pressure is indicated directly.

4.1.1 Calibration

The pitot tube used had the same basic features and proportions as required in ASHRAE standard 51-75. This type of pitot tube is considered a primary instrument, therefore no calibration was done.

4.1.2 Error

Pressure measurements made with the pitot tube were assumed to be correct to 0.3 percent (The American Society of Mechanical Engineers, 1971). Care was taken that the angle between the mean stream path and axis of the impact tip did not exceed the allowable limit of 12 degrees.

4.2 The Manometer

A liquid filled U-tube manometer was used. The manometer was fabricated from 8 mm glass tubes. For greater accuracy the manometers were mounted on an inclined board 75.13 degrees from the vertical. In these manometric tubes distilled water along with some food coloring was used to indicate pressure differences. These tubes were graduated to read millimeters of water. The actual pressure was the sine of the angle times the differential reading in mm on these tubes. The manometers used for the test set-up are shown in Figure 4.1.

4.2.1 Calibration

The U-tube manometers were calibrated with all tubes in place against a water filled hook gage. During calibration, no significant change in manometer reading was observed from that of the hook gage.

4.2.2 Error

With the inclined U-tube manometer a reading resolution of 0.5 mm was unavoidable, as the scale had a least count of one mm.

4.3 Velocity Pressure

The open end of the pitot tube was always pointed upstream in a direction parallel with the axis of the duct. Velocity pressure was measured by a manometer having one side connected to the impact tube,

Fig. 4.1 INSTRUMENTATION FOR THE TEST EQUIPMENT

A: MANOMETERIC TUBES

B: WATTMETER

C: DRY AND WET-BULB THERMOMETER

and the other side connected to the static tube. The differential obtained this way was the velocity pressure at the point of impact opening in the duct.

4.4 Static Pressure

Static pressure was measured by a manometer connected to the static tap of the pitot tube. The other leg of the manometer was exposed to the atmosphere. Average static pressure was also obtained with static pressure taps. Four static pressure taps 90 degrees apart were placed on the circumference of the duct. Care was taken that the holes drilled in the duct were smooth and free from irregularities, and the diameter did not exceed 0.125 inch (ASHRAE Standard 51-75). The four static pressure taps were connected to an equalising chamber, and this equalising chamber was connected to the manometer.

4.5 Dry and Wet Bulb Temperature

Both dry and wet bulb temperature were measured at an hourly interval with Celsius thermometers having a least count of 0.2°C. To measure the wet bulb temperature, the moistened wick covered bulb of the thermometer was placed in an air stream having a velocity of approximately 700 ft/min. The dry bulb thermometer was mounted upstream of the wet bulb thermometer, so the reading would not be depressed.

4.6 Barometric Pressure

The barometric pressures were obtained on hourly basis from the metrological observatory of the Atmospheric Environment Service located at the Industrial Airport, Edmonton. The barometric pressure in this observatory is obtained with a mercury column barometer, and is recorded in millibars.

4.7 Fan Speed

To measure the r.p.m. of the fan shaft, a General Radio* stroboscope type 1531-A with an internally controlled flashing rate up to 25,000 per minute, was used. The accuracy of stroboscopic speed measurements depends on the accuracy of the line frequency. A stroboscopic device triggered by the line frequency of a public utility is considered a primary instrument (ASHRAE Standard 51-75).

4.8 Power

Input power to the motor was measured with a wattmeter. Since the power required by the fan was never strictly steady the input power measured by the wattmeter was fluctuating with time. As these fluctuations were small and regular, the average input power was obtained visually.

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*General Radio, 300 Baker Avenue, Concord, Massachusetts, U.S.A.

CHAPTER 5

RESULTS AND DISCUSSION

In the development of a pneumatic assisted fertilizer applicator, pneumatic conveying presents a problem in design. The many variables of the material such as density, particle size, hygroscopic properties, etc. form a limitless variety of combinations for pneumatic conveying when integrated with variables of air flow in rigid boundary conditions. The simplicity and efficiency of pneumatic systems depends entirely on accurate design based on a comprehensive knowledge of harnessing of air movement to accomplish work. The discussion and information contained in this chapter is based on experience and data obtained during this study.

5.1 Fertilizer Characteristics

Rheological properties of material play a vital role in pneumatic conveying. Stoess (1970) states, "the art even today lies in intimacy with the characteristics of the material in question when it is under the influence of air". Often materials of the same name and general appearance have a wide variation in physical characteristics. Therefore, the fertilizers used to establish pneumatic conveying characteristics in this study were tested for their rheological properties. The important properties tested were density, particle size and angle of repose.

Density of the material effects volumetric capacity, as well as flowability. The densities of fertilizers used in this experiment in a poured condition were 69.87 lb/ft^3 and 48.70 lb/ft^3 for ammonium sulphate and urea respectively.

The other principle property that affects distribution is the particle size, or state of subdivision. This was determined by sieve analysis. The average particle diameter was 0.060 inch and 0.115 inch for ammonium sulphate and urea respectively. Prilling in urea reduced the fraction of fines and dust. Because of less dust, urea was far easier to handle as compared to ammonium sulphate.

The last property studied was angle of repose. Mehring (1930) states, "it can be shown that in the case of a substance having a kinetic angle of repose greater than 45° no free flow can occur". The angle of repose gives a rough indication of flowability. The factors which depend on angle of repose are:

i. the rate of delivery,

ii. the size of gate opening through which the fertilizer will be lost when the distributor is not operating

iii. delivery rate variations with depth change in the hopper, and

iv. uniformity of discharge.

The angle of repose for ammonium sulphate and urea was found to be 27° and 23° respectively.

5.2 Pneumatic Conveying

The known variables required for the design of a pneumatic system are the pipe diameter, the rate of flow of material, the pressure at the entrance to the line, or the pressure drop across the line, and the rate of flow of free air entering the line. To find the maximum possible material-to air ratio and the lowest air velocity, sufficient data was taken for a range of fertilizer-air mixtures.

5.2.1 System Performance Characteristics

To establish the performance characteristics of the series system of blower fans used, test runs on air flow measurement were conducted. As these fans were used as part of a complete unit, the performance of a fan may be modified due to proximity of other components. Therefore the methodical approach was to measure the overall performance of the assembly. Figure 5.1 illustrates the performance characteristics of the system at a fan speed of 2875 r.p.m. The total pressure (the sum of the static pressure and the velocity or dynamic pressure) for different values of air volume, i.e., at different stages of throttling of the fan inlet is shown in Figure 5.1. The measurements were made and corrected to standard atmospheric pressure and density. The input power required by the fan assembly at various air volumes is also shown in Figure 5.1. The power requirement shown includes the losses of the assembly therefore the values reported are slightly higher than actual. The system performance characteristics at other shaft speeds for which the experiment was performed are reported in Table 5.1. The system performance characteristics at different shaft speeds were individually obtained, because values derived for pressure, air volume, and power requirement at various r.p.m. by calculation from experimental results at one shaft speed, are not normally reliable. Segler (1951) reported that the theoretical fan laws upon which fan characteristics calculations must be based are not completely fulfilled in practice. Table 5.1 summarizes the results of the system performance characteristics.

5.2.2 Energy Losses due to Airflow

In steady incompressible flow in a pipe or duct the

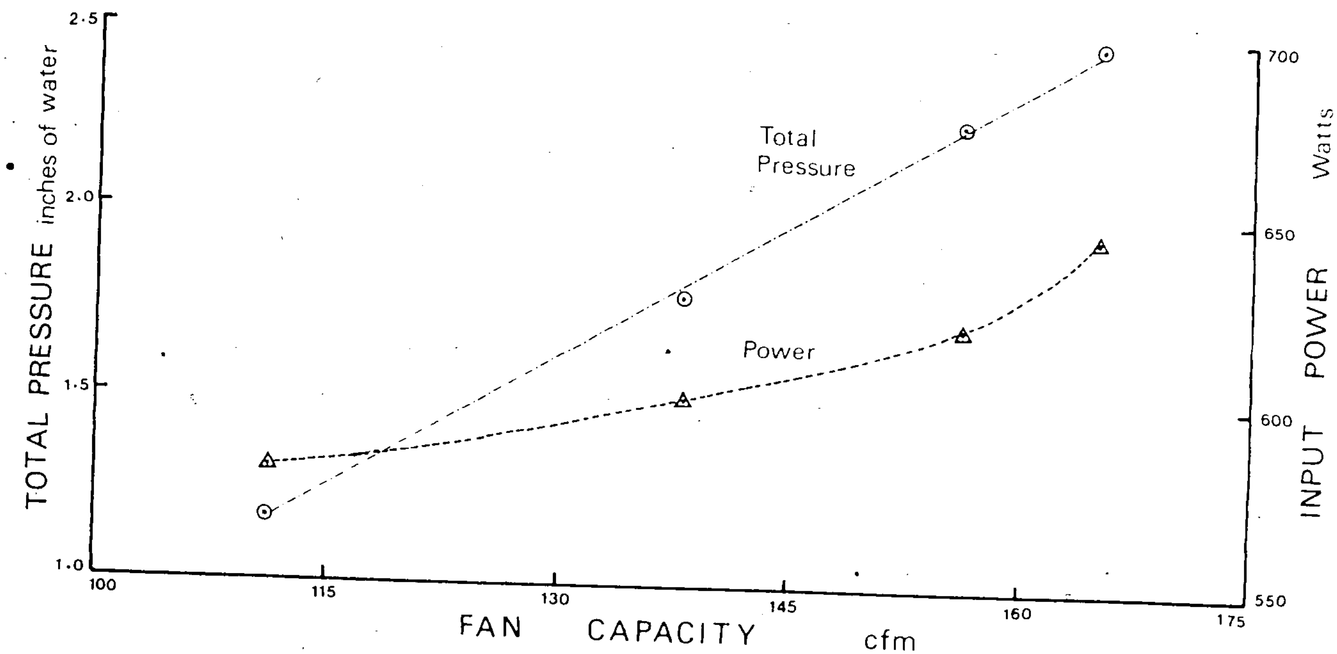


Fig. 5.1 COMBINED PERFORMANCE OF TWO, TYPE "E" BLOWERS USED IN EXPERIMENTAL SET-UP.

Table 5.1 SYSTEM PERFORMANCE CHARACTERISTICS.

Revolutions per minute	Particulars	Fan full open	Fan three quarter open	Fan half open	Fan one quarter open
2160	Q	126	121	105	93
	V	3705	3535	3083	2719
	W	500	470	460	450
2400	Q	134	131	118	101
	V	3935	3844	3459	2966
	W	510	490	480	460
2875	Q	165	156	138	111
	V	4848	4853	4057	3242
	W	640	620	600	580

Q = Volume rate of air flow at plane of traverse, cfm

V = Velocity at plane of traverse, fpm

W = Power input, Watts

irreversibilities are expressed in terms of a head loss. Losses or irreversibilities cause the hydraulic grade line to drop in the direction of flow. The Darcy-Weisbach equation (Streeter and Wylie, 1975)

$$h_f = f \frac{L}{D} \frac{V^2}{2g}$$

is generally adopted for pipe flow calculations, where h_f is the head loss, or drop in the hydraulic grade line in the pipe length L, having an inside diameter D and an average velocity V. Head losses of the hydraulic grade line can be easily calculated if the friction factor f of the assembly is known. The friction factor f is a dimensionless factor that is required to make the Darcy-Weisbach equation produce the correct value for losses. The friction factor instead of being a simple constant, depends upon seven quantities;

$$f = f(V, D, \mu, \rho, \varepsilon, \varepsilon', m)$$

where V = Velocity of fluid

D = Diameter of the duct

μ = Dynamic viscosity of the fluid

ρ = Density of the fluid

ε = Size of the roughness projections

ε' = Arrangement of the roughness elements

m = Form factor of the roughness projections

The plot of friction factor against the Reynolds number $(\frac{VD\rho}{\mu})$ on a log-log graph is known as a Stanton diagram. Blasius (Streeter and Wylie, 1975) calculated the friction factor by the following empirical formula that is valid up to about R = 100,000,

$$f = \frac{0.316}{R^{1/4}}$$

where R is Reynolds number. This empirical formula has been used for calculating friction factor values which are presented in Figure 5.2. The graph follows very closely the Moody diagram used for calculating flow in pipes. The Moody diagram is a Stanton diagram that expresses the friction factor as a function of relative roughness and the Reynolds number.

Dilute-phase conveying was used in this experimental set-up. This phase is characterized by high velocity flow of a stream of solid particles homogeneously dispersed in air. Because of the dilute-phase the calculated friction factor in the duct did not change appreciably when fertilizer was introduced into the duct. In the absence of experimental evidence no explanation can be given for this. However it can be supposed that the Magnus effect of rotation assists the flight of the particles and reduces the surface friction thus reducing the total resistance of the individual fertilizer particles to the air stream (Prandt and Tietjens, 1934). This effect was also reported by Segler (1951) while investigating pneumatic conveying of wheat. Segler states, "another effect of the air current is that the grain is made to rotate about its axis". Gasterstädt (Segler, 1951) determined by spark photography that this rotation, with wheat grains, is at the rate of 10,000-20,000 r.p.m., the peripheral speed being the same as the air velocity. Table 5.2a compares friction factors obtained with and without fertilizer. The conclusion is that to design a prototype, the friction factor can be obtained from Moody's diagram (Streeter and Wylie, 1975) and this be used with caution after adding a safety margin. In Table 5.2b the friction factor values obtained for the concentric bends used for fertilizer distribution to multiple points have been reported.

5.2.3 The Blockage Limit

The most important factor in the transport of fertilizer

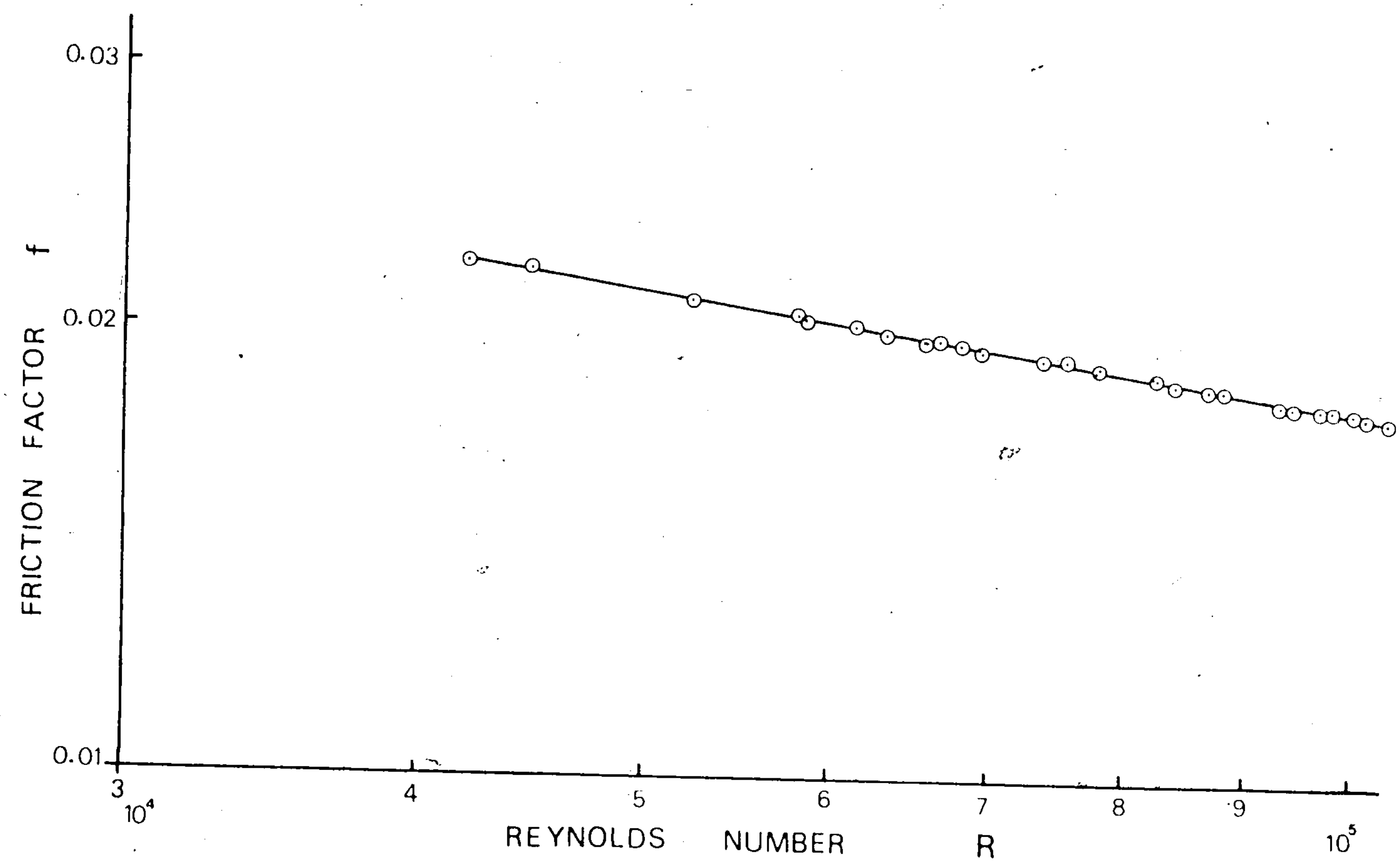


Fig. 5.2 STANTON DIAGRAM FOR THE RANGE OF EXPERIMENT.

Table 5.2a FRICTION FACTORS FOR VARIOUS THROUGHPUTS OF FERTILIZERS.

Revolutions per minute	Friction factor for air only	Friction factor for air+fertiliz.	Throughput of fertilize. lb/min	Fertilizer
2160	0.0189	0.0189	0.89	Urea
		0.0190	1.84	Urea
		0.0192	4.09	Urea
		0.0189	1.19	Amm. Sulphate
		0.0190	3.05	Amm. Sulphate
		0.0191	6.33	Amm. Sulphate
2400	0.0185	0.0185	0.89	Urea
		0.0185	1.84	Urea
		0.0187	4.09	Urea
		0.0185	1.19	Amm. Sulphate
		0.0185	3.05	Amm. Sulphate
		0.0187	6.33	Amm. Sulphate
2875	0.0176	0.0176	0.89	Urea
		0.0176	1.84	Urea
		0.0177	4.09	Urea
		0.0176	1.19	Amm. Sulphate
		0.0177	3.05	Amm. Sulphate
		0.0178	6.33	Amm. Sulphate

Table 5.2b FRICTION FACTORS* FOR AIR FLOW THROUGH MITRE BENDS.

Revolutions per minute	Measuring Station	Friction factor without Mitre bend	Friction factor with Mitre bend
2875	Upstream	0.0176	0.0178
	Downstream	0.0179	0.0184

*The friction factor remains constant in a system. However, in the experiment f values were calculated from Blasis formula which is sensitive to velocity changes in the duct. Therefore, values calculated from the downstream pressure measuring station were higher.

particles is the conveying velocity. The power required by pneumatic conveying is greatly influenced by the choice of correct air velocity. When air alone is blown, the power requirement rises approximately as the cube of the air velocity. In order to keep the power requirement as low as possible, the lowest possible air velocity should be used in the system. In the experiment, reference to the conveying velocity refers to the superficial air velocity - the velocity calculated from a measured air flow. The assumption is that the flow in the duct is a homogeneous fluid in turbulent flow. The lower limit of air velocity enhances the possibility of blockages. These blockages arise when the energy of the air flow is insufficient to sustain the conveying process. The limit at which blockage commences varies with air velocity and throughput.

The procedure adopted to determine the blockage limit was to observe changes in the velocity profile. As more and more material was introduced into the duct, the concentration of material increased. The effect of the increased material was to reduce the air velocity thereby changing the velocity profile in the duct. Initially the basic velocity profile in the duct was established. This velocity profile was taken as datum and changes that occurred in the velocity profile after introduction of fertilizer were observed to pin-point the blockage limit. Figure 5.3 shows the velocity profile as measured upstream in plan and elevation at 2875 r.p.m. As there were no disturbances in the duct the velocity profile was assumed to follow the same pattern for other fan speeds. The downstream velocity profile has not been plotted for two reasons. Firstly, the downstream velocity measurements could not be taken when fertilizer was flowing in the duct for the obvious reason that pitot

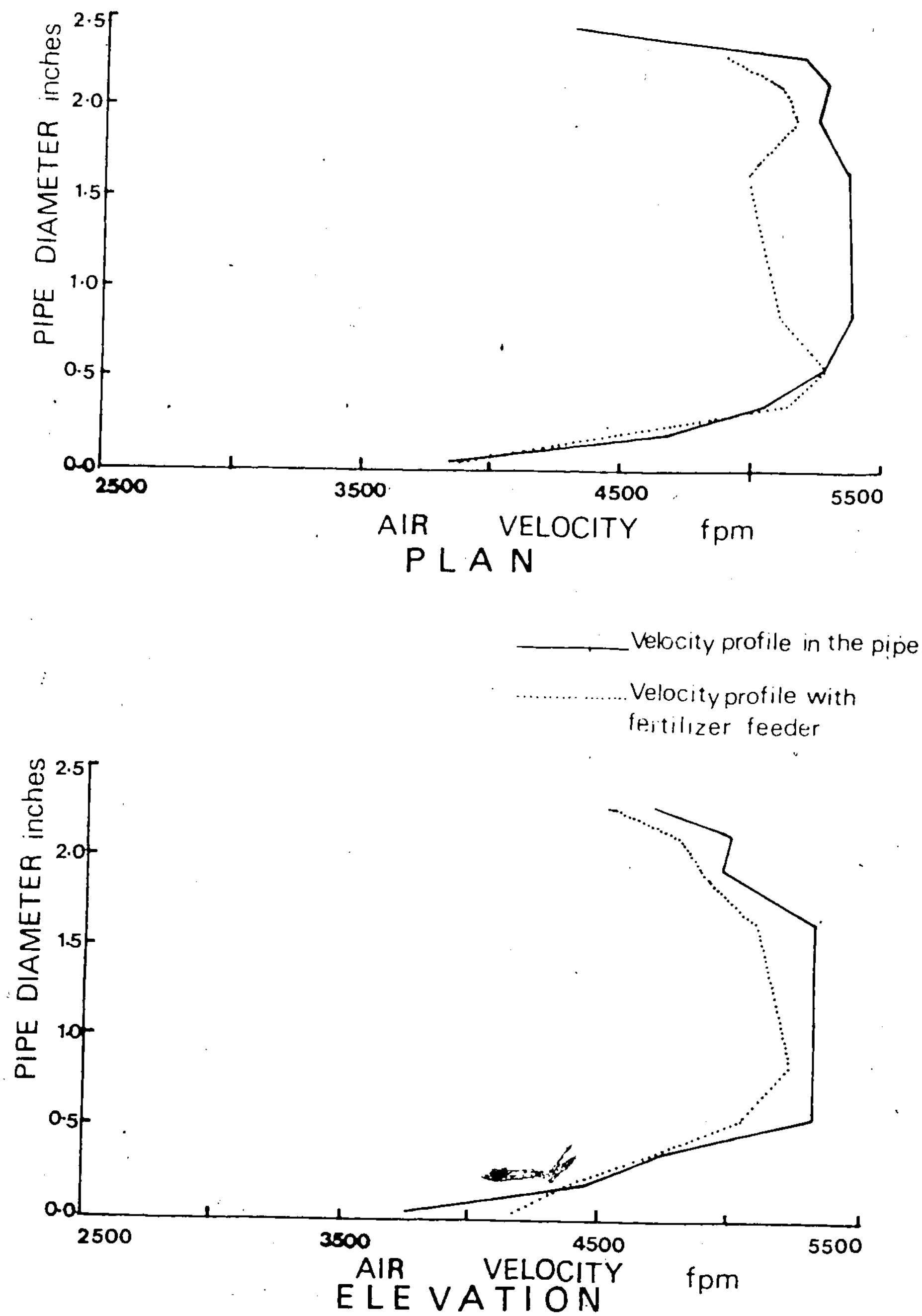


Fig. 5.3 DISTRIBUTION OF AIR VELOCITY IN THE DUCT WITH AND WITHOUT FERTILIZER FEEDER.

tube openings would be plugged because of fertilizer dust. Secondly, a symmetrical throttling device such as an orfice plate or adjustable cone was not placed at the discharge end of the duct.

The fertilizer feeder was fitted to the duct. Figure 5.3 shows the change in the velocity profile of air flow that occurred because of the fertilizer feeder, while the fan was operating at a speed of 2875 r.p.m. To determine the saturation ratio, i.e. air-material ratio that could be safely carried in an air stream without causing blockage of the conveying line, fertilizer was introduced into the duct. Velocity pressure traverses were measured in the duct. Velocity pressure traverses were measured at 2160, 2400, and 2875 r.p.m. for both fertilizers. Velocity profiles plotted from these observations are shown in figures 5.4, 5.5, 5.6, 5.7, 5.8, and 5.9 for ammonium sulphate and urea respectively.

Observing these velocity profiles one can conclude that ammonium sulphate had attained the blockage limit at a fan speed of 2160 r.p.m., while urea showed no sign of blockage limit because of less specific weight. At this speed all the ammonium sulphate particles were moving in the bottom of the duct and were not homogeneou dispersed in the air stream. This was reflected in the elevation of the velocity profile (Figure 5.4). This was substantiated in the photographs taken during the test (Figures 5.10(A), and 5.11(A)). The decrease in the superficial velocity in the bottom of the duct disappeared at a fan speed of 2400 r.p.m., indicating that a blockage limit did not exist at this speed. A series of photographs in Figures 5.10, and 5.11 shows the distribution of ammonium sulphate and urea during pneumatic conveying at fan speeds of 2160, 2400, and 2875 r.p.m.

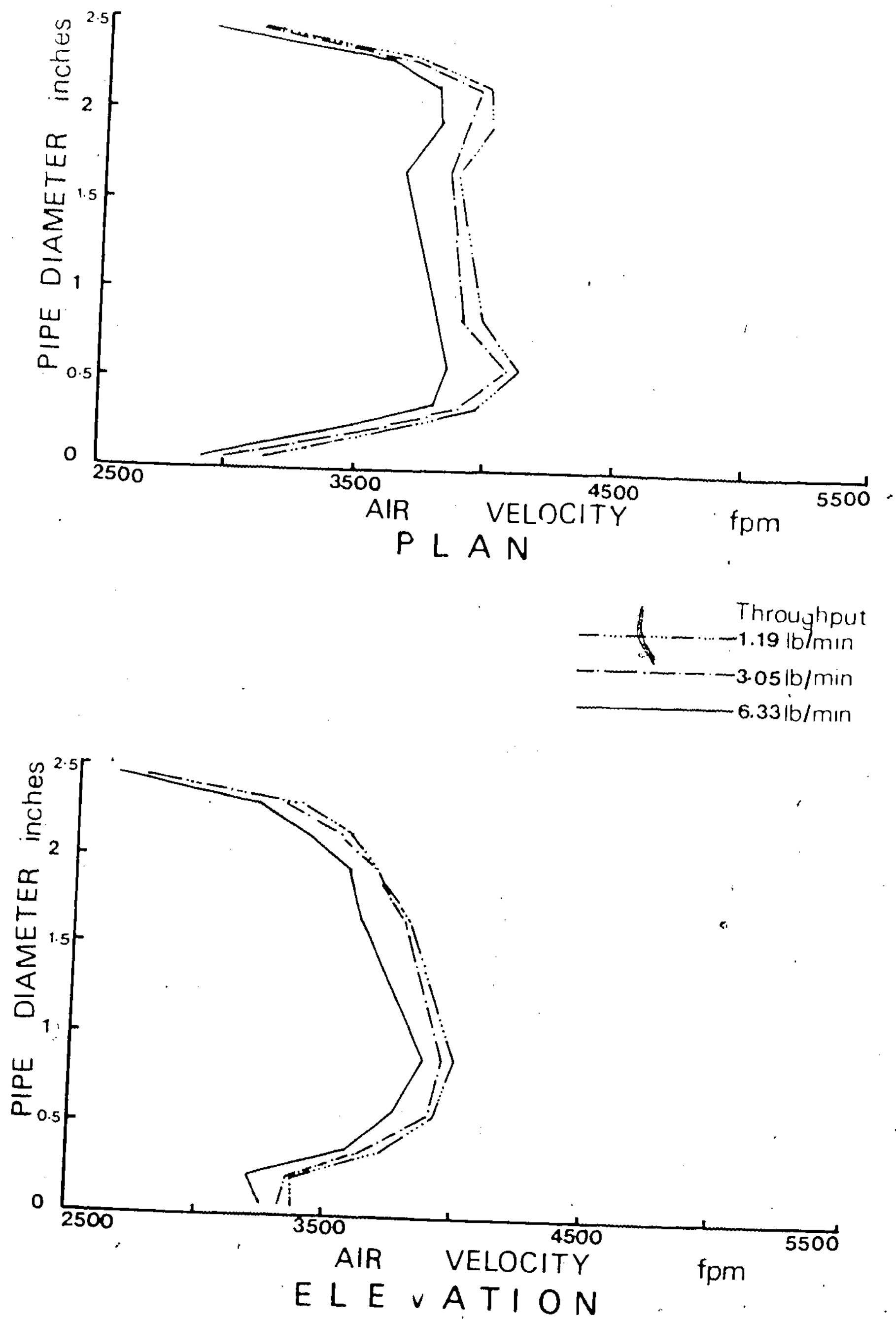


Fig. 5.4 DISTRIBUTION OF AIR VELOCITY AT 2160 r.p.m. WITH AMMONIUM SULPHATE IN THE DUCT.

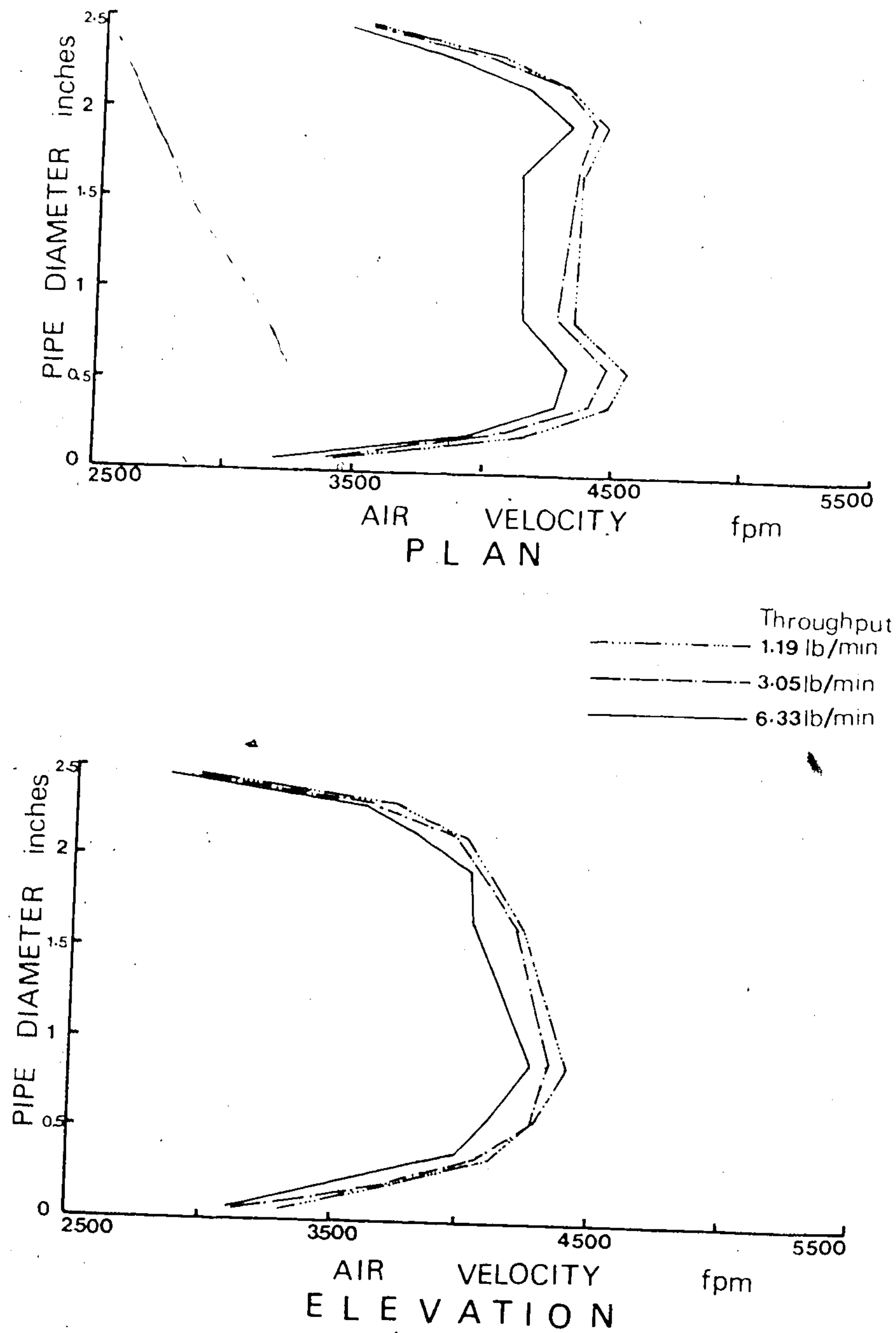


Fig. 5.5 DISTRIBUTION OF AIR VELOCITY AT 2400 r.p.m. WITH AMMONIUM SULPHATE IN THE DUCT.

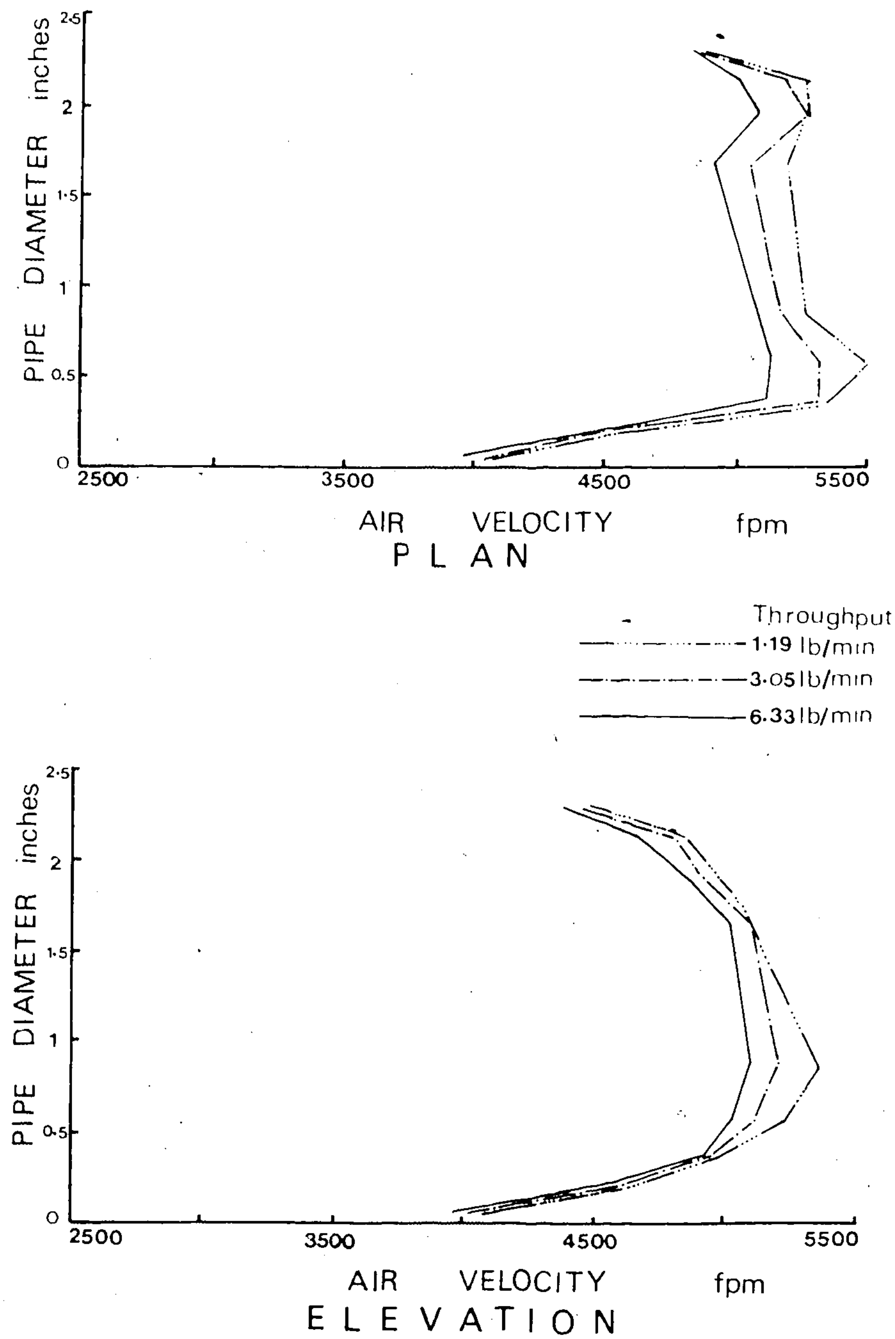


Fig. 5.6 DISTRIBUTION OF AIR VELOCITY AT 2875 r.p.m. WITH AMMONIUM SULPHATE IN THE DUCT.

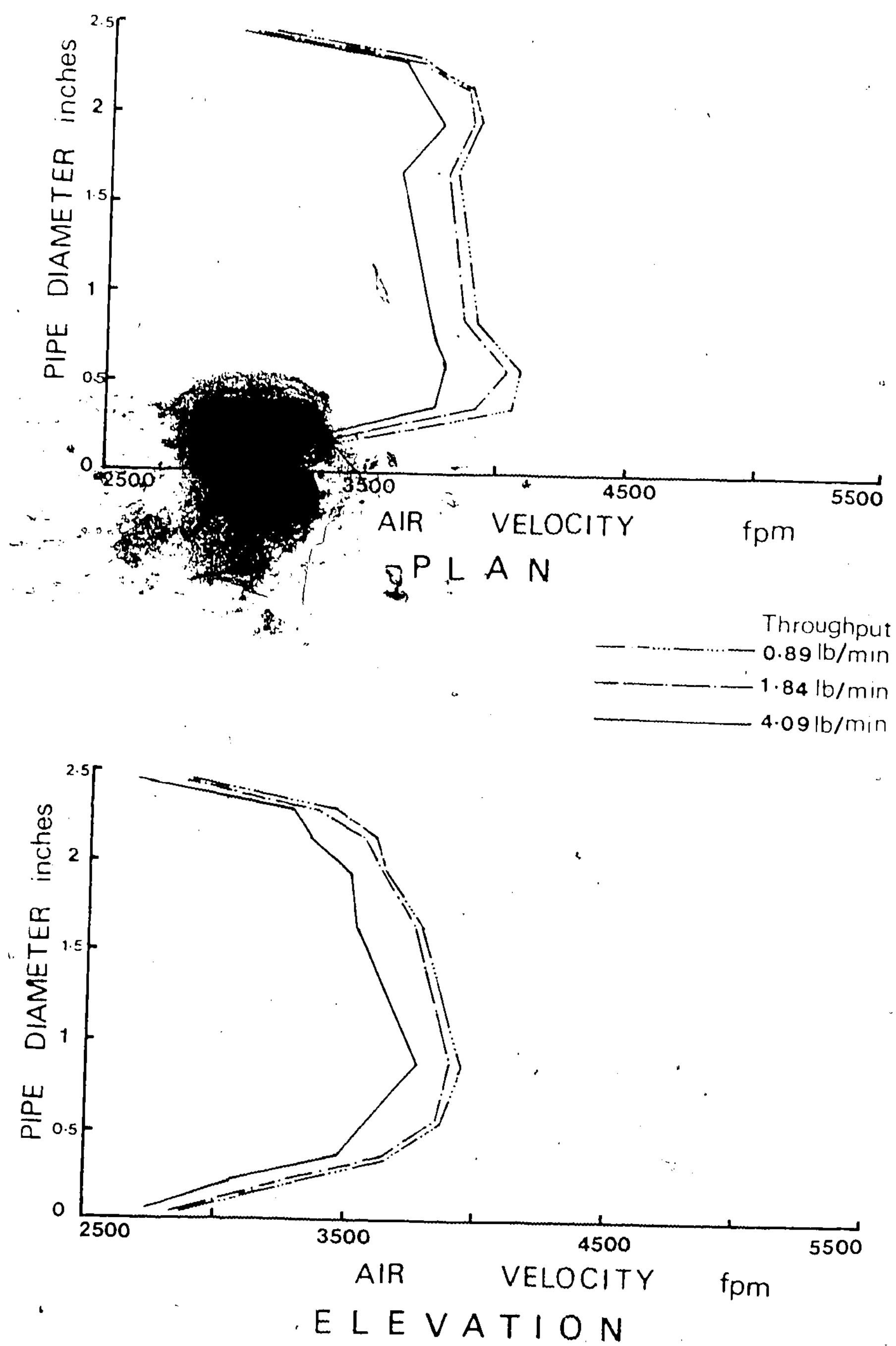
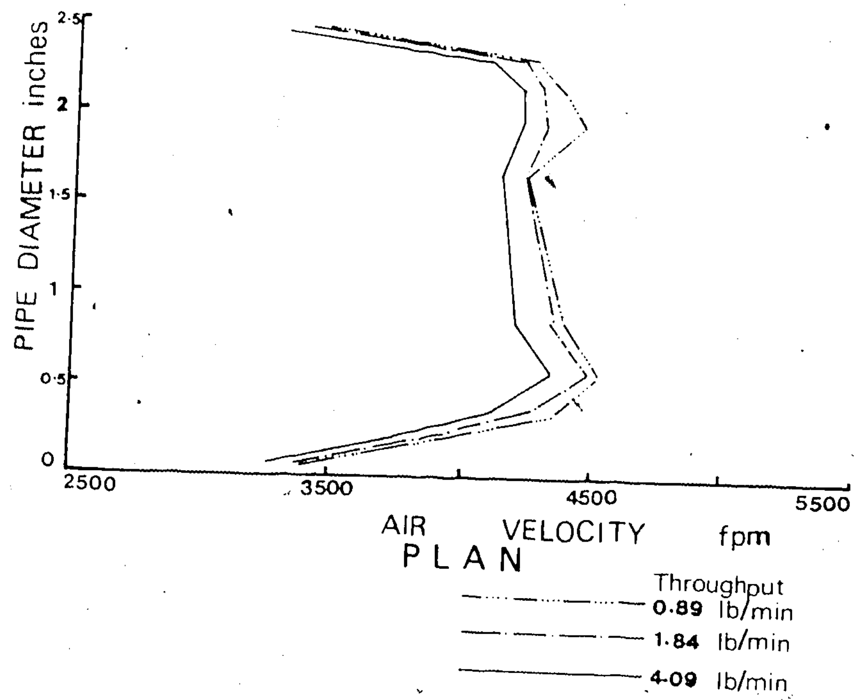


Fig. 5.7 DISTRIBUTION OF AIR VELOCITY AT 2160 r.p.m. WITH UREA IN THE DUCT.



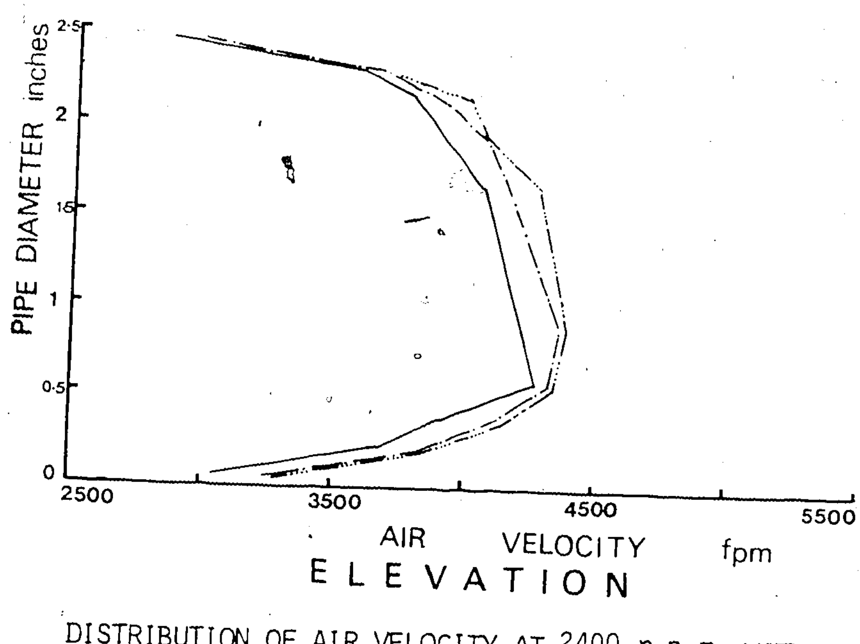


Fig. 5.8 DISTRIBUTION OF AIR VELOCITY AT 2400 r.p.m. WITH UREA IN THE DUCT.

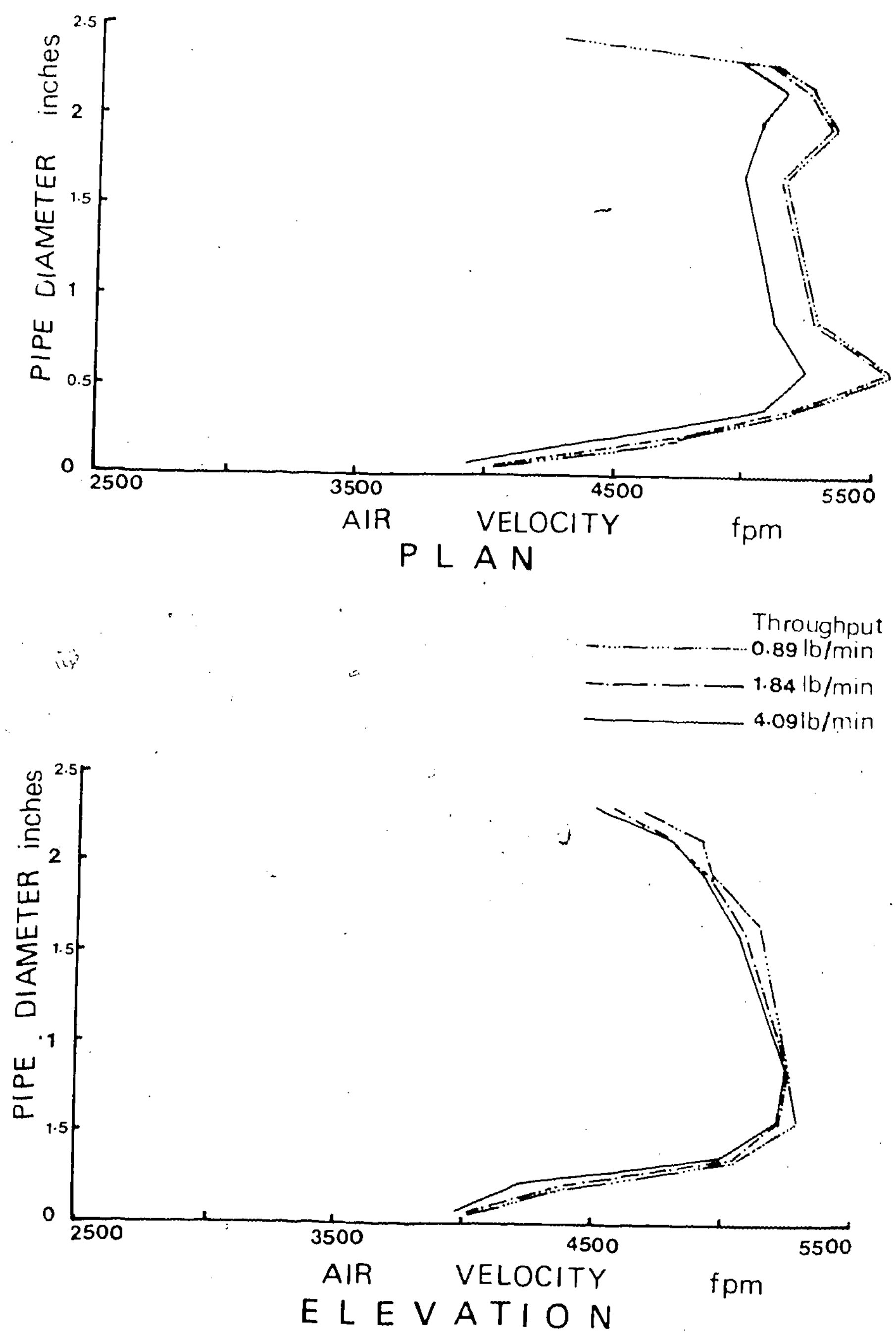


Fig. 5.9 DISTRIBUTION OF AIR VELOCITY AT 2875 r.p.m. WITH UREA IN THE DUCT.

A

B

C

Fig. 5.10 DISTRIBUTION OF AMMONIUM SULPHATE IN THE CONVEYING DUCT.

A. 2160 r.p.m. B. 2400 r.p.m. C. 2875 r.p.m.

A

B

C

Fig. 5.11 DISTRIBUTION OF UREA IN THE CONVEYING DUCT

A. 2160 r.p.m. B. 2400 r.p.m. C. 2875 r.p.m.

The blockage limit was apparent at other test speeds, i.e. 1250, 1500, and 1750 r.p.m. when particles began to settle and form drifts, and could be heard trickling along the pipe. The blockage at lower speeds together with entry of fertilizers in the conveying duct is shown in Figures 5.12 and 5.13.

5.2.4 Fertilizer Feeder

The feeder was designed with the aim that the duct diameter at the entry section is narrowed down. This accelerated the air stream to a higher velocity at the feeder throat. Narrowing down the section also prevented the fertilizer from being blown back because the static head that was present between the fan and the feeder was converted to velocity head. Reducing the static pressure to a minimum at the entry section expedited the entry of fertilizer into the duct. Air movement from the feeder throat to the fertilizer conveying tubes at fan speeds of 2160, 2400, and 2875 r.p.m. was minimal, however at, fan speeds lower than 2160 r.p.m. and throughput of 6.33 lb/min of ammonium sulphate the air was blown back into the fertilizer hopper.

5.2.5 Throughput

In the design of pneumatic conveying systems one must know the air-material ratio in terms of cubic feet of air per pound of material. In Figure 5.14 the volume of air in cfm has been plotted against throughput in lb/min. Both ammonium sulphate and urea tend to show a linear relationship at 2875 r.p.m. In Figure 5.15 the throughput has been plotted against Reynolds number which is a dimensionless group of $VD\rho/\mu$. Of these, V is the velocity, D is the diameter, ρ the mass density, and μ the viscosity. Therefore plotting throughput against Reynolds number describes the experiment in its entirety in relation to

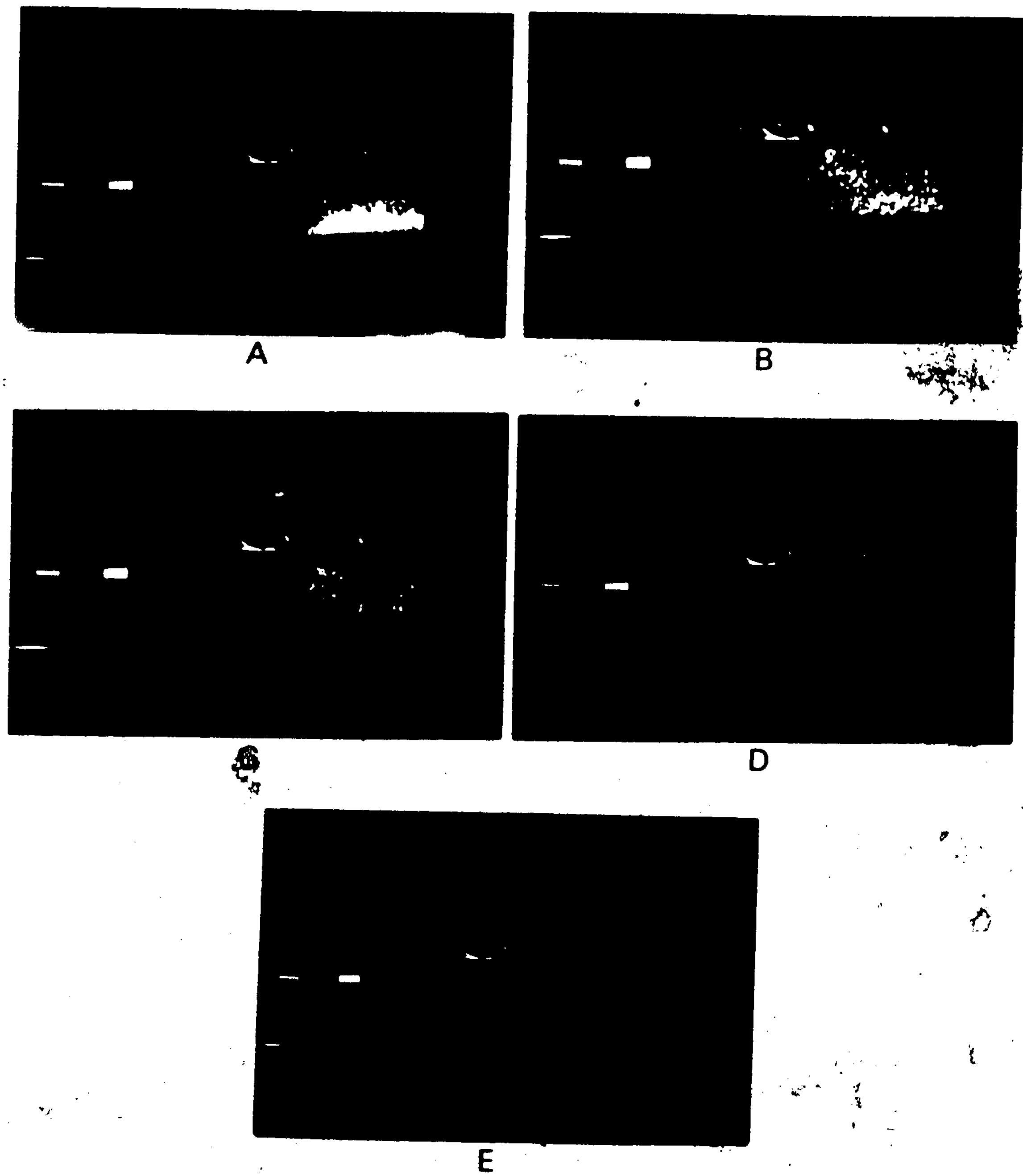
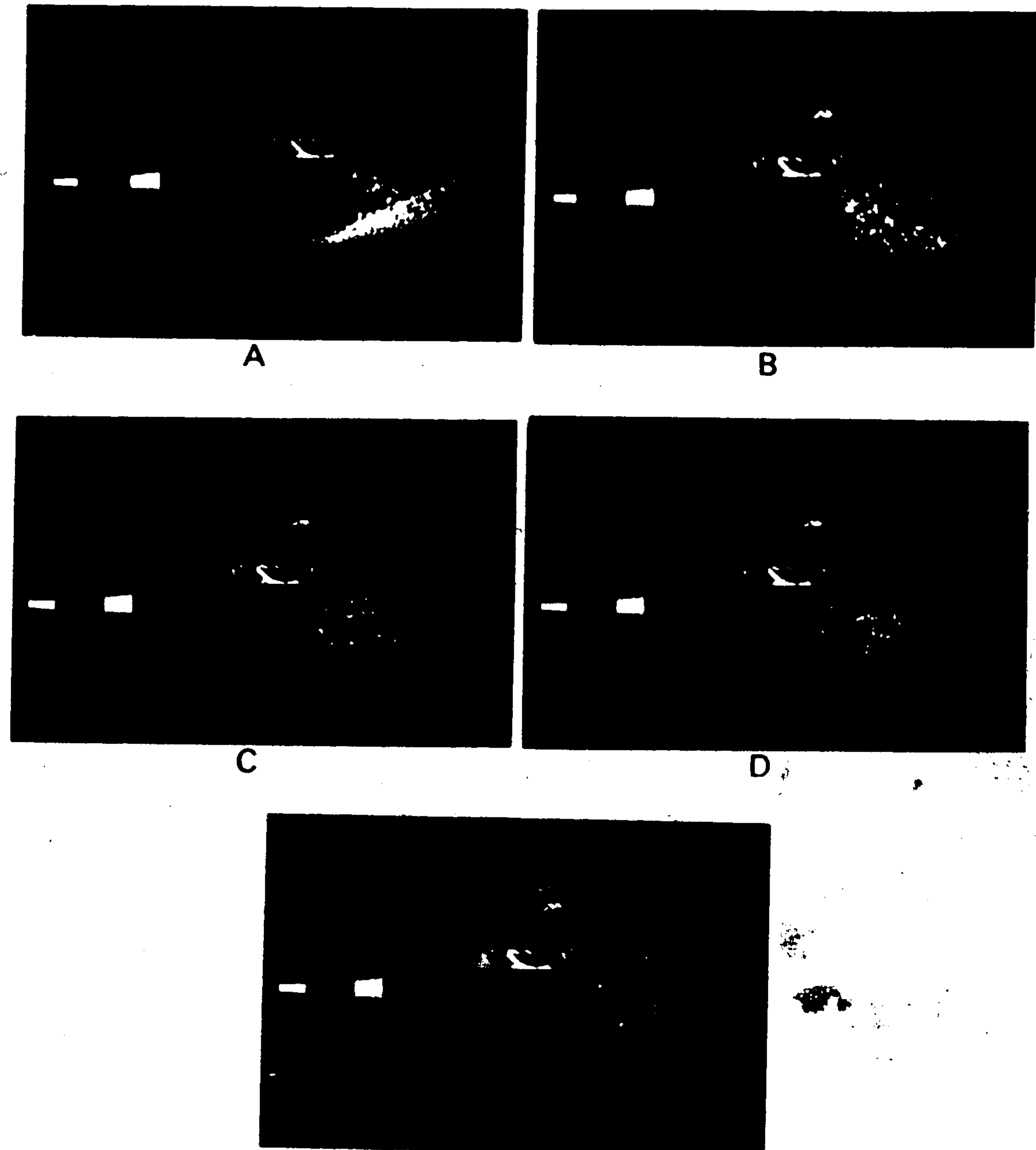


Fig. 5.12 ENTRY OF AMMONIUM SULPHATE IN THE CONVEYING DUCT

A. 1225 r.p.m. B. 1500 r.p.m.

C. 2160 r.p.m. D. 2400 r.p.m.

E. 2875 r.p.m.



A B C D E

Fig. 5.13 ENTRY OF UREA IN THE CONVEYING DUCT.

A. 1225 r.p.m. B. 1500 r.p.m.

C. 2160 r.p.m. D. 2400 r.p.m.

E. 2875 r.p.m.

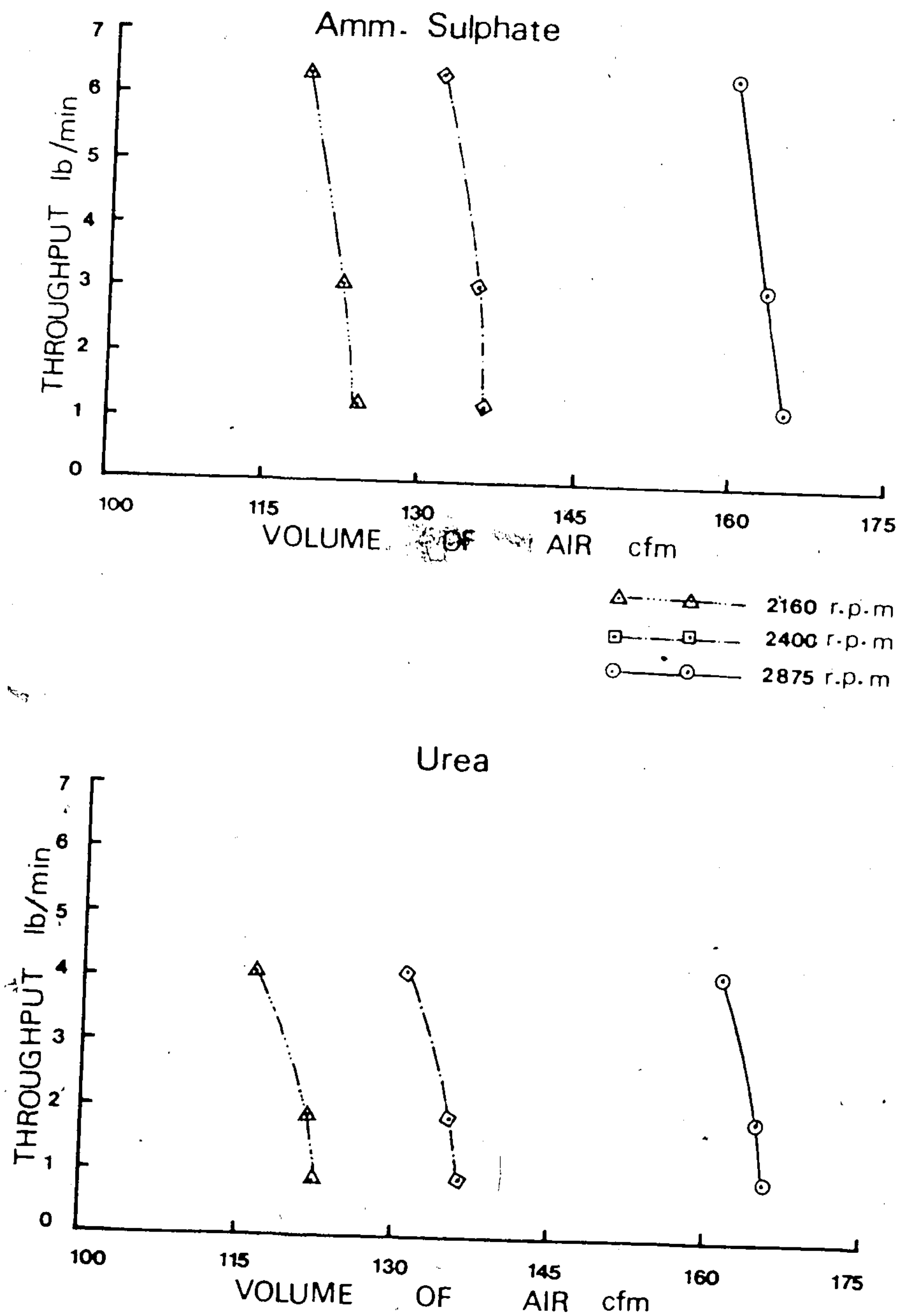


Fig. 5.14 THROUGHPUT OF FERTILIZER VS. VOLUME OF AIR

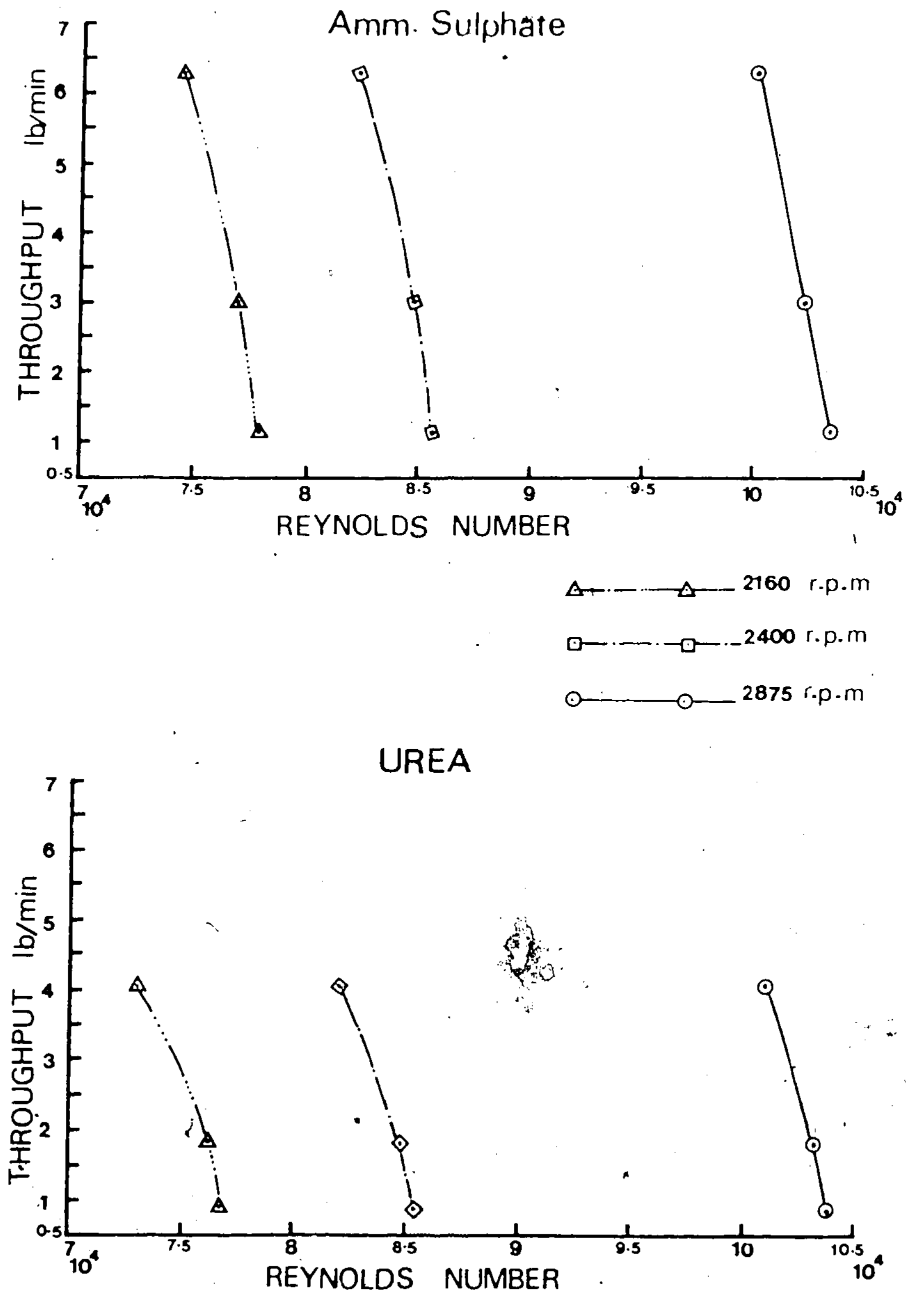


Fig. 5.15 THROUGHPUT VS REYNOLDS NUMBER

the parameters of the Reynolds number.

The distinction between static and total pressure is important because the former is conventionally used as the basis for the system design, but the latter determines the actual mechanical energy that must be supplied to the system. In Figures 5.16 and 5.17 throughput has been plotted against static pressure and total pressure for ammonium sulphate and urea. Within the range of the experiment, throughput exhibits a linear relationship against static and total pressure. At higher throughputs urea required more static and total pressure than ammonium sulphate because of its larger particle size. Tables 5.3 and 5.4 summarize the results obtained for pneumatic conveying of fertilizers.

5.3 Multiple Point Distribution of Fertilizer

Dilute-phase conveying was used for two reasons. Firstly, the low air-material ratio used permits handling of materials with a minimum of contact between particles, resulting in less break-up and dust. This makes the system ideal for handling a variety of particle shapes and sizes without blockage. Thus with the new fertilizer applicator, a farmer can also diversify his operations by spraying insecticide and pesticide powders with the same machine. Secondly, this system carries particles homogeneously dispersed in the air stream.

Concentric mitre bends were used to divide the fertilizer into three fractions. Ower and Pankhurst (1966) state, "some improvement can be effected by rounding of sharp corners of the elbow, particularly the inner corners". Based on the results of Frey*, Ower and Pankhurst suggested that mitre bends with inner corners rounded according to the

*Frey, K., Verminderung des Strömungswiderstandes von Körpern durch Leitflächen, Forsch. Ing. Wes. 5(1934) 105.

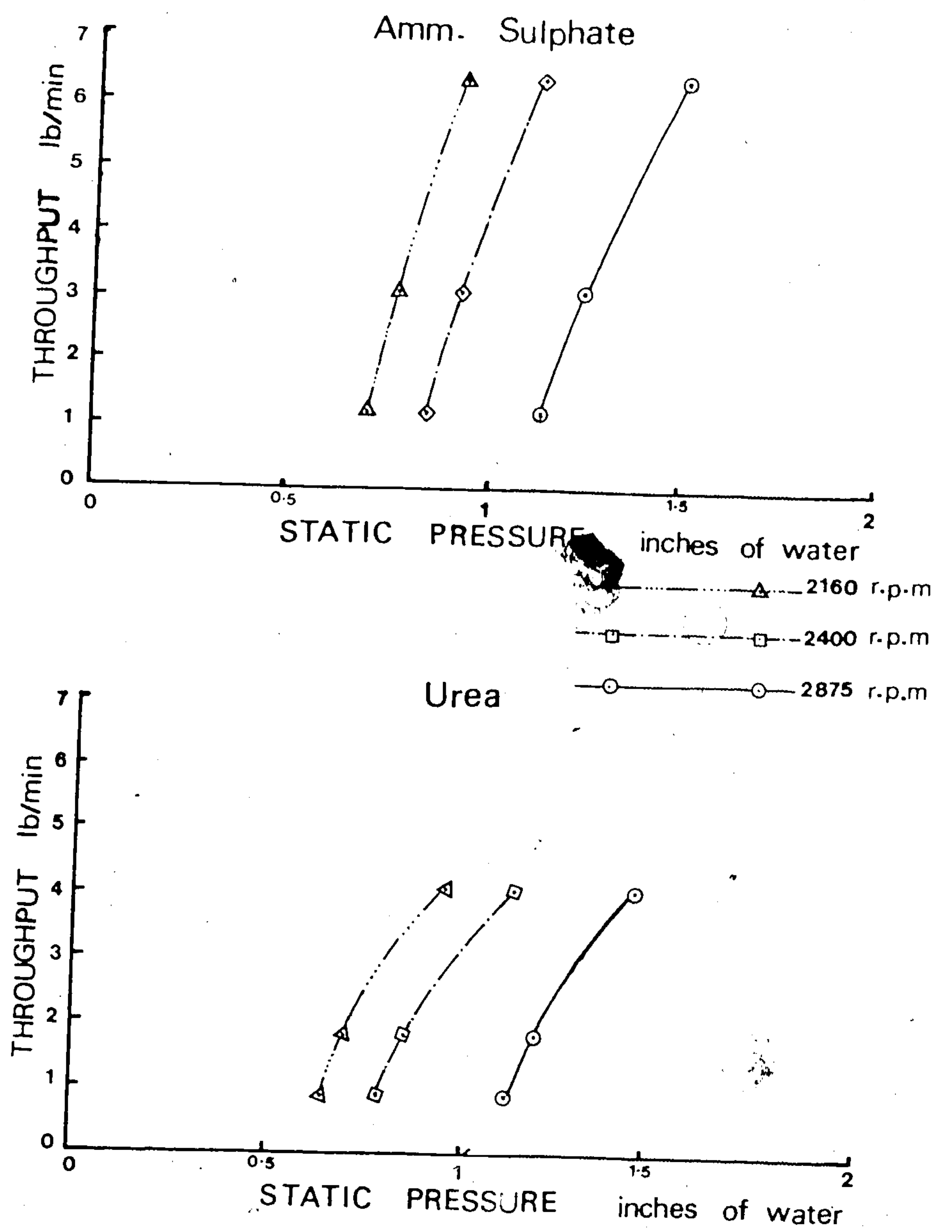


Fig. 5.16 THROUGHPUT VS. STATIC PRESSURE

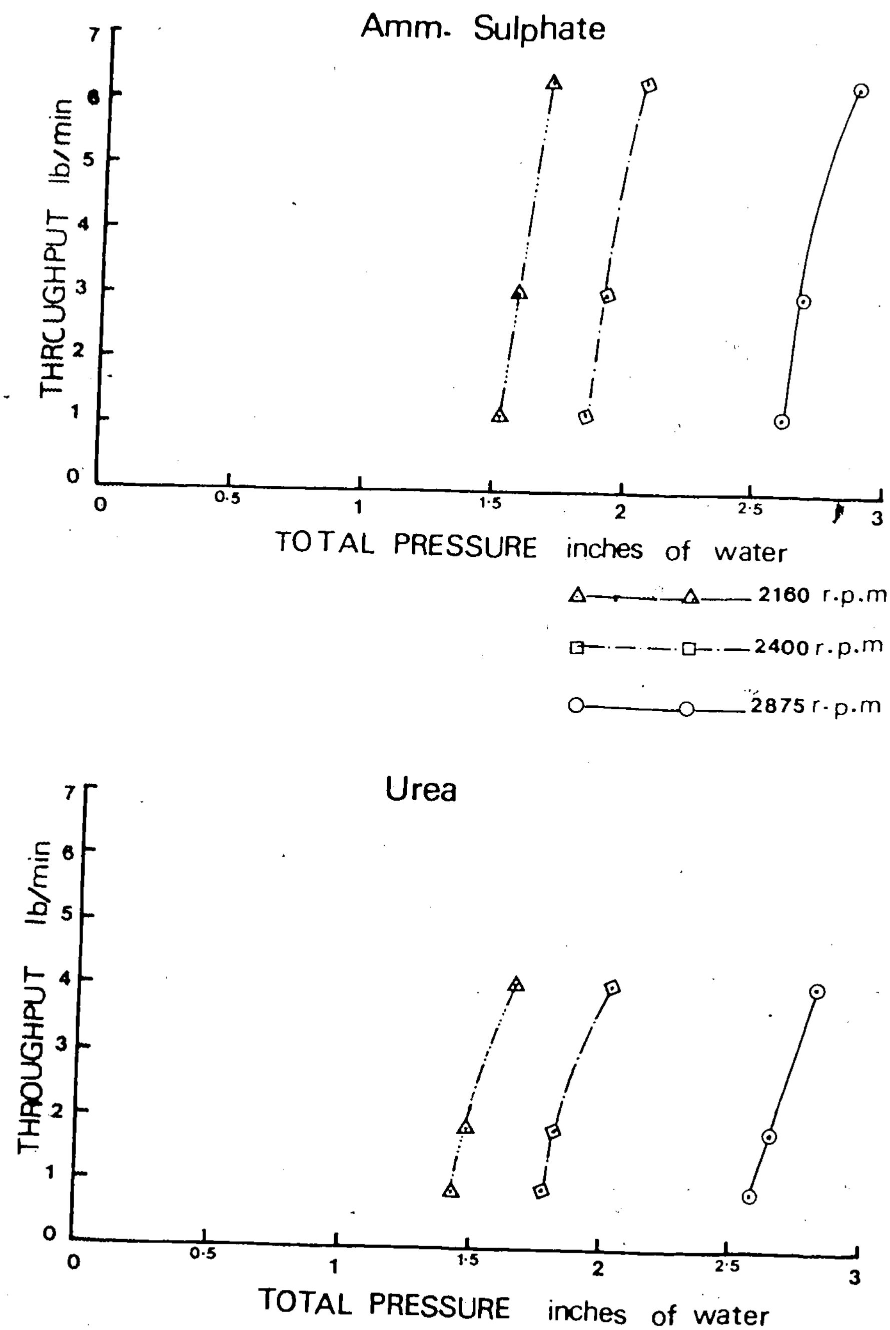


Fig. 5.17 THROUGHPUT VS. TOTAL PRESSURE

Table 5.3 PNEUMATIC CONVEYING CHARACTERISTICS. DATA FOR AMMONIUM SULPHATE.

R.P.M.	Throughput lb./min.	Rate of Flow cu.ft/min.	Reynolds Number	Total Pressure in.water	Static Pressure in.water
2160	1.19	124.3	7.782E+04	1.53	0.70
	3.05	122.7	7.683E+04	1.59	0.78
	6.33	118.6	7.429E+04	1.70	0.94
2400	1.19	136.7	8.559E+04	1.85	0.85
	3.05	135.3	8.471E+04	1.92	0.94
	6.33	131.3	8.219E+04	2.06	1.13
2875	1.19	165.1	1.034E+05	2.61	1.15
	3.05	163.2	1.022E+05	2.68	1.25
	6.33	159.7	1.000E+05	2.87	1.50

Table 5.4 PNEUMATIC CONVEYING CHARACTERISTICS. DATA FOR UREA.

R.P.M.	Throughput lb/min	Rate of Flow cu.ft/min	Reynolds Number	Total Pressure in. water	Static Pressure in. water
2160	0.89	122.5	7.673E+04	1.45	0.64
	1.84	121.7	7.619E+04	1.50	0.70
	4.09	116.4	7.288E+04	1.68	0.95
2400	0.89	136.5	8.548E+04	1.79	0.79
	1.84	135.3	8.473E+04	1.83	0.85
	4.09	130.9	8.196E+04	2.04	1.12
2875	0.89	165.9	1.039E+05	2.60	1.12
	1.84	164.9	1.032E+05	2.64	1.18
	4.09	161.3	1.010E+05	2.83	1.43

formula, $\frac{r_i}{h} = 0.25$, where r_i = inner radius, and h = height or diameter of duct, offered least resistance to air flow. The mitre bends were designed such that each concentric circle facing the air stream has the same area, thus having a probability that each of the mitre bends will catch the same number of particles from the air stream. Table 5.5 shows the fractions caught in the three mitre bends. This component did not work as anticipated. The outer bend always carried double the amount of fertilizer by weight as compared to the inner bend. More trials are needed before efficient distribution from such bends can be achieved. The only reason which can be attributed to this di epancy is the non homogeneous dispersion of fertilizer p icles in the conveying duct.

5.4 Design of Prototype

The dynamic similitude as outlined by Yalin (1971) between model and prototype requires (1) that there be exact geometric similitude and (2) that the ratio of dynamic pressures at corresponding points be a constant; i.e. the stream lines must be geometrically similar. In steady flow in a pipe, viscous and inertial forces are the only ones of consequence; hence, for geometric similitude, the same Reynolds number in the model and prototype provides dynamic similitude. Therefore the Reynolds number obtained from the study should provide the dynamic similarity if the design of the prototype is based on this. A suggested procedure for the design of a pneumatic system is given below.

i. Determine the superficial velocity of the flow of air from the model study. In the design of prototypes based on

Table 5.5 DISTRIBUTION OF AMMONIUM SULPHATE FROM MITRE BENDS.

S. No	Hopper Notch Setting	Weight of fertilizer			% of fertilizer		
		Outer kg	Center kg	Inner kg	Outer	Center	Inner
1	10	5.434	2.498	1.868	55.45	25.[illegible]	19.06
2		5.410	2.538	1.988	54.45	25.5[illegible]	20.00
3		5.820	2.339	1.800	58.44	23.49	18.07
4	6	3.198	1.820	1.539	48.77	27.76	23.47
5		3.030	1.843	1.612	46.72	28.42	24.86
6		3.108	1.863	1.647	46.96	28.15	24.89
7	3	1.157	0.819	0.772	42.10	29.803	28.09
8		1.131	0.872	0.750	41.08	31.68	27.24
9		1.163	0.837	0.791	41.670	29.99	28.34
				Average %	48.40	27.81	23.78

Reynolds number the velocity is inversely proportional to the ratio of the length scale between prototype and model. Because of blockages set by the material in the pneuma conveying pipe line, strict fulfillment of this requir is generally impossible to achieve.

ii. Models based on Reynolds number require that the scales of μ and ρ be taken as one. To fulfill this requirement calculate ρ in the model from the data obtained.

$$\rho = \frac{(\text{Weight of air}) + (\text{Weight of material})}{\left(\begin{array}{c}\text{Specific volume of air at}\\ \text{average pipe conditions}\end{array}\right) + (\text{Volume of material})}$$

iii. From the material flow rate obtained during the test and the area of the test pipeline, calculate the mass rate flow in pounds per minute per square foot of pipe area.

iv. To determine the pipe size calculate the ratio of the required rate of material flow to the mass rate of flow. This ratio is the area of the pipeline for the prototype in ft^2.

v. Compare this area with the area of the commercial sizes of pipes and select the size that co sponds closely with the area.

vi. Determine the prototype air flow requirement by multiplying the value of velocity obtained from step one with the area of the pipe selected.

The following data was obtained from this study and this data can be used for design purposes.

Air flow ------ 159 cfm at standard conditions (14.7 psi pressure, 70°F temperature)

Material flow - 4.09 lb/min of urea

6.33 lb/min of ammonium sulphate.

Blower data - Total discharge pressure at inlet to conveying

line 2.87 in. of water.

Reynolds number - 1.0×10^5

Velocity - 4685 fpm.

Test line - 2.5 in. inside diameter, drawn tube of plexiglass.

CHAPTER 6

Recommendations For Further Work

Based on the results obtained in this study the following further work should be undertaken:

i. The relationship between pipe diameter and throughput should be investigated to select the optimum pipe size for conveying.

ii. This study is based on a maximum throughput of 6.33 lb/min ammonium sulphate and total pressure of 2.5 inch of water. As in hydraulic models, extrapolation is not recommended, therefore further work should be done with higher pressures and throughputs to extend the range of the experiment.

iii. Flowability of fertilizers is profoundly affected by changes in the relative humidity of the atmosphere in which they are stored, and only slightly by differences in temperature. This phase was not investigated in this thesis, therefore the study of the effect of humidity would be worthwhile.

iv. A number of mechanical components needed for the final design of a pneumatic system need investigation. Mitre bends were investigated for metering and distribution of fertilizer; however to perfect them further work is needed.

v. Another important component which needs consideration is some device to disperse excess velocity of air before fertilizer enters the soil. This is necessary to prevent the blowing of soil particles into the atmosphere and to prevent fertilizer scattering because of rebound from the soil surface.

CHAPTER 7

SUMMARY AND CONCLUSIONS

The thesis was primarily associated with the design of fertilizer placement equipment which does not have the inherent disadvantage of the gravity flow system, i.e., frequent stoppage of fertilizer flow in the conveying tubes. A heavy duty cultivator unit equipped with two fertilizer hoppers and associated metering equipment was t in field conditions. Various boots were designed for this cultivator unit and were mounted behind the chisel points to have minimum interference with the basic operation of the cultivator. The equipment worked well at low application rates of fertilizer; however, the conveying tubes showed a tendency to plug at higher application rates.

Some mechanical refinement to the equipment was desired. The use of pneumatic power to give additional velocity to the fertilizer particles moving in the conveying tubes was assessed. Two possible alternatives, a medium-air pressure, and a low pressure high volume system, were investigated.

Both of these systems require pneumatic conveying of fertilizers and the art of conveying lies in an intimacy with which rheological properties of the material under consideration are known. Therefore rheological properties namely, density, particle size, and angle of repose for ammonium sulphate and urea were established. The following table summarizes the rheological properties of the fertilizers used.

Property	Amm. Sulphate	Urea
Density	69.87 lb/ft^3	48.70 lb/ft^3
Avg. Particle Size	0.060 inch	0.115 inch
Angle of Repose	27°	23°

The medium-air pressure system was investigated in an attempt to prevent frequent plugging of fertilizer conveying tubes. Air at 30 psig was injected into the conveying tubes by nozzles. The method did not prove successful because of limitations in size and space in the fertilizer conveying tubes.

As the information available on fertilizer conveying was meagre the design data required for the low pressure conveying system was obtained by actual tests performed on ammonium sulphate and urea in an experimental air-duct. The duct was designed according to the standards set by ASHRE for measurement of air flow for rating purposes.

The basic fan characteristics, and velocity profile in the duct with two "Canadian Blower 2E" fans arranged in series were established. Various throughputs of the fertilizers were introduced to find the optimum superficial air velocity that would convey the fertilizer without causing blockage in the air-duct. An increase in the amount of fertilizer affected the velocity profile in the duct from which the blockage limit could be determined. Results based on this approach indicate that blockage in the duct did not exist at a Reynolds number of 1.0×10^5. The throughput of ammonium sulphate in the duct at this Reynolds number was 6.33 lb/min.

The results were expressed in terms of Reynolds number because this number expresses the relationship between velocity of air, diameter of duct, and kinematic viscosity. The Reynolds number also provides dynamic similitide between prototype and model in flows which are limited by rigid flow boundaries. This criteria has been used for design procedure of scale up.

To predict energy losses due to airflow in pneumatic conveying the Darcy-Weisbach equation is generally used. In the design of a pneumatic assisted fertilizer applicator losses of energy can be accounted for if the friction factor f is known. To find the friction factor in the conveying unit, the empirical formula obtained by Blasis was used. The results indicate that this factor did not change appreciably when fertilizer was introduced into the duct. This may have been due to the Magnus effect of rotation that assists the flight of the particles. Therefore for design purposes the friction factor can be obtained from Moody's diagram and this can be used with caution after adding a safety margin.

The following data was obtained from this study, which can be used for design purposes.

Air flow	159 cfm at standard conditions (14.7 psi pressure, 70°F temperature)
Material flow..........	6.35 lb/min of ammonium sulphate. 4.09 lb/min of urea.
Blower data	Total discharge pressure at inlet to conveying line 2.87 in. of water.
Reynolds number	1.0×10^5
Velocity	4685 fpm.
Test line	2.5 in. inside diameter, drawn tube of plexiglass.

For multiple point distribution of the fertilizer from the central conveying duct, the feasibility of using concentric mitre bends was investigated. The outer bend always carried more fertilizer because of non-homogeneous dispersion of fertilizer particles in the duct.

The design suggested offers a possibility of pneumatic assisted fertilizer application to the soil. However, before a prototype could be attempted detailed investigations are needed for a number of mechanical components, namely mitre bends and a device to disperse excess velocity of air before fertilizer enters the soil.

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Appendix A

Computation of Results.

A - 1 DEFINITIONS RELATING VARIABLES USED IN COMPUTER PROGRAMME FOR DETERMINATION OF FAN DELIVERY VOLUME

AVGS = average static pressure in the duct, in. of water.

CORVEL = vertical velocity pressure corrected to standard air conditions, in. of water.

CORVST = vertical static pressure corrected to standard air conditions, in. of water.

F = friction factor.

J. = traverse points in the duct.

PVPR = partial vapor pressure in atmosphere, in. of Hg.

Q = volume rate of flow, cfm.

RAYNO = Reynolds number.

RHOAIR = density of atmospheric air, lb/ft^3.

SATVPR = saturated vapor pressure at wet bulb temperature, in. of Hg.

SAVGV = average velocity pressure in the duct, in. of water.

SQCOR = square root of velocity pressure.

STDRHO = correction factor for air density.

STATPR or ISTAT = observed static pressure, mm of water.

SUMS = sum of corrected static pressure for the traverse.

SUMV = sum of the velocity pressure for the traverse.

TEMPA = dry-bulb temperature, °F.

TEMPW = wet-bulb temperature, °F.

V = velocity of air in the duct, fpm.

VEL = velocity of air at individual traverse points.

VELPR or IVEL = observed velocity pressure, mm of water.

VSTATI = vertical static pressure, in. of water.

VSTATP = vertical static pressure, mm. of water.

VVELPI = vertical velocity pressure, in. of water.

VVELPR = vertical velocity pressure, mm of water.

A-2 COMPUTATION OF RESULTS

A detailed description of computations of several basic quantities required in the final calculations is given below:

Density of Atmospheric air*:

The density of atmospheric air as determined from the observed barometric pressure and the dry and wet bulb temperature of the atmospheric air in the vicinity of the fan inlet:

$$\rho a = \frac{P_a - 0.38p_p}{0.754T_a}$$

ρa = Density of atmospheric air, lb/cu. ft.

T_a = Absolute temperature of atmospheric air, °F + 460.

P_a = Barometric pressure, in. of Hg.

p_p = Partial vapor pressure in atmosphere, in of Hg.

$$p_p = P_g - \frac{P_a(t_a - t_w)}{2700}$$

P_g = Saturated vapor pressure at wet bulb temperature. In. of Hg (from steam tables corresponding to t_w)

t_a = Dry-bulb temperature, °F.

t_w = Wet-bulb temperature, °F.

Correction factor for air Density*:

At constant speed, pressure varies directly as the ratio of air densities. Therefore to correct to standard air conditions, the observed values were multiplied by the ratio of air densitie

$$\frac{\rho a_s}{\rho a_a} = \frac{0.075}{\rho a_a}$$

*Madison, R.D. (1948).

Average Static Pressure*:

At the pressure measuring station, the pressure traverse gave twenty readings of static pressure, one for each traverse point (Fig. 3.8). An arithmetic average of these readings, corrected to standard air conditions yielded a static pressure at the plane of traverse.

Average Velocity Pressure*:

At the same pressure measuring station; a velocity traverse gave twenty readings ov velocity pressure; one for ach t v se point. The readings were corrected to standard air nd the square root of each corrected reading was then taken .verage calculated. The average squared yielded true average velocity pressure.

Velocity, at Plane of Traverse*:

$$V = 60\sqrt{\frac{2g.h \times d_w}{12\rho a_s}} = 1096.2\sqrt{\frac{P_v}{\rho a_s}}$$

V = Average velocity in duct at plane of traverse, fpm

P_v = Velocity pressure at plane of traverse, in. water

ρa_s = Density of air, lb. per cu. ft.

Volume Rate of Flow*:

$$Q = A \times V$$

Q = Volume of air flow, at plane of traverse, cfm

V = Velocity at plane of traverse, fpm

A = Area of duct at plane of traverse, sq ft.

Reynolds Number*:

$$R_e = \frac{D \times V \times \rho a}{60 \times \mu}$$

*Madison, R.D. (1948).

D = Duct diameter, ft.

V = Velocity of air, fpm

ρa = Density of air, lb per cft

μ = Viscosity of air, lb.s/ft^2

Friction Factor[+]:

$$f = \frac{0.316}{R_e^{.25}}$$

f = Friction factor

R_e = Reynolds number

[+] Streeter, V.L. and E.B. Wylie (1975).

A-3 COMPUTER PROGRAMME FOR DETERMINATION OF FAN DELIVERY VOLUME.

```
MTS  FORTRAN IV G CCMFILER (OS REL 21.8)                        MAIN

      DIMENSION BAROPR(20),SATVPR(20),TEMPA(20),TEMPW(20),
     5STATPR(20),VELPR(20),STDRHO(20),RHOAIR(20),VEL(20),
     5VSTATP(20),VSTATI(20),CORVST(20),VVELPI(20),CCRVEL(20),
     5ISTAT(20),IVEL(20),J(20)
      READ (5,100) N
100   FORMAT (I3)
      SUMS=0
      SUMV=0
      RHODUC=0
      READ (5,105) (BAROPR(I),SATVPR(I),TEMPA(I),TEMPW(I),
     5VELPR(I),STATPR(I),I=1,N)
105   FORMAT(F8.3,1X,F5.4,1X,F5.2,1X,F5.2,13X,F5.0,1X,F5.0)
      DO200 I=1,N
      J(I)=I
      IVEL(I)=VELPR(I)
      ISTAT(I)=STATPR(I)
      PVPR=SATVPR(I)-BAROPR(I)*(TEMPA(I)-TEMPW(I))/2700
      RHOAIR(I)=(BAROPR(I)-0.38*PVPR)/(0.754*(460+TEMPA(I)))
      STDRHO(I)=0.075/RHOAIR(I)
      VSTATP(I)=STATPR(I)*0.25663
      VSTATI(I)=VSTATP(I)/25.4
      CORVST(I)=VSTATI(I)*STDRHO(I)
      SUMS=SUMS+CCRVST(I)
      VVELPR=VELPR(I)*0.25663
      VVELPI(I)=VVELPR/25.4
      CORVEL(I)=VVELPI(I)*STDRHO(I)
      VEL(I)=1096.2*(SQRT(CORVEL(I)/.075))
      SQCOR=SQRT(CCRVEL(I))
200   SUMV=SUMV+SQCOR
      AVGS=SUMS/N
      AVGV=SUMV/N
      SAVGV=AVGV*AVGV
      V=1096.2*(SQRT((AVGV*AVGV)/.075))
      IV=V
      Q=0.034088462*V
      RAYNO=(V*2.5/12)/(60*1.22E-05/.075)
      F=0.316/RAYNO**0.25
      PRINT250
250   FORMAT('1',14(/),11X,'TRAV.',2X,'BAROMET.',1X,'D.BULB',1X,
     5'WETBULB',1X,'O.ST.O.VEL.SAT.VP.',2X,'DENSITY',1X,
     5'COR.FAC.','CR.ST.CR.VEL. VELOCITY')
      PRINT260
260   FORMAT(11X,'POINT',2X,' PRES.',3X,'TEMP.',3X,'TEMP.',2X,
     5'PRES.PRES.',2X,'PRES.',5X,'AIR',3X,'DENSITY',2X,'PRES.',
     52X,'PRES.',2X,'OF AIR')
      PRINT270
270   FORMAT(/,17X,'(IN.HG)',3X,'( F)',4X,'( F)',3X,'(MM)',1X,'(MM)',
     52X,'(IN.HG)',1X,'(LB./C.FT)',8X,'(INW)',1X,'(INW)',1X,'    (FPM)')
      WRITE(6,300)(J(I),BARCPR(I),TEMPA(I),TEMPW(I),ISTAT(I),IVEL(I),
     5SATVFR(I),RHOAIR(I),STCRHO(I),CORVST(I),CCFVEL(I),VEL(I),I=1,N)
300   FORMAT(12X,I2,4X,F6.3,3X,F5.2,3X,F5.2,2X,I3,2X,I3,3X,F6.4,3X,F6.4,
     52X,F6.4,3X,F4.2,3X,F4.2,3X,F7.1)
      PRINT340
340   FORMAT(/,11X,'RATE OF',8X,'REYNOLDS',6X,'FRICTION',6X,' AVG.STATIC'
     5,6X,'AVG.VELOCITY',10X,'AVERAGE')
      PRINT345
345   FORMAT(12X,'FLOW',11X,'NUMBER',8X,'FACTOR',8X,'PRESSURE',9X,
     5'PRESSURE',12X,'VELOCITY')
      WRITE(6,350)Q,RAYNO,F,AVGS,SAVGV,IV
350   FORMAT(/,11X,F5.1,1X,'CFM',3X,1PE10.3,7X,0PF6.4,8X,F4.2,1X,
     5'INW',9X,F4.2,1X,'INW',13X,I4,1X,'FPM',10(/))
      STOP
      END
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APPENDIX B

Observations and Computations

for System Performance Characteristics.

TABLE B-1: OBSERVATIONS AND COMPUTATIONS FOR FAN PERFORMANCE CHARACTERISTICS AT 2160 r.p.m.
Fan - Full open.

Measuring Station - Upstream

TRAV. POINT	BAROMET. PRES.	D.BULB TEMP.	WETBULB TEMP.	O.ST. PRES.	O.VEL. PRES.	SAT.VP. PRES.	DENSITY AIR	COR.FAC. DENSITY	CR.ST. PRES.	CR.VEL. PRES.	VELOCITY OF AIR
	(IN.HG)	(F)	(F)	(MM)	(MM)	(IN.HG)	(LB./C.FT)		(INW)	(INW)	(FPM)
1	27.782	70.88	61.70	54	78	0.5543	0.0690	1.0874	0.59	0.86	3705.5

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AVG.STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
126.3 CFM	7.910E+04	0.0188	0.59 INW	0.86 INW	3705 FPM

Measuring Station - Downstream

TRAV. POINT	BAROMET. PRES.	D.BULB TEMP.	WETBULB TEMP.	O.ST. PRES.	O.VEL. PRES.	SAT.VP. PRES.	DENSITY AIR	COR.FAC. DENSITY	CR.ST. PRES.	CR.VEL. PRES.	VELOCITY OF AIR
	(IN.HG)	(F)	(F)	(MM)	(MM)	(IN.HG)	(LB./C.FT)		(INW)	(INW)	(FPM)
1	27.782	70.88	61.70	15	60	0.5543	0.0690	1.0874	0.16	0.66	3249.9

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AVG.STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
110.8 CFM	6.937E+04	0.0195	0.16 INW	0.66 INW	3249 FPM

TABLE B-2: OBSERVATIONS AND COMPUTATIONS FOR FAN PERFORMANCE CHARACTERISTICS AT 2160 r.p.m.
Fan - 3/4 open.

Measuring Station - Upstream

TRAV. POINT	BAROMET. PRES.	D.BULB TEMP.	WETBULB TEMP.	O.ST. PRES.	O.VEL. PRES.	SAT.VP. PRES.	DENSITY AIR	COR.FAC. DENSITY	CR.ST. PRES.	CR.VEL. PRES.	VELOCITY OF AIR
	(IN.HG)	(F)	(F)	(MM)	(MM)	(IN.HG)	(LB./C.FT)		(INW)	(INW)	(FPM)
1	27.782	70.88	61.70	49	71	0.5543	0.0690	1.0874	0.54	0.78	3535.3

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AVG.STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
120.5 CFM	7.546E+04	0.0191	0.54 INW	0.78 INW	3535 FPM

Measuring Station - Downstream

TRAV. POINT	BAROMET. PRES.	D.BULB TEMP.	WETBULE TEMP.	O.ST. PRES.	O.VEL. PRES.	SAT.VP. PRES.	DENSITY AIR	COR.FAC. DENSITY	CR.ST. PRES.	CR.VEL. PRES.	VELOCITY OF AIR
	(IN.HG)	(F)	(F)	(MM)	(MM)	(IN.HG)	(LB./C.FT)		(INW)	(INW)	(FPM)
1	27.782	70.88	61.70	15	58	0.5543	0.0690	1.0874	0.16	0.64	3195.3

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AVG.STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
108.9 CFM	6.821E+04	0.0196	0.16 INW	0.64 INW	3195 FPM

TABLE B-3: OBSERVATIONS AND COMPUTATIONS FOR FAN PERFORMANCE CHARACTERISTICS AT 2160 r.p.m.
Fan - 1/2 open.

Measuring Station - Upstream

TRAV. POINT	BAROMET. PRES.	D.BULB TEMP.	WETBULB TEMP.	O.ST. PRES.	O.VEL. PRES.	SAT.VP. PRES.	DENSITY AIR	COR.FAC. DENSITY	CR.ST. PRES.	CR.VEL. PRES.	VELOCITY OF AIR
	(IN.HG)	(F)	(F)	(MM)	(MM)	(IN.HG)	(LB./C.FT)		(INW)	(INW)	(FPM)
1	27.782	70.88	61.70	42	54	0.5543	0.0690	1.0874	0.46	0.59	3083.2

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AVG.STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
105.1 CFM	6.581E+04	0.0197	0.46 INW	0.59 INW	3083 FPM

Measuring Station - Downstream

TRAV. POINT	BAROMET. PRES.	D.BULB TEMP.	WETBULB TEMP.	O.ST. PRES.	O.VEL. PRES.	SAT.VP. PRES.	DENSITY AIR	COR.FAC. DENSITY	CR.ST. PRES.	CR.VEL. PRES.	VELOCITY OF AIR
	(IN.HG)	(F)	(F)	(MM)	(MM)	(IN.HG)	(LB./C.FT)		(INW)	(INW)	(FPM)
1	27.782	70.88	61.70	13	47	0.5543	0.0690	1.0874	0.14	0.52	2876.4

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AVG.STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
98.1 CFM	6.140E+04	0.0201	0.14 INW	0.52 INW	2876 FPM

TABLE B-4: OBSERVATIONS AND COMPUTATIONS FOR FAN PERFORMANCE CHARACTERISTICS AT 2160 r.p.m.

Measuring Station - Upstream

TRAV. POINT	BAROMET. PRES. (IN.HG)	D.BULB TEMP. (F)	WETBULB TEMP. (F)	O.ST. PRES. (MM)	O.VEL. PRES. (MM)	SAT.VP. PRES. (IN.HG)	DENSITY AIR (LB./C.FT)	COR.FAC. DENSITY	CR.ST. PRES. (INW)	CR.VEL. PRES. (INW)	VELOCITY OF AIR (FPM)
1	27.782	70.88	61.70	30	42	0.5543	0.0690	1.0874	0.33	0.46	2719.1

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AVG.STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
92.7 CFM	5.804E+04	0.0204	0.33 INW	0.46 INW	2719 FPM

Measuring Station - Downstream

TRAV. POINT	BAROMET. PRES. (IN.HG)	D.BULB TEMP. (F)	WETBULB TEMP. (F)	O.ST. PRES. (MM)	O.VEL. PRES. (MM)	SAT.VP. PRES. (IN.HG)	DENSITY AIR (LB./C.FT)	COR.FAC. DENSITY	CR.ST. PRES. (INW)	CR.VEL. PRES. (INW)	VELOCITY OF AIR (FPM)
1	27.782	70.88	61.70	12	34	0.5543	0.0690	1.0874	0.13	0.37	2446.5

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AVG.STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
83.4 CFM	5.222E+04	0.0209	0.13 INW	0.37 INW	2446 FPM

TABLE B-5: OBSERVATIONS AND COMPUTATIONS FOR FAN PERFORMANCE CHARACTERISTICS AT 2400 r.p.m.
Fan - Full open.

Measuring Station - Upstream

TRAV. POINT	BAROMET. PRES.	D.BULB TEMP.	WETBULB TEMP.	O.ST. PRES.	O.VEL. PRES.	SAT.VP. PRES.	DENSITY AIR	COR.FAC. DENSITY	CR.ST. PRES.	CR.VEL. PRES.	VELOCITY OF AIR
	(IN.HG)	(F)	(F)	(MM)	(MM)	(IN.HG)	(LB./C.FT)		(INW)	(INW)	(FPM)
1	27.797	71.24	60.80	65	88	0.5369	0.0690	1.0871	0.71	0.97	3935.3

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AVG.STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
134.1 CFM	8.400E+04	0.0186	0.71 INW	0.97 INW	3935 FPM

Measuring Station - Downstream

TRAV. POINT	BAROMET. PRES.	D.BULB TEMP.	WETBULB TEMP.	O.ST. PRES.	O.VEL. PRES.	SAT.VP. PRES.	DENSITY AIR	COR.FAC. DENSITY	CR.ST. PRES.	CR.VEL. PRES.	VELOCITY OF AIR
	(IN.HG)	(F)	(F)	(MM)	(MM)	(IN.HG)	(LB./C.FT)		(INW)	(INW)	(FPM)
1	27.797	71.24	60.80	19	75	0.5369	0.0690	1.0871	0.21	0.82	3633.0

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AVG.STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
123.8 CFM	7.755E+04	0.0189	0.21 INW	0.82 INW	3633 FPM

TABLE B-6: OBSERVATIONS AND COMPUTATIONS FOR FAN PERFORMANCE CHARACTERISTICS AT 2400 r.p.m.
Fan - 3/4 open.

Measuring Station - Upstream

TRAV. POINT	BAROMET. PRES.	D.BULB TEMP.	WETBULE TEMP.	O.ST. PRES.	O.VEL. PRES.	SAT.VP. PRES.	DENSITY AIR	COR.FAC. DENSITY	CR.ST. PRES.	CR.VEL. PRES.	VELOCITY OF AIR
	(IN.HG)	(F)	(F)	(MM)	(MM)	(IN.HG)	(LB./C.FT)		(INW)	(INW)	(FPM)
1	27.79	1.24	60.80	60	84	0.5369	0.0690	1.0871	0.66	0.92	3844.8

RATE OF FLOW	YNOLDS NUMBER	FRICTION FACTOR	AVG.STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
131.1 CFM	8.207E+04	0.0187	0.66 INW	0.92 INW	3844 FPM

Measuring Station - Downstream

TRAV. POINT	BAROMET. PRES.	D.BULB TEMP.	WETBULE TEMP.	O.ST. PRES.	O.VEL. PRES.	SAT.VP. PRES.	DENSITY AIR	COR.FAC. DENSITY	CR.ST. PRES.	CR.VEL. PRES.	VELOCITY OF AIR
	(IN.HG)	(F)	(F)	(MM)	(MM)	(IN.HG)	(LB./C.FT)		(INW)	(INW)	(FPM)
1	27.797	71.24	60.80	17	75	0.5369	0.0690	1.0871	0.19	0.82	3633.0

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AVG.STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
123.8 CFM	7.755E+04	0.0189	0.19 INW	0.82 INW	3633 FPM

TABLE B-7: OBSERVATIONS AND COMPUTATIONS FOR FAN PERFORMANCE CHARACTERISTICS AT 2400 r.p.m.
Fan - 1/2 open.

Measuring Station - Upstream

TRAV. POINT	BAROMET. PRES.	D.BULB TEMP.	WETBULB TEMP.	O.ST. PRES.	O.VEL. PRES.	SAT.VP. PRES.	DENSITY AIR	COR.FAC. DENSITY	CR.ST. PRES.	CR.VEL. PRES.	VELOCITY OF AIR
	(IN.HG)	(F)	(F)	(MM)	(MM)	(IN.HG)	(LB./C.FT)		(INW)	(INW)	(FPM)
1	27.797	71.24	60.80	50	68	0.5369	0.0690	1.0871	0.55	0.75	3459.3

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AVG.STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
117.9 CFM	7.384E+04	0.0192	0.55 INW	0.75 INW	3459 FPM

Measuring Station - Downstream

TRAV. POINT	BAROMET. PRES.	D.BULB TEMP.	WETBULB TEMP.	O.ST. PRES.	O.VEL. PRES.	SAT.VP. PRES.	DENSITY AIR	COR.FAC. DENSITY	CR.ST. PRES.	CR.VEL. PRES.	VELOCITY OF AIR
	(IN.HG)	(F)	(F)	(MM)	(MM)	(IN.HG)	(LB./C.FT)		(INW)	(INW)	(FPM)
1	27.797	71.24	60.80	14	60	0.5369	0.0690	1.0871	0.15	0.66	3249.5

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AVG.STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
110.8 CFM	6.936E+04	0.0195	0.15 INW	0.66 INW	3249 FPM

TABLE B-8: OBSERVATIONS AND COMPUTATIONS FOR FAN PERFORMANCE CHARACTERISTICS AT 2400 r.p.m.
Fan - 1/4 open.

Measuring Station - Upstream

TRAV. POINT	BAROMET. PRES.	D.BULB TEMP.	WETBULE TEMP.	O.ST. PRES.	O.VEL. PRES.	SAT.VP. PRES.	DENSITY AIR	COR.FAC. DENSITY	CR.ST. PRES.	CR.VEL. PRES.	VELOCITY OF AIR
	(IN.HG)	(F)	(F)	(MM)	(MM)	(IN.HG)	(LB./C.FT)		(INW)	(INW)	(FPM)
1	27.797	71.24	60.80	36	50	0.5369	0.0690	1.0871	0.40	0.55	2966

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AVG.STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
101.1 CFM	6.332E+04	0.0199	0.40 INW	0.55 INW	2966 FPM

Measuring Station - Downstream

TRAV. POINT	BAROMET. PRES.	D.BULB TEMP.	WETBULE TEMP.	O.ST. PRES.	O.VEL. PRES.	SAT.VP. PRES.	DENSITY AIR	COR.FAC. DENSITY	CR.ST. PRES.	CR.VEL. PRES.	VELOCITY OF AIR
	(IN.HG)	(F)	(F)	(MM)	(MM)	(IN.HG)	(LB./C.FT)		(INW)	(INW)	(FPM)
1	27.797	71.24	60.80	14	42	0.5369	0.0690	1.0871	0.15	0.46	2718.7

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AVG.STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
92.7 CFM	5.803E+04	0.0204	0.15 INW	0.46 INW	2718 FPM

TABLE B-9: OBSERVATIONS AND COMPUTATIONS FOR FAN PERFORMANCE CHARACTERISTICS AT 2875 r.p.m.
Fan - Full open.

Measuring Station - Upstream

TRAV. POINT	BAROMET. PRE (IN.HG)	D.BULB TEMP. (F)	WETBULB TEMP. (F)	O.ST. PRES. (MM)	O.VEL. PRES. (MM)	SAT.VP. PRES. (IN.HG)	DENSITY AIR (LB./C.FT)	COR.FAC. DENSITY	CR.ST. PRES. (INW)	CR.VEL. PRES. (INW)	VELOCITY OF AIR (FPM)
1	27.862	72.14	55.04	99	84	0.4365	0.0692	1.0839	1.08	0.92	3839.1
2	[illegible]	72.14	55.04	94	124	0.4365	0.0693	1.0824	1.03	1.36	4661.3
3	27.900	72.50	55.76	92	145	0.4481	0.0692	1.0834	1.01	1.59	5042.8
4	27.900	72.50	55.76	89	159	0.4481	0.0692	1.0834	0.97	1.74	5280.6
5	27.900	72.50	55.76	84	165	0.4481	0.0692	1.0834	0.92	1.81	5379.3
6	27.900	71.60	56.12	85	164	0.4540	0.0693	1.0818	0.93	1.79	5359.1
7	27.900	71.60	56.12	86	157	0.4540	0.0693	1.0818	0.94	1.72	5243.5
8	27.900	71.60	56.12	81	159	0.4540	0.0693	1.0818	0.89	1.74	5276.8
9	27.900	71.60	56.12	81	153	0.4540	0.0693	1.0818	0.89	1.67	5176.3
10	27.891	71.60	56.12	80	105	0.4540	0.0693	1.0822	0.87	1.15	4288.8
11	27.785	71.06	54.14	100	80	0.4225	0.0692	1.0845	1.10	0.88	3747.7
12	27.785	71.06	54.14	97	113	0.4225	0.0692	1.0845	1.06	1.24	4454.1
13	27.764	70.70	56.66	104	127	0.4632	0.0691	1.0857	1.14	1.39	4724.4
14	27.776	69.98	56.12	100	161	0.4540	0.0692	1.0836	1.09	1.76	5314.3
15	27.776	71.06	56.30	100	160	0.4571	0.0691	1.0857	1.10	1.76	5302.9
16	27.782	70.70	55.76	94	161	0.4481	0.0691	1.0846	1.03	1.76	5316.7
17	27.782	70.70	55.76	95	139	0.4481	0.0691	1.0846	1.04	1.52	4940.1
18	27.779	71.49	55.58	92	141	0.4452	0.0691	1.0861	1.01	1.55	4979.1
19	27.779	71.42	55.58	90	124	0.4452	0.0691	1.0860	0.99	1.36	4669.0
20	27.782	71.42	55.58	105	90	0.4452	0.0691	1.0859	1.15	0.99	3977.5

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AVG.STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
165.3 CFM	1.035E+05	0.0176	1.01 INW	1.47 INW	4848 FPM

TABLE B-10: OBSERVATIONS AND COMPUTATIONS FOR FAN PERFORMANCE CHARACTERISTICS AT 2875 r.p.m.
Fan - Full open.

Measuring Station - Downstream

TRAV. POINT	BAROMET. PRES. (IN.HG)	D.BULB TEMP. (F)	WETBULB TEMP. (F)	O.ST. PRES. (MM)	O.VEL. PRES. (MM)	SAT.VP. PRES. (IN.HG)	DENSITY AIR (LB./C.FT)	COR.FAC. DENSITY	CR.ST. PRES. (INW)	CR.VEL. PRES. (INW)	VELOCITY OF AIR (FPM)
1	27.862	72.14	55.04	24	83	0.4365	0.0692	1.0839	0.26	0.91	3816.2
2	27.900	72.14	55.04	24	101	0.4365	0.0693	1.0824	0.26	1.10	4206.8
3	27.900	72.50	55.76	22	115	0.4481	0.0692	1.0834	0.24	1.26	4490.9
4	27.900	72.50	55.76	22	130	0.4481	0.0692	1.0834	0.24	1.42	4774.8
5	27.900	72.50	55.76	21	151	0.4481	0.0692	1.0834	0.23	1.65	5146.0
6	27.900	71.60	56.12	21	146	0.4540	0.0693	1.0818	0.23	1.60	5056.5
7	27.900	71.60	56.12	19	135	0.4540	0.0693	1.0818	0.21	1.48	4862.3
8	27.900	71.60	56.12	19	129	0.4540	0.0693	1.0818	0.21	1.41	4753.0
9	27.900	71.60	56.12	18	118	0.4540	0.0693	1.0818	0.20	1.29	4545.8
10	27.891	71.60	56.12	17	81	0.4540	0.0693	1.0822	0.19	0.89	3766.9
11	27.785	71.06	54.14	28	72	0.4225	0.0692	1.0845	0.31	0.79	3555.4
12	27.785	71.06	54.14	26	104	0.4225	0.0692	1.0845	0.28	1.14	4273.0
13	27.764	70.70	56.66	29	105	0.4632	0.0691	1.0857	0.32	1.15	4295.8
14	27.776	69.98	56.12	25	139	0.4540	0.0692	1.0836	0.27	1.52	4937.9
15	27.776	71.06	56.30	27	148	0.4571	0.0691	1.0857	0.30	1.62	5100.2
16	27.782	70.70	55.76	23	148	0.4481	0.0691	1.0846	0.25	1.62	5097.6
17	27.782	70.70	55.76	26	139	0.4481	0.0691	1.0846	0.28	1.52	4940.1
18	27.779	71.49	55.58	25	130	0.4452	0.0691	1.0861	0.27	1.43	4780.9
19	27.779	71.42	55.58	24	116	0.4452	0.0691	1.0860	0.26	1.27	4515.9
20	27.782	71.42	55.58	28	82	0.4452	0.0691	1.0859	0.31	0.90	3796.6

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AVG.STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
154.6 CFM	9.682E+04	0.0179	0.26 INW	1.28 INW	4535 FPM

TABLE B-11: OBSERVATIONS AND COMPUTATIONS FOR FAN PERFORMANCE CHARACTERISTICS AT 2875 r.p.m.
Fan - 3/4 open.

Measuring Station - Upstream

TRAV. POINT	BAROMET. PRES. (IN.HG)	D.BULB TEMP. (F)	WETBULB TEMP. (F)	O.ST. PRES. (MM)	O.VEL. PRES. (MM)	SAT.VP. PRES. (IN.HG)	DENSITY AIR (LB./C.FT)	COR.FAC. DENSITY	CR.ST. PRES. (INW)	CR.VEL. PRES. (INW)	VELOCITY OF AIR (FPM)
1	27.862	72.14	55.04	86	74	0.4365	0.0692	1.0839	0.94	0.81	3603.3
2	27.900	72.14	55.04	84	116	0.4365	0.0693	1.0824	0.92	1.27	4508.4
3	27.900	72.50	55.76	89	131	0.4481	0.0692	1.0834	0.97	1.43	4793.1
4	27.900	72.50	55.76	78	149	0.4481	0.0692	1.0834	0.85	1.63	5111.8
5	27.900	72.50	55.76	82	138	0.4481	0.0692	1.0834	0.	1.51	4919.5
6	27.900	71.60	56.12	76	135	0.4540	0.0693	1.0818	0.63	1.48	4862.3
7	27.900	71.60	56.12	84	141	0.4540	0.0693	1.0818	0.92	1.54	4969.2
8	27.900	71.60	56.12	74	148	0.4540	0.0693	1.0818	0.81	1.62	5091.0
9	27.900	71.60	56.12	78	138	0.4540	0.0693	1.0818	0.85	1.51	4916.0
10	27.891	71.60	56.12	72	96	0.4540	0.0693	1.0822	0.79	1.05	4100.9
11	27.785	71.06	54.14	95	64	0.4225	0.0692	1.0845	1.04	0.70	3352.0
12	27.785	71.06	54.14	96	99	0.4225	0.0692	1.0845	1.05	1.08	4169.0
13	27.764	70.70	56.66	96	127	0.4632	0.0691	1.0857	1.05	1.39	4724.4
14	27.776	69.98	65.12	94	144	0.4540	0.0691	1.0850	1.03	1.58	5029.1
15	27.776	71.06	56.30	93	148	0.4571	0.0691	1.0857	1.02	1.62	5100.2
16	27.782	70.70	55.76	88	142	0.4481	0.0691	1.0846	0.96	1.56	4993.2
17	27.782	70.70	55.76	88	130	0.4481	0.0691	1.0846	0.96	1.42	4777.5
18	27.779	71.49	55.58	84	126	0.4452	0.0691	1.0861	0.92	1.38	4706.8
19	27.779	71.42	55.58	84	105	0.4452	0.0691	1.0860	0.92	1.15	4296.4
20	27.782	71.42	55.58	98	76	0.4452	0.0691	1.0859	1.08	0.83	3655.1

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AVG.STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
156.3 CFM	9.785E+04	0.0179	0.94 INW	1.31 INW	4583 FPM

TABLE B-12: OBSERVATIONS AND COMPUTATIONS FOR FAN PERFORMANCE CHARACTERISTICS AT 2875 r.p.m.
Fan - 3/4 open.

Measuring Station - Downstream

TRAV. POINT	BAROMET. PRES. (IN.HG)	D.BULB TEMP. (F)	WETBULB TEMP. (F)	O.ST. PRES. (MM)	O.VEL. PRES. (MM)	SAT.VP. PRES. (IN.HG)	DENSITY AIR (LB./C.FT)	COR.FAC. DENSITY	CR.ST. PRES. (INW)	CR.VEL. PRES. (INW)	VELOCITY OF AIR (FPM)
1	27.862	72.14	55.04	21	75	0.4365	0.0692	1.0839	0.23	0.82	3627.6
2	27.900	72.14	55.04	17	97	0.4365	0.0693	1.0824	0.19	1.06	4122.7
3	27.900	72.50	55.76	20	105	0.4481	0.0692	1.0834	0.22	1.15	4291.2
4	27.900	72.50	55.76	13	124	0.4481	0.0692	1.0834	0.14	1.36	4663.3
5	27.900	72.50	55.76	19	132	0.4481	0.0692	1.0834	0.21	1.44	4811.4
6	27.900	71.60	56.12	18	138	0.4540	0.0693	1.0818	0.20	1.51	4916.0
7	27.900	71.60	56.12	17	128	0.4540	0.0693	1.0818	0.19	1.40	4734.6
8	27.900	71.60	56.12	15	121	0.4540	0.0693	1.0818	0.16	1.32	4603.3
9	27.900	71.60	56.12	15	107	0.4540	0.0693	1.0818	0.16	1.17	4328.8
10	27.891	71.60	56.12	14	73	0.4540	0.0693	1.0822	0.15	0.80	3576.1
11	27.785	71.06	54.14	19	64	0.4225	0.0692	1.0845	0.21	0.70	3352.0
12	27.785	71.06	54.14	26	97	0.4225	0.0692	1.0845	0.28	1.06	4126.7
13	27.764	70.70	56.66	27	105	0.4632	0.0691	1.0857	0.30	1.15	4295.8
14	27.776	69.98	65.12	25	126	0.4540	0.0691	1.0850	0.27	1.38	4704.3
15	27.776	71.06	56.30	26	133	0.4571	0.0691	1.0857	0.29	1.46	4834.9
16	27.782	70.70	55.76	24	142	0.4481	0.0691	1.0846	0.26	1.56	4993.2
17	27.782	70.70	55.76	24	128	0.4481	0.0691	1.0846	0.26	1.40	4740.6
18	27.779	71.49	55.58	23	117	0.4452	0.0691	1.0861	0.25	1.28	4535.6
19	27.779	71.42	55.58	22	105	0.4452	0.0691	1.0860	0.24	1.15	4296.4
20	27.782	71.42	55.58	27	73	0.4452	0.0691	1.0859	0.30	0.80	3582.2

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AVG.STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
148.5 CFM	9.300E+04	0.0181	0.23 INW	1.18 INW	4356 FPM

TABLE B-13: OBSERVATIONS AND COMPUTATIONS FOR FAN PERFORMANCE CHARACTERISTICS AT 2875 r.p.m.
Fan - 1/2 open.

Measuring Station - Upstream

TRAV. POINT	BAROMET. PRES. (IN.HG)	D.BULB TEMP. (F)	WETBULB TEMP. (F)	O.ST. PRES. (MM)	O.VEL. PRES. (MM)	SAT.VP. PRES. (IN.HG)	DENSITY AIR (LB./C.FT)	COR.FAC. DENSITY	CR.ST. PRES. (INW)	CR.VEL. PRES. (INW)	VELOCITY OF AIR (FPM)
1	27.862	72.14	55.04	72	58	0.4365	0.0692	1.0839	0.79	0.64	3190.1
2	27.900	72.14	55.04	74	75	0.4365	0.0693	1.0824	0.81	0.82	3625.1
3	27.900	72.50	55.76	65	101	0.4481	0.0692	1.0834	0.71	1.11	4208.7
4	27.900	72.50	55.76	68	106	0.4481	0.0692	1.0834	0.74	1.16	4311.6
5	27.900	72.50	55.76	65	110	0.4481	0.0692	1.0834	0.71	1.20	4392.2
6	27.900	71.60	56.12	66	110	0.4540	0.0693	1.0818	0.72	1.20	4389.0
7	27.900	71.60	56.12	57	120	0.4540	0.0693	1.0818	0.62	1.31	4584.2
8	27.900	71.60	56.12	64	114	0.4540	0.0693	1.0818	0.70	1.25	4468.1
9	27.900	71.60	56.12	55	114	0.4540	0.0693	1.0818	0.60	1.25	4468.1
10	27.891	71.60	56.12	62	72	0.4540	0.0693	1.0822	0.68	0.79	3551.5
11	27.785	71.06	54.14	73	60	0.4225	0.0692	1.0845	0.80	0.66	3245.6
12	27.785	71.06	54.14	76	80	0.4225	0.0692	1.0845	0.83	0.88	3747.7
13	27.764	70.70	56.77	76	99	0.4632	0.0691	1.0857	0.83	1.09	4171.2
14	27.776	69.98	56.12	76	111	0.4540	0.0692	1.0836	0.83	1.22	4412.6
15	27.776	71.06	56.30	74	119	0.4571	0.0691	1.0857	0.81	1.31	4573.3
16	27.782	70.70	55.76	72	110	0.4481	0.0691	1.0846	0.79	1.21	4394.7
17	27.782	70.70	55.76	68	103	0.4481	0.0691	1.0846	0.75	1.13	4252.6
18	27.779	71.49	55.58	67	95	0.4452	0.0691	1.0861	0.74	1.04	4087.0
19	27.779	71.42	55.58	66	82	0.4452	0.0691	1.0860	0.72	0.90	3796.8
20	27.782	71.42	55.58	75	61	0.4452	0.0691	1.0859	0.82	0.67	3274.6

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AVG.STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
138.3 CFM	8.660E+04	0.0184	0.75 INW	1.03 INW	4057 FPM

TABLE B-14: OBSERVATIONS AND COMPUTATIONS FOR FAN PERFORMANCE CHARACTERISTICS AT 2875 r.p.m.
Fan - 1/2 open.

Measuring Station - Downstream

TRAV. POINT	BAROMET. PRES. (IN.HG)	D.BULB TEMP. (F)	WETBULB TEMP. (F)	O.ST. PRES. (MM)	O.VEL. PRES. (MM)	SAT.VP. PRES. (IN.HG)	DENSITY AIR (LB./C.FT)	COR.FAC. DENSITY	CR.ST. PRES. (INW)	CR.VEL. PRES. (INW)	VELOCITY OF AIR (FPM)
1	27.862	72.14	55.04	15	61	0.4365	0.0692	1.0839	0.16	0.67	3271.6
2	27.900	72.14	55.04	13	75	0.4365	0.0693	1.0824	0.14	0.82	3625.1
3	27.900	72.50	55.76	14	85	0.4481	0.0692	1.0834	0.15	0.93	3861.0
4	27.900	72.50	55.76	10	93	0.4481	0.0692	1.0834	0.11	1.02	4038.6
5	27.900	72.50	55.76	14	106	0.4481	0.0692	1.0834	0.15	1.16	4311.6
6	27.900	71.60	56.12	14	107	0.4540	0.0693	1.0818	0.15	1.17	4328.8
7	27.900	71.60	56.12	13	101	0.4540	0.0693	1.0818	0.14	1.10	4205.7
8	27.900	71.60	56.12	11	89	0.4540	0.0693	1.0818	0.12	0.97	3947.9
9	27.900	71.60	56.12	11	83	0.4540	0.0693	1.0818	0.12	0.91	3812.5
10	27.891	71.60	56.12	11	54	0.4540	0.0693	1.0822	0.12	0.59	3075.7
11	27.785	71.06	54.14	17	53	0.4225	0.0692	1.0845	0.19	0.58	3050.4
12	27.785	71.06	54.14	22	73	0.4225	0.0692	1.0845	0.24	0.80	3580.0
13	27.764	70.70	56.77	23	89	0.4632	0.0691	1.0857	0.25	0.98	3955.0
14	27.776	69.98	56.12	22	98	0.4540	0.0692	1.0836	0.24	1.07	4146.2
15	27.776	71.06	56.30	22	105	0.4571	0.0691	1.0857	0.24	1.15	4295.9
16	27.782	70.70	55.76	21	110	0.4481	0.0691	1.0846	0.23	1.21	4394.7
17	27.782	70.70	55.76	20	102	0.4481	0.0691	1.0846	0.22	1.12	4231.9
18	27.779	71.49	55.58	19	89	0.4452	0.0691	1.0861	0.21	0.98	3955.8
19	27.779	71.42	55.58	19	82	0.4452	0.0691	1.0860	0.21	0.90	3796.8
20	27.782	71.42	55.58	21	61	0.4452	0.0691	1.0859	0.23	0.67	3274.6

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AVG.STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
131.5 CFM	8.235E+04	0.0187	0.18 INW	0.93 INW	3857 FPM

TABLE B-15: OBSERVATIONS AND COMPUTATIONS FOR FAN PERFORMANCE CHARACTERISTICS AT 2875 r.p.m.
Fan - 1/4 open.

Measuring Station Upstream

TRAV. POINT	BAR. MET. PRES.	D.BULB TEMP.	WETBULB TEMP.	O.ST. PRES.	O.VEL. PRES.	SAT.VP. PRES.	DENSITY AIR	COR.FAC. DENSITY	CR.ST. PRES.	CR.VEL. PRES.	VELOCITY OF AIR
	(IN.HG)	(F)	(F)	(MM)	(MM)	(IN.HG)	(LB./C.FT)		(INW)	(INW)	(FPM)
	27.862	72.14	55.04	46	28	0.4365	0.0692	1.0839	0.50	0.31	2216.5
	27.900	72.14	55.04	44	46	0.4365	0.0693	1.0824	0.48	0.50	2839.0
3	27.900	72.50	55.76	48	58	0.4481	0.0692	1.0834	0.53	0.63	3189.3
4	27.900	72.50	55.76	42	62	0.4481	0.0692	1.0834	0.46	0.68	3297.5
5	27.900	72.50	55.76	48	69	0.4481	0.0692	1.0834	0.53	0.76	3478.6
6	27.900	71.60	56.12	38	78	0.4540	0.0693	1.0818	0.42	0.85	3695.9
7	27.900	71.60	56.12	42	83	0.4540	0.0693	1.0818	0.46	0.91	3812.5
8	27.900	71.60	56.12	39	76	0.4540	0.0693	1.0818	0.43	0.83	3648.2
9	27.900	71.60	56.12	42	76	0.4540	0.0693	1.0818	0.46	0.83	3648.2
10	27.891	71.60	56.12	38	49	0.4540	0.0693	1.0822	0.42	0.54	2929.8
11	27.785	71.06	54.14	54	31	0.4225	0.0692	1.0845	0.59	0.34	2332.9
12	27.785	71.06	54.14	48	48	0.4225	0.0692	1.0845	0.53	0.53	2902.9
13	27.764	70.06	56.66	54	64	0.4632	0.0692	1.0845	0.59	0.70	3351.9
14	27.776	69.98	56.12	47	69	0.4540	0.0692	1.0836	0.51	0.76	3479.0
15	27.776	71.06	56.30	52	80	0.4571	0.0691	1.0857	0.57	0.88	3749.8
16	27.782	70.70	55.76	50	70	0.4481	0.0691	1.0846	0.55	0.77	3505.7
17	27.782	70.70	55.76	50	75	0.4481	0.0691	1.0846	0.55	0.82	3628.8
18	27.779	71.49	55.58	48	65	0.4452	0.0691	1.0861	0.53	0.71	3380.6
19	27.779	71.49	55.58	48	59	0.4452	0.0691	1.0861	0.53	0.65	3220.8
20	27.782	71.42	55.58	53	37	0.4452	0.0691	1.0859	0.58	0.41	2550.3

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AVG.STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
110.5 CFM	6.922E+04	0.0195	0.51 INW	0.66 INW	3242 FPM

TABLE B-16: OBSERVATIONS AND COMPUTATIONS FOR FAN PERFORMANCE CHARACTERISTICS AT 2875 r.p.m.
Fan - 1/4 open.

Measuring Station - Downstream

TRAV. POINT	BAROMET. PRES.	D.BULB TEMP.	WETBULB TEMP.	Q.ST. PRES.	Q.VEL. PRES.	SAT.VP. PRES.	DENSITY AIR	COR.FAC. DENSITY	CR.ST. PRES.	CR.VEL. PRES.	VELOCITY OF AIR
	(IN.HG)	(F)	(F)	(MM)	(MM)	(IN.HG)	(LB./C.FT)		(INW)	(INW)	(FPM)
1	27.862	72.14	55.04	9	35	0.4365	0.0692	1.0839	0.10	0.38	2478.1
2	27.900	72.14	55.04	8	49	0.4365	0.0693	1.0824	0.09	0.54	2930.2
3	27.900	72.50	55.76	8	57	0.4481	0.0692	1.0834	0.09	0.62	3161.7
4	27.900	72.50	55.76	5	63	0.4481	0.0692	1.0834	0.05	0.69	3324.0
5	27.900	72.50	55.76	9	73	0.4481	0.0692	1.0834	0.10	0.80	3578.1
6	27.900	71.60	56.12	7	74	0.4540	0.0693	1.0818	0.08	0.81	3599.9
7	27.900	71.60	56.12	7	66	0.4540	0.0693	1.0818	0.08	0.72	3399.7
8	27.900	71.60	56.12	5	57	0.4540	0.0693	1.0818	0.05	0.62	3159.4
9	27.900	71.60	56.12	6	53	0.4540	0.0693	1.0818	0.07	0.58	3046.6
10	27.891	71.60	56.12	7	37	0.4540	0.0693	1.0822	0.08	0.40	2545.9
11	27.785	71.06	54.14	15	31	0.4225	0.0692	1.0845	0.16	0.34	2332.9
12	27.785	71.06	54.14	15	48	0.4225	0.0692	1.0845	0.16	0.53	2902.9
13	27.764	70.06	56.66	18	58	0.4632	0.0692	1.0845	0.20	0.64	3190.9
14	27.776	69.98	56.12	16	64	0.4540	0.0692	1.0836	0.18	0.70	3350.6
15	27.776	71.06	56.30	17	68	0.4571	0.0691	1.0857	0.19	0.75	3457.1
16	27.782	70.70	55.76	16	70	0.4481	0.0691	1.0846	0.18	0.77	3505.7
17	27.782	70.70	55.76	15	68	0.4481	0.0691	1.0846	0.16	0.75	3455.3
18	27.779	71.49	55.58	15	62	0.4452	0.0691	1.0861	0.16	0.68	3301.7
19	27.779	71.49	55.58	15	53	0.4452	0.0691	1.0861	0.16	0.58	3052.7
20	27.782	71.42	55.58	14	37	0.4452	0.0691	1.0859	0.15	0.41	2550.3

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AVG.STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
106.2 CFM	6.652E+04	0.0197	0.12 INW	0.61 INW	3116 FPM

APPENDIX C

Observations and Computations for Fertilizer Feeder Characteristics.

TABLE C-1: OBSERVATIONS AND COMPUTATIONS FOR FERTILIZER FEEDER CHARACTERISTICS AT 1225 r.p.m.
Fan - Full open.

Measuring Station - Upstream

TRAV. POINT	BAROMET. PRES. (IN.HG)	D.BULB TEMP. (F)	WETBULB TEMP. (F)	O.ST. PRES. (MM)	O.VEL. PRES. (MM)	SAT.VP. PRES. (IN.HG)	DENSITY AIR (LB./C.FT)	COR.FAC. DENSITY	CR.ST. PRES. (INW)	CR.VEL. PRES. (INW)	VELOCITY OF AIR (FPM)
1	27.265	70.70	55.94	23	21	0.4510	0.0679	1.1054	0.26	0.23	1938.5
2	27.256	70.34	55.58	26	24	0.4452	0.0679	1.1049	0.29	0.27	2C71.9
3	27.247	70.88	55.76	26	30	0.4481	0.0678	1.1064	0.29	0.34	2318.0
4	27.277	70.88	55.58	26	32	0.4452	0.0679	1.1051	0.29	0.36	2392.6
5	27.277	70.88	55.04	25	31	0.4365	0.0679	1.1049	0.28	0.35	2354.7
6	27.401	70.52	55.94	24	30	0.4510	0.0682	1.0995	0.27	0.33	2310.8
7	27.404	70.34	55.58	24	31	0.4452	0.0683	1.0989	0.27	0.34	2348.3
8	27.386	70.52	55.04	25	30	0.4365	0.0682	1.0997	0.28	0.33	2311.0
9	27.416	70.70	55.22	25	25	0.4394	0.0682	1.0990	0.28	0.28	2108.9
10	27.419	70.70	55.58	25	21	0.4452	0.0682	1.0990	0.28	0.23	1932.9
11	27.814	71.06	60.62	24	16	0.5335	0.0691	1.0860	0.26	0.18	1677.2
12	27.817	71.78	60.26	24	18	0.5267	0.0690	1.0871	0.26	0.20	1779.8
13	27.797	71.78	60.26	25	24	0.5267	0.0689	1.0879	0.27	0.26	2055.9
14	27.797	71.96	59.18	25	27	0.5068	0.0689	1.0878	0.27	0.30	2180.5
15	27.791	72.14	60.08	25	30	0.5233	0.0689	1.0888	0.28	0.33	2299.4
16	27.138	70.52	57.56	22	24	0.4782	0.0675	1.1109	0.25	0.27	2077.5
17	27.150	70.52	57.56	24	24	0.4782	0.0675	1.1104	0.27	0.27	2077.0
18	27.182	70.34	57.56	24	23	0.4782	0.0676	1.1087	0.27	0.26	2031.8
19	27.182	70.34	57.92	24	21	0.4845	0.0676	1.1089	0.27	0.24	1941.6
20	27.265	70.70	55.22	19	13	0.4394	0.0679	1.1051	0.21	0.15	1525.0

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AVG.STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
71.1 CFM	4.454E+04	0.0218	0.27 INW	0.27 INW	2086 FPM

TABLE C-2: OBSERVATIONS AND COMPUTATIONS FOR FERTILIZER FEEDER CHARACTERISTICS AT 1225 r.p.m.
Fan - Full open.

Measuring Station - Downstream

TRAV. POINT	BAROMET. PRES.	D.BULB TEMP.	WETBULB TEMP.	O.ST. PRES.	O.VEL. PRES.	SAT.VP. PRES.	DENSITY AIR	COR.FAC. DENSITY	CR.ST. PRES.	CR.VEL. PRES.	VELOCITY OF AIR
	(IN.HG)	(F)	(F)	(MM)	(MM)	(IN.HG)	(LB./C.FT)		(INW)	(INW)	(FPM)
1	27.265	70.70	55.94	12	17	0.4510	0.0679	1.1054	0.13	0.19	1744.1
2	27.256	70.34	55.58	10	22	0.4452	0.0679	1.1049	0.11	0.25	1983.7
3	27.247	70.88	55.76	16	26	0.4481	0.0678	1.1064	0.18	0.29	2157.9
4	27.277	70.88	55.58	13	26	0.4452	0.0679	1.1051	0.15	0.29	2156.6
5	27.277	70.88	55.04	15	30	0.4365	0.0679	1.1049	0.18	0.33	2316.4
6	27.401	70.52	55.94	10	29	0.4510	0.0682	1.0995	0.11	0.32	2271.9
7	27.404	70.34	55.58	15	26	0.4452	0.0683	1.0989	0.17	0.29	2150.6
8	27.386	70.52	55.04	11	23	0.4365	0.0682	1.0997	0.12	0.26	2023.5
9	27.416	70.70	55.22	14	18	0.4394	0.0682	1.0990	0.16	0.20	1789.5
10	27.419	70.70	55.58	13	16	0.4452	0.0682	1.0990	0.14	0.18	1687.1
11	27.814	71.06	60.62	7	13	0.5335	0.0691	1.0860	0.08	0.14	1511.8
12	27.817	71.78	60.26	9	17	0.5267	0.0690	1.0871	0.10	0.19	1729.7
13	27.797	71.78	60.26	7	20	0.5267	0.0689	1.0879	0.08	0.22	1876.8
14	27.797	71.96	59.18	8	22	0.5068	0.0689	1.0878	0.09	0.24	1968.3
15	27.791	72.14	60.08	10	26	0.5233	0.0689	1.0888	0.11	0.29	2140.7
16	27.138	70.52	57.56	11	26	0.4782	0.0675	1.1109	0.12	0.29	2162.3
17	27.150	70.52	57.56	15	25	0.4782	0.0675	1.1104	0.17	0.28	2119.9
18	27.182	70.34	57.56	15	23	0.4782	0.0676	1.1087	0.17	0.26	2031.8
19	27.182	70.34	57.92	12	20	0.4845	0.0676	1.1089	0.13	0.22	1894.8
20	27.265	70.70	55.22	10	13	0.4394	0.0679	1.1051	0.11	0.15	1525.0

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AVG.STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
66.9 CFM	4.188E+04	0.0221	0.13 INW	0.24 INW	1962 FPM

TABLE C-3: OBSERVATIONS AND COMPUTATIONS FOR FERTILIZER FEEDER CHARACTERISTICS AT 2875 r.p.m.
Fan - Full open.

Measuring Station - Upstream

TRAV. POINT	BAROMET. PRES. (IN.HG)	D.BULB TEMP. (F)	WETBULB TEMP. (F)	O.ST. PRES. (MM)	O.VEL. PRES. (MM)	SAT.VP. PRES. (IN.HG)	DENSITY AIR (LB./C.FT)	COR.FAC. DENSITY	CR.ST. PRES. (INW)	CR.VEL. PRES. (INW)	VELOCITY OF AIR (FPM)
1	27.265	70.70	55.94	107	85	0.4510	0.0679	1.1054	1.19	0.95	3900.0
2	27.256	70.34	55.58	106	115	0.4452	0.0679	1.1049	1.18	1.28	4535.3
3	27.247	70.88	55.76	111	148	0.4481	0.0678	1.1064	1.24	1.65	5148.5
4	27.277	70.88	55.58	108	157	0.4452	0.0679	1.1051	1.21	1.75	5299.6
5	27.277	70.88	55.04	108	146	0.4365	0.0679	1.1049	1.21	1.63	5110.1
6	27.401	70.52	55.94	101	139	0.4510	0.0682	1.0995	1.12	1.54	4973.9
7	27.404	70.34	55.58	104	150	0.4452	0.0683	1.0989	1.15	1.67	5165.6
8	27.386	70.52	55.04	99	146	0.4365	0.0682	1.0997	1.10	1.62	5098.2
9	27.416	70.70	55.22	100	134	0.4394	0.0682	1.0990	1.11	1.49	4882.4
10	27.419	70.70	55.58	99	95	0.4452	0.0682	1.0990	1.10	1.05	4111.0
11	27.814	71.06	60.62	119	99	0.5335	0.0691	1.0860	1.31	1.09	4171.9
12	27.817	71.78	60.26	114	109	0.5267	0.0690	1.0871	1.25	1.20	4379.8
13	27.797	71.78	60.26	117	125	0.5267	0.0689	1.0879	1.29	1.37	4691.9
14	27.797	71.96	59.18	115	144	0.5068	0.0689	1.0878	1.26	1.58	5035.6
15	27.791	72.14	60.08	113	155	0.5233	0.0689	1.0888	1.24	1.71	5226.7
16	27.138	70.52	57.56	108	144	0.4782	0.0675	1.1109	1.21	1.62	5088.8
17	27.150	70.52	57.56	103	132	0.4782	0.0675	1.1104	1.16	1.48	4871.1
18	27.182	70.34	57.56	100	127	0.4782	0.0676	1.1087	1.12	1.42	4774.3
19	27.182	70.34	57.92	101	113	0.4845	0.0676	1.1089	1.13	1.27	4503.8
20	27.265	70.70	55.22	94	70	0.4394	0.0679	1.1051	1.05	0.78	3538.7

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AVG.STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
161.1 CFM	1.009E+05	0.0177	1.18 INW	1.39 INW	4725 FPM

TABLE C-4: OBSERVATIONS AND COMPUTATIONS FOR FERTILIZER FEEDER CHARACTERISTICS AT 2875 r.p.m.
Fan - Full open.

Measuring Station - Downstream

TRAV. POINT	BAROMET. PRES. (IN.HG)	D.BULB TEMP. (F)	WETBULB TEMP. (F)	O.ST. PRES. (MM)	O.VEL. PRES. (MM)	SAT.VP. PRES. (IN.HG)	DENSITY AIR (LB./C.FT)	COR.FAC. DENSITY	CR.ST. PRES. (INW)	CR.VEL. PRES. (INW)	VELOCITY OF AIR (FPM)
1	27.265	70.70	55.94	27	73	0.4510	0.0679	1.1054	0.30	0.82	3614.2
2	27.256	70.34	55.58	26	102	0.4452	0.0679	1.1049	0.29	1.14	4271.3
3	27.247	70.88	55.76	28	123	0.4481	0.0678	1.1064	0.31	1.37	4693.5
4	27.277	70.88	55.58	26	136	0.4452	0.0679	1.1051	0.29	1.52	4932.4
5	27.277	70.88	55.04	27	142	0.4365	0.0679	1.[illegible]49	0.30	1.59	5039.6
6	27.401	70.52	55.94	22	139	0.4510	0.0682	1.[illegible]95	0.24	1.54	4573.9
7	27.404	70.34	55.58	24	122	0.4452	0.0683	1.0989	0.27	1.35	4658.6
8	27.386	70.52	55.04	22	106	0.4365	0.0682	1.0997	0.24	1.18	4344.1
9	27.416	70.70	55.22	24	93	0.4394	0.0682	1.0990	0.27	1.03	4067.5
10	27.419	70.70	55.58	20	66	0.4452	0.0682	1.0990	0.22	0.73	3426.6
11	27.814	71.06	60.62	30	76	0.5335	0.0691	1.0860	0.33	0.83	3655.3
12	27.817	71.78	60.26	29	94	0.5267	0.0690	1.0871	0.32	1.03	4067.2
13	27.797	71.78	60.26	28	109	0.5267	0.0689	1.0879	0.31	1.20	4381.3
14	27.797	71.96	59.18	28	120	0.5068	0.0689	1.0878	0.31	1.32	4596.8
15	27.791	72.14	60.08	29	126	0.5233	0.0689	1.0888	0.32	1.39	4712.4
16	27.138	70.52	57.56	27	158	0.4782	0.0675	1.1109	0.30	1.77	5330.4
17	27.150	70.52	57.56	26	138	0.4782	0.0675	1.1104	0.29	1.55	4980.5
18	27.182	70.34	57.56	25	122	0.4782	0.0676	1.1087	0.28	1.37	4679.4
19	27.182	70.34	57.92	23	109	0.4845	0.0676	1.1089	0.26	1.22	4423.4
20	27.265	70.70	55.22	19	69	0.4394	0.0679	1.1051	0.21	0.77	3513.3

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AVG.STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
150.6 CFM	9.431E+04	0.0180	0.28 INW	1.22 INW	4418 FPM

TABLE D-1: OBSERVATIONS AND COMPUTATIONS FOR CONVEYING CHARACTERISTICS OF AMMONIUM SULPHATE AT 2160 r.p.m. Fan - Full open. Rate of Flow - 1.19 lb/min.

TRAV. POINT	BAROMET. PRES. (IN.HG)	D.BULB TEMP. (F)	WETBULB TEMP. (F)	O.ST. PRES. (MM)	O.VEL. PRES. (MM)	SAT.VP. PRES. (IN.HG)	DENSITY AIR (LB./C.FT)	COR.FAC. DENSITY	CR.ST. PRES. (INW)	CR.VEL. PRES. (INW)	VELOCITY OF AIR (FPM)
1	27.563	70.34	53.78	65	56	0.4170	0.0687	1.0918	0.72	0.62	3146.0
2	27.563	70.34	53.78	66	72	0.4170	0.0687	1.0918	0.73	0.79	3567.3
3	27.563	70.34	53.78	66	89	0.4170	0.0687	1.0918	0.73	0.98	3966.1
4	27.560	69.98	54.14	66	96	0.4225	0.0687	1.0914	0.73	1.06	4118.3
5	27.560	69.98	54.14	64	89	0.4225	0.0687	1.0914	0.71	0.98	3965.3
6	27.560	69.98	54.14	66	84	0.4225	0.0687	1.0914	0.73	0.93	3852.3
7	27.566	69.98	54.32	62	90	0.4253	0.0687	1.0912	0.68	0.99	3987.2
8	27.566	69.98	54.32	61	90	0.4253	0.0687	1.0912	0.67	0.99	3987.2
9	27.566	69.98	54.32	59	78	0.4253	0.0687	1.0912	0.65	0.86	3711.9
10	27.560	69.98	54.32	62	54	0.4253	0.0687	1.0915	0.68	0.60	3088.8
11	27.560	69.08	54.14	65	65	0.4225	0.0688	1.0897	0.72	0.72	3386.1
12	27.560	69.08	54.14	63	65	0.4225	0.0688	1.0897	0.69	0.72	3386.1
13	27.616	70.34	55.40	64	78	0.4423	0.0688	1.0903	0.71	0.86	3710.4
14	27.616	70.34	55.40	66	87	0.4423	0.0688	1.0903	0.73	0.96	3918.6
15	27.616	70.34	55.40	64	90	0.4423	0.0688	1.0903	0.71	0.99	3985.6
16	27.622	70.34	54.50	62	82	0.4281	0.0688	1.0897	0.68	0.90	3803.3
17	27.622	70.34	54.50	62	76	0.4281	0.0688	1.0897	0.68	0.84	3661.6
18	27.622	70.34	54.50	62	72	0.4281	0.0688	1.0897	0.68	0.79	3563.9
19	27.643	70.34	54.14	62	64	0.4225	0.0689	1.0888	0.68	0.70	3358.6
20	27.643	70.34	54.14	62	43	0.4225	0.0689	1.0888	0.68	0.47	2752.9

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AVG.STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
124.3 CFM	7.782E+04	0.0189	0.70 INW	0.83 INW	3645 FPM

TABLE D-2: OBSERVATIONS AND COMPUTATIONS FOR CONVEYING CHARACTERISTICS OF AMMONIUM SULPHATE AT 2160 r.p.m. Fan - Full open. Rate of Flow - 3.05 lb/min.

TRAV. POINT	BAROMET. PRES.	D.BULB TEMP.	WETBULB TEMP.	O.ST. PRES.	O.VEL. PRES.	SAT.VP. PRES.	DENSITY AIR	COR.FAC. DENSITY	CR.ST. PRES.	CR.VEL. PRES.	VELOCITY OF AIR
	(IN.HG)	(F)	(F)	(MM)	(MM)	(IN.HG)	(LB./C.FT)		(INW)	(INW)	(FPM)
1	27.563	70.34	53.78	73	51	0.4170	0.0687	1.0918	0.81	0.56	3002.3
2	27.563	70.34	53.78	74	70	0.4170	0.0687	1.0918	0.82	0.77	3517.4
3	27.563	70.34	53.78	73	86	0.4170	0.0687	1.0918	0.81	0.95	3898.7
4	27.560	69.98	54.14	73	94	0.4225	0.0687	1.0914	0.80	1.04	4075.2
5	27.560	69.98	54.14	70	86	0.4225	0.0687	1.0914	0.77	0.95	3897.9
6	27.560	69.98	54.14	70	83	0.4225	0.0687	1.0914	0.77	0.92	3829.3
7	27.566	69.98	54.32	68	86	0.4253	0.0687	1.0912	0.75	0.95	3897.6
8	27.566	69.98	54.32	70	88	0.4253	0.0687	1.0912	0.77	0.97	3942.7
9	27.566	69.98	54.32	66	76	0.4253	0.0687	1.0912	0.73	0.84	3664.0
10	27.560	69.08	54.14	70	54	0.4225	0.0688	1.0897	0.77	0.59	3086.3
11	27.560	69.08	54.14	73	63	0.4225	0.0688	1.0897	0.80	0.69	3333.6
12	27.560	69.08	54.14	72	64	0.4225	0.0688	1.0897	0.79	0.70	3360.0
13	27.616	70.34	55.40	72	76	0.4423	0.0688	1.0903	0.79	0.84	3662.5
14	27.616	70.34	55.40	69	86	0.4423	0.0688	1.0903	0.76	0.95	3896.1
15	27.616	70.34	55.40	72	88	0.4423	0.0688	1.0903	0.79	0.97	3941.1
16	27.622	70.34	54.50	70	81	0.4281	0.0688	1.0897	0.77	0.89	3780.1
17	27.622	70.34	54.50	70	76	0.4281	0.0688	1.0897	0.77	0.84	3661.6
18	27.622	70.34	54.50	70	70	0.4281	0.0688	1.0897	0.77	0.77	3514.0
19	27.643	70.34	54.14	69	62	0.4225	0.0689	1.0888	0.76	0.68	3305.7
20	27.643	70.34	54.14	64	42	0.4225	0.0689	1.0888	0.70	0.46	2720.7

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AVG.STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
122.7 CFM	7.683E+04	0.0190	0.78 INW	0.81 INW	3599 FPM

TABLE D-3: OBSERVATIONS AND COMPUTATIONS FOR CONVEYING CHARACTERISTICS OF AMMONIUM SULPHATE AT 2160 r.p.m. Fan - Full open. Rate of Flow - 6.33 lb/min.

TRAV. POINT	BAROMET. PRES.	D.BULB TEMP.	WETBULB TEMP.	O.ST.PRES.	O.VEL.PRES.	SAT.VP. PRES.	DENSITY AIR	COR.FAC. DENSITY	CR.ST. PRES.	VEL. PRES.	VELOCITY OF AIR
	(IN.HG)	(F)	(F)	(MM)	(MM)	(IN.HG)	(LB./C.FT)		(INW)	(INW)	(FPM)
1	27.563	70.34	53.78	85	48	0.4170	0.0687	1.0918	0.94	0.53	2912.7
2	27.563	70.34	53.78	86	65	0.4170	0.0687	1.0918	0.95	0.72	3389.4
3	27.563	70.34	53.78	90	82	0.4170	0.0687	1.0918	0.99	0.90	3806.9
4	27.560	69.98	54.14	87	84	0.4225	0.0687	1.0914	0.96	0.93	3852.3
5	27.560	69.98	54.14	86	82	0.4225	0.0687	1.0914	0.95	0.90	3806.2
6	27.560	69.98	54.14	86	76	0.4225	0.0687	1.0914	0.95	0.84	3664.3
7	27.566	69.98	54.32	84	82	0.4253	0.0687	1.0912	0.93	0.90	3805.9
8	27.566	69.98	54.32	83	82	0.4253	0.0687	1.0912	0.92	0.90	3805.9
9	27.566	69.98	54.32	85	72	0.4253	0.0687	1.0912	0.94	0.79	3566.3
10	27.560	69.08	54.14	83	48	0.4225	0.0688	1.0897	0.91	0.53	2909.8
11	27.560	69.08	54.14	82	60	0.4225	0.0688	1.0897	0.90	0.66	3253.3
12	27.560	69.08	54.14	87	58	0.4225	0.0688	1.0897	0.96	0.64	3198.6
13	27.616	70.34	55.40	79	73	0.4423	0.0688	1.0903	0.87	0.80	3589.5
14	27.616	70.34	55.40	87	80	0.4423	0.0688	1.0903	0.96	0.88	3757.7
15	27.616	70.34	55.40	88	85	0.4423	0.0688	1.0903	0.97	0.94	3873.3
16	27.622	70.34	54.50	86	74	0.4281	0.0688	1.0897	0.95	0.81	3613.1
17	27.622	70.34	54.50	87	72	0.4281	0.0688	1.0897	0.96	0.79	3563.9
18	27.622	70.34	54.50	84	65	0.4281	0.0688	1.0897	0.92	0.72	3386.2
19	27.643	70.34	54.14	83	58	0.4225	0.0689	1.0888	0.91	0.64	3197.3
20	27.643	70.34	54.14	84	40	0.4225	0.0689	1.0888	0.92	0.44	2655.2

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AVG. STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
118.[illegible] CFM	7.429E+04	0.0191	0.94 INW	0.76 INW	3480 FPM

TABLE D-4: OBSERVATIONS AND COMPUTATIONS FOR CONVEYING CHARACTERISTICS OF AMMONIUM SULPHATE AT 2400 r.p.m. Fan - Full open. Rate of Flow - 1.19 lb/min.

TRAV. POINT	BAROMET. PRES. (IN.HG)	D.BULB TEMP. (F)	WETBULB TEMP. (F)	O.ST. PRES. (MM)	O.VEL. PRES. (MM)	SAT.VP. PRES. (IN.HG)	DENSITY AIR (LB./C.FT)	COR.FAC. DENSITY	CR.ST. PRES. (INW)	CR.VEL. PRES. (INW)	VELOCITY OF AIR (FPM)
1	27.684	70.88	54.50	78	66	0.4281	0.0689	1.0883	0.86	0.73	3409.9
2	27.684	70.88	54.50	78	98	0.4281	0.0689	1.0883	0.86	1.08	4155.1
3	27.684	70.88	54.50	78	113	0.4281	0.0689	1.0883	0.86	1.24	4461.8
4	27.673	70.34	54.14	79	117	0.4225	0.0690	1.0876	0.87	1.29	4538.6
5	27.673	70.34	54.14	79	106	0.4225	0.0690	1.0876	0.87	1.16	4320.0
6	27.673	70.34	54.14	79	107	0.4225	0.0690	1.0876	0.87	1.18	4340.3
7	27.652	70.52	53.06	76	111	0.4061	0.0689	1.0883	0.84	1.22	4422.2
8	27.652	70.52	53.06	79	104	0.4061	0.0689	1.0883	0.87	1.14	4280.5
9	27.652	70.52	53.06	81	90	0.4061	0.0689	1.0883	0.89	0.99	3982.0
10	27.578	70.52	53.60	74	70	0.4143	0.0687	1.0915	0.82	0.77	3516.9
11	27.578	70.52	53.60	78	62	0.4143	0.0687	1.0915	0.86	0.68	3309.8
12	27.578	70.52	53.60	80	77	0.4143	0.0687	1.0915	0.88	0.85	3688.5
13	27.575	69.80	53.60	80	96	0.4143	0.0688	1.0902	0.88	1.06	4116.2
14	27.575	69.80	53.60	77	104	0.4143	0.0688	1.0902	0.85	1.15	4284.2
15	27.575	69.80	53.60	78	110	0.4143	0.0688	1.0902	0.86	1.21	4406.1
16	27.578	69.98	53.96	76	101	0.4197	0.0688	1.0906	0.84	1.11	4222.7
17	27.578	69.98	53.96	76	95	0.4197	0.0688	1.0906	0.84	1.05	4095.3
18	27.578	69.98	53.96	75	90	0.4197	0.0688	1.0906	0.83	0.99	3986.1
19	27.569	70.34	53.78	74	78	0.4170	0.0687	1.0916	0.82	0.86	3712.5
20	27.569	70.34	53.70	75	49	0.4170	0.0687	1.0916	0.83	0.54	2942.5

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AVG.STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
136.7 CFM	8.559E+04	0.0185	0.85 INW	1.00 INW	4009 FPM

TABLE D-5: OBSERVATIONS AND COMPUTATIONS FOR CONVEYING CHARACTERISTICS OF AMMONIUM SULPHATE AT 2400 r.p.m. Fan - Full open. Rate of Flow - 3.05 lb/min.

TRAV. POINT	BAROMET. PRES. (IN.HG)	D.BULB TEMP. (F)	WETBULB TEMF. (F)	O.ST. PRES. (MM)	O.VEL. PRES. (MM)	SAT.VP. PRES. (IN.HG)	DENSITY AIR (LB./C.FT)	COR.FAC. DENSITY	CR.ST. PRES. (INW)	CR.VEL. PRES. (INW)	VELOCITY OF AIR. (FPM)
1	27.684	70.88	54.50	88	65	0.4281	0.0689	1.0883	0.97	0.71	3384.0
2	27.684	70.88	54.50	88	94	0.4281	0.0689	1.0883	0.97	1.03	4069.5
3	27.684	70.88	54.50	86	110	0.4281	0.0689	1.0883	0.95	1.21	4402.2
4	27.673	70.34	54.14	88	113	0.4225	0.0690	1.0876	0.97	1.24	4460.3
5	27.673	70.34	54.14	86	103	0.4225	0.0690	1.0876	0.95	1.13	4258.4
6	27.673	70.34	54.14	86	106	0.4225	0.0690	1.0876	0.95	1.16	4320.0
7	27.652	70.52	53.06	84	109	0.4061	0.0689	1.0883	0.92	1.20	4382.2
8	27.652	70.52	53.06	83	103	0.4061	0.0689	1.0883	0.91	1.13	4259.9
9	27.652	70.52	53.06	82	89	0.4061	0.0689	1.0883	0.90	0.98	3959.8
10	27.578	70.52	53.60	87	70	0.4143	0.0687	1.0915	0.96	0.77	3516.9
11	27.578	70.52	53.60	87	56	0.4143	0.0687	1.0915	0.96	0.62	3145.6
12	27.578	70.52	53.60	86	77	0.4143	0.0687	1.0915	0.95	0.85	3688.5
13	27.575	69.80	53.60	87	94	0.4143	0.0688	1.0902	0.96	1.04	4073.1
14	27.575	69.80	53.60	87	104	0.4143	0.0688	1.0902	0.96	1.15	4284.2
15	27.575	69.80	53.60	86	107	0.4143	0.0688	1.0902	0.95	1.18	4345.6
16	27.578	69.98	53.96	84	100	0.4197	0.0688	1.0906	0.93	1.10	4201.7
17	27.578	69.98	53.96	84	94	0.4197	0.0688	1.0906	0.93	1.04	4073.7
18	27.578	69.98	53.96	82	89	0.4197	0.0688	1.0906	0.90	0.98	3963.9
19	27.569	70.34	53.78	81	76	0.4170	0.0687	1.0916	0.89	0.84	3664.6
20	27.569	70.34	53.78	87	48	0.4170	0.0687	1.0916	0.96	0.53	2912.3

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AVG.STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
135.3 CFM	8.471E+04	0.0185	0.94 INW	0.98 INW	3968 FPM

TABLE D-6: OBSERVATIONS AND COMPUTATIONS FOR CONVEYING CHARACTERISTICS OF AMMONIUM SULPHATE AT 2400 r.p.m. Fan - Full open. Rate of Flow - 6.33 lb/min.

TRAV. POINT	BAROMET. PRES. (IN.HG)	D.BULB TEMP. (F)	WETBULB TEMP. (F)	O.ST. PRES. (MM)	O.VEL. PRES. (MM)	SAT.VP. PRES. (IN.HG)	DENSITY AIR (LB./C.FT)	COR.FAC. DENSITY	CR.ST. PRES. (INW)	CR.VEL. PRES. (INW)	VELOCITY OF AIR (FPM)
1	27.684	70.88	54.50	106	58	0.4281	0.0689	1.0883	1.17	0.64	3196.6
2	27.684	70.88	54.50	107	89	0.4281	0.0689	1.0883	1.18	0.98	3959.7
3	27.684	70.88	54.50	105	104	0.4281	0.0689	1.0883	1.15	1.14	4280.4
4	27.673	70.34	54.14	106	106	0.4225	0.0690	1.0876	1.16	1.16	4320.0
5	27.673	70.34	54.14	106	97	0.4225	0.0690	1.0876	1.16	1.07	4132.5
6	27.673	70.34	54.14	106	96	0.4225	0.0690	1.0876	1.16	1.05	4111.1
7	27.652	70.52	53.06	104	105	0.4061	0.0689	1.0883	1.14	1.15	4301.0
8	27.652	70.52	53.06	102	97	0.4061	0.0689	1.0883	1.12	1.07	4133.9
9	27.652	70.52	53.06	102	84	0.4061	0.0689	1.0883	1.12	0.92	3847.0
10	27.578	70.52	53.60	97	67	0.4143	0.0687	1.0915	1.07	0.74	3440.7
11	27.578	70.52	53.60	105	55	0.4143	0.0687	1.0915	1.16	0.61	3117.4
12	27.578	70.52	53.60	104	70	0.4143	0.0687	1.0915	1.15	0.77	3516.9
13	27.575	69.80	53.60	104	90	0.4143	0.0688	1.0902	1.15	0.99	3985.5
14	27.575	69.80	53.60	103	96	0.4143	0.0688	1.0902	1.13	1.06	4116.2
15	27.575	69.80	53.60	102	103	0.4143	0.0688	1.0902	1.12	1.13	4263.6
16	27.578	69.98	53.96	100	92	0.4197	0.0688	1.0906	1.10	1.01	4030.2
17	27.578	69.98	53.96	107	91	0.4197	0.0688	1.0906	1.18	1.00	4008.2
18	27.578	69.98	53.96	99	82	0.4197	0.0688	1.0906	1.09	0.90	3804.8
19	27.569	70.34	53.78	98	73	0.4170	0.0687	1.0916	1.08	0.81	3591.6
20	27.569	70.34	53.78	96	46	0.4170	0.0687	1.0916	1.06	0.51	2851.0

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AVG.STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
131.3 CFM	8.219E+04	0.0187	1.13 INW	0.93 INW	3850 FPM

TABLE D-7: OBSERVATIONS AND COMPUTATIONS FOR CONVEYING CHARACTERISTICS OF AMMONIUM SULPHATE AT 2875 r.p.m. Fan -- Full open. Rate of Flow - 1.19 lb/min.

TRAV. POINT	BAROMET. PRES.	D.BULB TEMP.	WETBULB TEMP.	O.ST. PRES.	O.VEL. PRES.	SAT.VP. PRES.	DENSITY AIR	COR.FAC. DENSITY	CR.ST. PRES.	CR.VEL. PRES.	VELOCITY OF AIR
	(IN.HG)	(F)	(F)	(MM)	(MM)	(IN.HG)	(LB./C.FT)		(INW)	(INW)	(FPM)
1	27.670	69.98	55.04	105	93	0.4365	0.0690	1.0874	1.15	1.02	4046.0
2	27.670	69.98	55.C4	105	122	0.4365	0.0690	1.0874	1.15	1.34	4634.1
3	27.670	69.98	55.04	109	163	0.4365	0.0690	1.0874	1.20	1.79	5356.5
4	27.670	69.98	55.22	105	172	0.4394	0.0690	1.0874	1.15	1.89	5502.5
5	27.670	69.98	55.22	106	157	0.4394	0.0690	1.0874	1.16	1.72	5257.1
6	27.670	69.98	55.22	103	153	0.4394	0.0690	1.0874	1.13	1.68	5189.7
7	27.670	70.34	54.32	102	158	0.4253	0.0689	1.0878	1.12	1.74	5274.6
8	27.670	70.34	54.32	104	157	0.4253	0.0689	1.0878	1.14	1.73	5257.9
9	27.67C	70.34	54.32	100	134	0.4253	0.0689	1.0878	1.10	1.47	4857.5
10	27.661	70.15	54.50	100	102	0.4281	0.0689	1.0878	1.10	1.12	4238.2
11	27.661	70.15	54.5C	107	94	0.4281	0.0689	1.0878	1.18	1.03	4068.6
12	27.661	70.15	54.5C	107	121	0.4281	0.0689	1.0878	1.18	1.33	4616.0
13	27.652	70.34	54.32	106	139	0.4253	0.0689	1.0885	1.17	1.53	4949.0
14	27.652	70.34	54.32	105	155	0.4253	0.0689	1.0885	1.15	1.70	5226.0
15	27.652	70.34	54.32	104	163	0.4253	0.0689	1.0885	1.14	1.79	5359.2
16	27.678	70.52	53.96	103	148	0.4197	0.0690	1.0877	1.13	1.63	5104.7
17	27.678	70.52	53.96	104	140	0.4197	0.0690	1.0877	1.14	1.54	4964.8
18	27.678	70.52	53.96	105	133	0.4197	0.0690	1.0877	1.15	1.46	4839.1
19	27.705	69.80	53.42	102	114	0.4115	0.0691	1.0850	1.12	1.25	4474.7
20	27.705	69.80	53.42	105	76	0.4115	0.0691	1.0850	1.15	0.83	3653.6

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AVG.STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
165.1 CFM	1.034E+05	0.0176	1.15 INW	1.46 INW	4843 FPM

TABLE D-8: OBSERVATIONS AND COMPUTATIONS FOR CONVEYING CHARACTERISTICS OF AMMONIUM SULPHATE AT 2875 r.p.m. Fan - Full open. Rate of Flow - 3.05 lb/min.

TRAV. POINT	BAROMET. PRES. (IN.HG)	D.BULB TEMP. (F)	WETBULB TEMP. (F)	O.ST. PRES. (MM)	O.VEL. PRES. (MM)	SAT.VP. PRES. (IN.HG)	DENSITY AIR (LB./C.FT)	COR.FAC. DENSITY	CR.ST. PRES. (INW)	CR.VEL. PRES. (INW)	VELOCITY OF AIR (FPM)
1	27.670	69.98	55.04	112	93	0.4365	0.0690	1.0874	1.23	1.02	4046.0
2	27.670	69.98	55.04	113	115	0.4365	0.0690	1.0874	1.24	1.26	4499.2
3.	27.670	69.98	55.04	117	161	0.4365	0.0690	1.0874	1.29	1.77	5323.5
4	27.670	69.98	55.22	117	161	0.4394	0.0690	1.0874	1.29	1.77	5323.7
5	27.670	69.98	55.22	115	152	0.4394	0.0690	1.0874	1.26	1.67	5172.7
6	27.670	69.98	55.22	113	145	0.4394	0.0690	1.0874	1.24	1.59	5052.2
7	27.670	70.34	54.32	113	158	0.4253	0.0689	1.0878	1.24	1.74	5274.6
8	27.670	70.34	54.32	109	153	0.4253	0.0689	1.0878	1.20	1.68	5190.5
9	27.670	70.34	54.32	111	134	0.4253	0.0689	1.0878	1.22	1.47	4857.5
10	27.661	70.15	54.50	110	102	0.4281	0.0689	1.0878	1.21	1.12	4238.2
11	27.661	70.15	54.50	116	92	0.4281	0.0689	1.0878	1.27	1.01	4025.1
12	27.661	70.15	54.50	117	120	0.4281	0.0689	1.0878	1.29	1.32	4596.9
13	27.652	70.34	54.32	117	139	0.4253	0.0689	1.0885	1.29	1.53	4949.0
14	27.652	70.34	54.32	117	149	0.4253	0.0689	1.0885	1.29	1.64	5123.9
15	27.652	70.34	54.32	116	154	0.4253	0.0689	1.0885	1.28	1.69	5209.2
16	27.678	70.52	53.96	109	148	0.4197	0.0690	1.0877	1.20	1.63	5104.7
17	27.678	70.52	53.96	113	136	0.4197	0.0690	1.0877	1.24	1.49	4893.4
18	27.678	70.52	53.96	112	131	0.4197	0.0690	1.0877	1.23	1.44	4802.6
19	27.705	69.98	53.42	114	113	0.4115	0.0691	1.0854	1.25	1.24	4455.8
20	27.705	69.98	53.42	112	74	0.4115	0.0691	1.0854	1.23	0.81	3605.8

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AVG.STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
163.2 CFM	1.022E+05	0.0177	1.25 INW	1.43 INW	4787 FPM

TABLE D-9: OBSERVATIONS AND COMPUTATIONS FOR CONVEYING CHARACTERISTICS FOR AMMONIUM SULPHATE AT 2875 r.p.m. Fan - Full open. Rate of Flow - 6.33 lb/min.

TRAV. POINT	BAROMET. PRES. (IN.HG)	D.BULB TEMP. (F)	WETBULB TEMP. (F)	O.ST. PRES. (MM)	O.VEL. PRES. (MM)	SAT.VP. PRES. (IN.HG)	DENSITY AIR (LB./C.FT)	COR.FAC. DENSITY	CR.ST. PRES. (INW)	CR.VEL. PRES. (INW)	VELOCITY OF AIR (FPM)
1	27.670	69.98	55.04	138	89	0.4365	0.0690	1.0874	1.52	0.98	3958.0
2	27.670	69.98	55.04	136	115	0.4365	0.0690	1.0874	1.49	1.26	4499.2
3	27.670	69.98	55.04	138	149	0.4365	0.0690	1.0874	1.52	1.64	5121.3
4	27.670	69.98	55.22	139	150	0.4394	0.0690	1.0874	1.53	1.65	5138.6
5	27.670	69.98	55.22	139	147	0.4394	0.0690	1.0874	1.53	1.62	5086.9
6	27.670	69.98	55.22	137	137	0.4394	0.0690	1.0874	1.51	1.51	4910.9
7	27.670	70.34	54.32	136	147	0.4253	0.0689	1.0878	1.49	1.62	5087.7
8	27.670	70.34	54.32	135	142	0.4253	0.0689	1.0878	1.48	1.56	5000.4
9	27.670	70.34	54.32	134	132	0.4253	0.0689	1.0878	1.47	1.45	4821.2
10	27.661	70.15	54.50	133	97	0.4281	0.0689	1.0878	1.46	1.07	4133.0
11	27.661	70.15	54.50	140	89	0.4281	0.0689	1.0878	1.54	0.98	3958.9
12	27.661	70.15	54.50	140	117	0.4281	0.0689	1.0878	1.54	1.29	4539.1
13	27.652	70.34	54.32	138	138	0.4253	0.0689	1.0885	1.52	1.52	4931.1
14	27.652	70.34	54.32	141	144	0.4253	0.0689	1.0885	1.55	1.58	5037.2
15	27.652	70.34	54.32	138	148	0.4253	0.0689	1.0885	1.52	1.63	5106.7
16	27.678	70.52	53.96	136	143	0.4197	0.0690	1.0877	1.49	1.57	5017.8
17	27.678	70.52	53.96	134	132	0.4197	0.0690	1.0877	1.47	1.45	4820.9
18	27.678	70.52	53.96	135	123	0.4197	0.0690	1.0877	1.48	1.35	4653.7
19	27.705	69.80	53.42	133	109	0.4115	0.0691	1.0850	1.46	1.19	4375.5
20	27.705	69.80	53.42	137	70	0.4115	0.0691	1.0850	1.50	0.77	3506.4

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AVG.STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
159.7 CFM	1.000E+05	0.0178	1.50 INW	1.37 INW	4685 FPM

TABLE D-10: OBSERVATIONS AND COMPUTATIONS FOR CONVEYING CHARACTERISTICS FOR UREA AT 2160 r.p.m.
Fan - Full open. Rate of Flow - 0.89 lb/min.

TRAV. POINT	BAROMET. PRES.	D.BULB TEMP.	WETBULB TEMP.	O.ST. PRES.	O.VEL. PRES.	SAT.VP. PRES.	DENSITY AIR	COR.FAC. DENSITY	CR.ST. PRES.	CR.VEL. PRES.	VELOCITY OF AIR
	(IN.HG)	(F)	(F)	(MM)	(MM)	(IN.HG)	(LB./C.FT)		(INW)	(INW)	(FPM)
1	27.342	70.34	54.68	56	50	0.4309	0.0681	1.1010	0.62	0.56	2985.3
2	27.342	70.34	54.68	61	70	0.4309	0.0681	1.1010	0.68	0.78	3532.2
3	27.342	70.34	54.68	59	93	0.4309	0.0681	1.1010	0.66	1.03	4071.4
4	27.330	71.24	55.66	60	94	0.4630	0.0679	1.1039	0.67	1.05	4098.5
5	27.330	71.24	55.66	56	86	0.4630	0.0679	1.1039	0.62	0.96	3920.2
6	27.330	71.24	55.66	58	82	0.4630	0.0679	1.1039	0.65	0.91	3828.0
7	27.277	71.24	58.46	54	86	0.4939	0.0678	1.1070	0.60	0.96	3925.7
8	27.277	71.24	58.46	62	84	0.4939	0.0678	1.1070	0.69	0.94	3879.8
9	27.277	71.24	58.46	54	76	0.4939	0.0678	1.1070	0.60	0.85	3690.4
10	27.271	71.24	58.28	56	54	0.4907	0.0677	1.1071	0.63	0.60	3111.0
11	27.250	71.06	56.30	58	45	0.4570	0.0678	1.1068	0.65	0.50	2839.5
12	27.250	71.06	56.30	59	58	0.4570	0.0678	1.1068	0.66	0.65	3223.7
13	27.250	71.06	56.30	56	75	0.4570	0.0678	1.1068	0.63	0.84	3665.8
14	27.295	69.98	56.66	59	84	0.4630	0.0680	1.1031	0.66	0.94	3872.9
15 ✓	27.295	69.98	56.66	58	87	0.4630	0.0680	1.1031	0.65	0.97	3941.4
16	27.295	69.98	56.66	57	80	0.4630	0.0680	1.1031	0.64	0.89	3779.6
17	27.315	70.70	58.10	55	74	0.4876	0.0679	1.1042	0.61	0.83	3637.0
18	27.315	70.70	58.10	56	72	0.4876	0.0679	1.1042	0.62	0.80	3587.5
19	27.315	70.70	58.10	54	66	0.4876	0.0679	1.1042	0.60	0.74	3434.8
20	27.324	71.06	58.10	57	46	0.4876	0 [illegible]79	1.1046	0.64	0.51	2867.9

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AV[illegible] [illegible]RES	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
122.5 CFM	7.673E+04	0.0190	[illegible] INW	0.81 INW	3594 FPM

TABLE D-11: OBSERVATIONS AND COMPUTATIONS FOR CONVEYING CHARACTERISTICS FOR UREA AT 2160 r.p.m.
Fan - Full open. Rate of Flow - 1.84 lb/min.

TRAV. POINT	BAROMET. PRES. (IN.HG)	D.BULB TEMP. (F)	WETBULB TEMP. (F)	O.ST. PRES. (MM)	O.VEL. PRES. (MM)	SAT.VP. PRES. (IN.HG)	DENSITY AIR (LB./C.FT)	COR.FAC. DENSITY	CR.ST. PRES. (INW)	CR.VEL. PRES. (INW)	VELOCITY OF AIR (FPM)
1	27.342	70.34	54.68	62	50	0.4309	0.0681	1.1010	0.69	0.56	2985.3
2	27.342	70.34	54.68	66	67	0.4309	0.0681	1.1010	0.73	0.75	3455.7
3	27.342	70.34	54.68	64	87	0.4309	0.0681	1.1010	0.71	0.97	3937.8
4	27.330	71.24	56.66	66	92	0.4630	0.0679	1.1041	0.74	1.03	4055.0
5	27.330	71.24	56.66	63	84	0.4630	0.0679	1.1041	0.70	0.94	3874.6
6	27.330	71.24	56.66	63	81	0.4630	0.0679	1.1041	0.70	0.90	3804.8
7	27.277	71.24	58.46	62	85	0.4939	0.0678	1.1070	0.69	0.95	3902.8
8	27.277	71.24	58.46	62	84	0.4939	0.0678	1.1070	0.69	0.94	3879.8
9	27.277	71.24	58.46	62	76	0.4939	0.0678	1.1070	0.69	0.85	3690.4
10	27.271	71.24	58.28	61	52	0.4907	0.0677	1.1071	0.68	0.58	3052.8
11	27.250	71.06	56.30	62	45	0.4570	0.0678	1.1068	0.69	0.50	2839.5
12	27.250	71.06	56.30	64	58	0.4570	0.0678	1.1068	0.72	0.65	3223.7
13	27.250	71.06	56.30	62	75	0.4570	0.0678	1.1068	0.69	0.84	3665.8
14	27.295	69.98	56.66	63	84	0.4630	0.0680	1.1031	0.70	0.94	3872.9
15	27.295	69.98	56.66	64	86	0.4630	0.0680	1.1031	0.71	0.96	3918.7
16	27.295	69.98	56.66	62	80	0.4630	0.0680	1.1031	0.69	0.89	3779.6
17	27.315	70.70	58.10	60	74	0.4876	0.0679	1.1042	0.67	0.83	3637.0
18	27.315	70.70	58.10	61	71	0.4876	0.0679	1.1042	0.68	0.79	3562.5
19	27.315	70.70	58.10	60	64	0.4876	0.0679	1.1042	0.67	0.71	3382.3
20	27.324	71.06	58.10	60	46	0.4876	0.0679	1.1046	0.67	0.51	2867.9

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AVG.STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
121.7 CFM	7.619E+04	0.0190	0.70 INW	0.80 INW	3569 FPM

TABLE D-12: OBSERVATIONS AND COMPUTATIONS FOR CONVEYING CHARACTERISTICS FOR UREA AT 2160 r.p.m.
Fan - Full open. Rate of Flow - 4.09 lb/min.

TRAV. POINT	BAROMET. PRES.	D.BULB TEMP.	WETBULB TEMP.	O.ST. PRES.	O.VEL. PRES.	SAT.VP. PRES.	DENSITY AIR	COR.FAC. DENSITY	CR.ST. PRES.	CR.VEL. PRES.	VELOCITY OF AIR
	(IN.HG)	(F)	(F)	(MM)	(MM)	(IN.HG)	(LB./C.FT)		(INW)	(INW)	(FPM)
1	27.342	70.34	54.68	91	46	0.4309	0.0681	1.1010	1.01	0.51	2863.4
2	27.342	70.34	54.68	83	64	0.4309	0.0681	1.1010	0.92	0.71	3377.4
3	27.342	70.34	54.68	79	80	0.4309	0.0681	1.1010	0.88	0.89	3776.1
4	27.330	71.24	56.66	88	81	0.4630	0.0679	1.1041	0.98	0.90	3804.8
5	27.330	71.24	56.66	89	78	0.4630	0.0679	1.1041	0.99	0.87	3733.7
6	27.330	71.24	56.66	87	73	0.4630	0.0679	1.1041	0.97	0.81	3612.0
7	27.277	71.24	58.46	86	80	0.4939	0.0678	1.1070	0.96	0.89	3786.3
8	27.277	71.24	58.46	84	76	0.4939	0.0678	1.1070	0.94	0.85	3690.4
9	27.277	71.24	58.46	85	73	0.4939	0.0678	1.1070	0.95	0.82	3616.8
10	27.271	71.24	58.28	83	50	0.4907	0.0677	1.1071	0.93	0.56	2993.5
11	27.250	71.06	56.30	85	42	0.4570	0.0678	1.1068	0.95	0.47	2743.2
12	27.250	71.06	56.30	84	52	0.4570	0.0678	1.1068	0.94	0.58	3052.4
13	27.250	71.06	56.30	87	68	0.4570	0.0678	1.1068	0.97	0.76	3490.5
14	27.295	69.98	56.66	88	73	0.4630	0.0680	1.1031	0.98	0.81	3610.4
15	27.295	69.98	56.66	86	80	0.4630	0.0680	1.1031	0.96	0.89	3779.6
16	27.295	69.98	56.66	86	70	0.4630	0.0680	1.1031	0.96	0.78	3535.4
17	27.315	70.70	58.10	88	69	0.4876	0.0679	1.1042	0.98	0.77	3512.0
18	27.315	70.70	58.10	86	63	0.4876	0.0679	1.1042	0.96	0.70	3355.8
19	27.315	70.70	58.10	85	60	0.4876	0.0679	1.1042	0.95	0.67	3274.9
20	27.324	71.06	58.10	81	40	0.4876	0.0679	1.1046	0.90	0.45	2674.4

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AVG.STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
116.4 CFM	7.288E+04	0.0192	0.95 INW	0.73 INW	3414 FPM

TABLE D-13: OBSERVATIONS AND COMPUTATIONS FOR CONVEYING CHARACTERISTICS FOR UREA AT 2400 r.p.m.
Fan - Full open. Rate of Flow - 0.89 lb/min.

TRAV. POINT	BAROMET. PRES.	D.BULB TEMP.	WETBULB TEMP.	O.ST. PRES.	O.VEL. PRES.	SAT.VP. PRES.	DENSITY AIR	COR.FAC. DENSITY	CR.ST. PRES.	CR.VEL. PRES.	VELOCITY OF AIR
	(IN.HG)	(F)	(F)	(MM)	(MM)	(IN.HG)	(LB./C.FT)		(INW)	(INW)	(FPM)
1	27.446	69.26	57.92	68	64	0.4844	0.0684	1.0961	0.75	0.71	3369.[illegible]
2	27.446	69.26	57.92	74	85	0.4844	0.0684	1.0961	0.82	0.94	3883.6
3	27.446	69.26	57.92	74	107	0.4844	0.0684	1.0961	0.82	1.18	4357.2
4	27.484	69.98	58.28	73	115	0.4907	0.0684	1.0961	0.81	1.27	4517.2
5	27.484	69.98	58.28	72	108	0.4907	0.0684	1.0961	0.80	1.20	4377.6
6	27.484	69.80	58.10	70	100	0.4876	0.0685	1.0957	0.77	1.11	4211.5
7	27.484	69.80	58.10	70	111	0.4876	0.0685	1.0957	0.77	1.23	4437.1
8	27.484	69.80	58.10	67	107	0.4876	0.0685	1.0957	0.74	1.18	4356.4
9	27.661	67.28	54.50	71	103	0.4281	0.0693	1.0824	0.78	1.13	4248.2
10	27.661	67.28	54.50	71	68	0.4281	0.0693	1.0824	0.78	0.74	34[illegible]3
11	27.675	68.00	54.86	75	60	0.4337	0.0692	1.0833	0.82	0.66	32[illegible]8
12	27.675	68.00	54.86	74	84	0.4337	0.0692	1.0833	0.81	0.92	3838.1
13	27.675	68.00	54.86	74	98	0.4337	0.0692	1.0833	0.81	1.07	4145.6
14	27.681	71.96	55.40	74	107	0.4423	0.0688	1.0908	0.82	1.18	4346.8
15	27.681	71.96	55.40	72	109	0.4423	0.0688	1.0908	0.79	1.20	4387.2
16	27.681	71.96	55.40	70	103	0.4423	0.0688	1.0908	0.77	1.14	4264.7
17	27.690	70.88	55.04	70	93	0.4365	0.0689	1.0883	0.77	1.02	4047.7
18	27.690	70.88	55.04	71	90	0.4365	0.0689	1.0883	0.78	0.99	3981.9
19	27.690	70.88	55.04	67	76	0.4365	0.0689	1.0883	0.74	0.84	3659.1
20	27.673	70.88	55.04	69	50	0.4365	0.0689	1.0890	0.76	0.55	2968.8

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AVG.STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
136.5 CFM	8.548E+04	0.0185	0.79 INW	1.00 INW	4004 FPM

TABLE D-14: OBSERVATIONS AND COMPUTATIONS FOR CONVEYING CHARACTERISTICS FOR UREA AT 2400 r.p.m.
Fan - Full open. Rate of Flow - 1.84 lb/min.

TRAV. POINT	BAROMET. PRES. (IN.HG)	D.BULB TEMP. (F)	WETBULB TEMP. (F)	O.ST. PRES. (MM)	O.VEL. PRES. (MM)	SAT.VP. PRES. (IN.HG)	DENSITY AIR (LB./C.FT)	COR.FAC. DENSITY	CR.ST PRES. (INW)	CR.VEL. PRES. (INW)	VELOCITY OF AIR (FPM)
1	27.446	69.26	57.92	77	64	0.4844	0.0684	1.0961	0.85	0.71	3369.8
2	27.446	69.26	57.92	79	85	0.4844	0.0684	1.0961	0.87	0.94	3883.6
3	27.446	69.26	57.92	78	103	0.4844	0.0684	1.0961	0.86	1.14	4275.0
4	27.484	69.98	58.28	78	113	0.4907	0.0684	1.0961	0.86	1.25	4477.7
5	27.484	69.98	58.28	76	106	0.4907	0.0684	1.0961	0.84	1.17	4336.8
6	27.484	69.80	58.10	76	100	0.4876	0.0685	1.0957	0.84	1.11	4211.5
7	27.484	69.80	58.10	75	104	0.4876	0.0685	1.0957	0.83	1.15	4294.9
8	27.484	69.80	58.10	75	103	0.4876	0.0685	1.0957	0.83	1.14	4274.2
9	27.661	67.28	54.50	76	101	0.4281	0.0693	1.0824	0.83	1.10	4206.8
10	27.661	67.28	54.50	77	68	0.4281	0.0693	1.0824	0.84	0.74	3451.8
11	27.675	68.00	54.86	81	60	0.4337	0.0692	1.0833	0.89	0.66	3243.8
12	27.675	68.00	54.86	78	84	0.4337	0.0692	1.0833	0.85	0.92	3838.1
13	27.675	68.00	54.86	80	96	0.4337	0.0692	1.0833	0.88	1.05	4103.1
14	27.681	71.96	55.40	80	106	0.4423	0.0688	1.0908	0.88	1.17	4326.4
15	27.681	71.96	55.40	78	108	0.4423	0.0688	1.0908	0.86	1.19	4367.0
16	27.681	71.96	55.40	77	98	0.4423	0.0688	1.0908	0.85	1.08	4159.9
17	27.690	70.88	55.04	76	93	0.4365	0.0689	1.0883	0.84	1.02	4047.7
18	27.690	70.88	55.04	76	86	0.4365	0.0689	1.0883	0.84	0.95	3892.4
19	27.690	70.88	55.04	74	76	0.4365	0.0689	1.0883	0.81	0.84	3659.1
20	27.673	70.88	55.04	76	50	0.4365	0.0689	1.0890	0.84	0.56	2968.8

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AVG.STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
135.3 CFM	8.473E+04	0.0185	0.85 INW	0.98 INW	3969 FPM

TABLE D-15: OBSERVATIONS AND COMPUTATIONS FOR CONVEYING CHARACTERISTICS FOR UREA AT 2400 r.p.m.
Fan - Full open. Rate of Flow - 4.09 lb/min.

TRAV. POINT	BAROMET. PRES.	D.BULB TEMP.	WETBULB TEMP.	O.ST. PRES.	O.VEL. PRES.	SAT.VP. PRES.	DENSITY AIR	COR.FAC. DENSITY	CR.ST. PRES.	CR.VEL. PRES.	VELOCITY OF AIR
	(IN.HG)	(F)	(F)	(MM)	(MM)	(IN.HG)	(LB./C.FT)		(INW)	(INW)	(FPM)
1	27.446	69.26	57.92	98	60	0.4844	0.0684	1.0961	1.09	0.66	3262.8
2	27.446	69.26	57.92	103	79	0.4844	0.0684	1.0961	1.14	0.87	3744.0
3	27.446	69.26	57.92	98	96	0.4844	0.0684	1.0961	1.09	1.06	4127.2
4	27.484	69.98	58.28	103	106	0.4907	0.0684	1.0961	1.14	1.17	4336.8
5	27.484	69.98	58.28	104	99	0.4907	0.0684	1.0961	1.15	1.10	4191.2
6	27.484	69.80	58.10	103	96	0.4876	0.0685	1.0957	1.14	1.06	4126.4
7	27.484	69.80	58.10	103	100	0.4876	0.0685	1.0957	1.14	1.11	4211.5
8	27.484	69.80	58.10	105	100	0.4876	0.0685	1.0957	1.16	1.11	4211.5
9	27.661	67.28	54.50	98	95	0.4281	0.0693	1.0824	1.07	1.04	4079.9
10	27.661	67.28	54.50	102	62	0.4281	0.0693	1.0824	1.12	0.68	3296.0
11	27.665	68.00	54.86	102	53	0.4437	0.0692	1.0839	1.12	0.58	3049.5
12	27.665	68.00	54.86	103	77	0.4337	0.0692	1.0837	1.13	0.84	3675.4
13	27.675	68.00	54.86	106	86	0.4337	0.0692	1.0833	1.16	0.94	3883.5
14	27.681	71.96	55.40	103	103	0.4423	0.0688	1.0908	1.14	1.14	4264.7
15	27.691	71.96	55.40	102	100	0.4423	0.0688	1.0904	1.12	1.10	4201.4
16	27.691	71.96	55.40	101	93	0.4423	0.0688	1.0904	1.11	1.02	4051.7
17	27.690	70.88	55.04	102	86	0.4365	0.0689	1.0883	1.12	0.95	3892.4
18	27.690	70.88	55.04	103	81	0.4365	0.0689	1.0883	1.13	0.89	3777.5
19	27.690	70.88	55.04	100	72	0.4365	0.0689	1.0883	1.10	0.79	3561.5
20	27.673	70.88	55.04	98	46	0.4365	0.0689	1.0890	1.08	0.51	2847.6

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AVG.STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
130.9 CFM	8.196E+04	0.0187	1.12 INW	0.92 INW	[illegible]839 FPM

TABLE D-16: OBSERVATIONS AND COMPUTATIONS FOR CONVEYING CHARACTERISTICS FOR UREA AT 2875 r.p.m. Fan - Full open. Rate of Flow - 0.89 lb/min.

TRAV. POINT	BAROMET. PRES. (IN.HG)	D.BULB TEMP. (F)	WETBULB TEMP. (F)	O.ST. PRES. (MM)	O.VEL. PRES. (MM)	SAT.VP. PRES. (IN.HG)	DENSITY AIR (LB./C.FT)	COR.FAC. DENSITY	CR.ST. PRES. (INW)	CR.VEL. PRES. (INW)	VELOCITY OF AIR (FPM)
1	27.489	70.98	56.12	99	95	0.4540	0.0684	1.0967	1.10	1.05	4106.8
2	27.489	70.88	56.12	103	126	0.4540	0.0684	1.0967	1.14	1.40	4729.7
3	27.489	70.88	56.12	100	151	0.4540	0.0684	1.0967	1.11	1.67	5177.6
4	27.451	70.70	55.40	103	173	0.4423	0.0683	1.0976	1.14	1.92	5544.3
5	27.451	70.70	55.40	103	157	0.4423	0.0683	1.0976	1.14	1.74	5281
6	27.451	70.70	55.40	99	149	0.4423	0.0683	1.0976	1.10	1.65	514
7	27.427	70.70	55.58	96	161	0.4452	0.0683	1.0987	1.07	1.79	5351.1
8	27.421	70.70	55.58	99	155	0.4452	0.0683	1.0989	1.10	1.72	5251.0
9	27.427	70.70	55.58	97	145	0.4452	0.0683	1.0987	1.08	1.61	5078.2
10	27.407	70.88	54.50	102	102	0.4281	0.0682	1.0994	1.13	1.13	4260.6
11	27.407	70.88	54.50	105	91	0.4281	0.0682	1.0994	1.17	1.01	4024.3
12	27.407	70.88	54.50	103	108	0.4281	0.0682	1.0994	1.14	1.20	4384.1
13	27.339	70.70	53.96	103	145	0.4197	0.0681	1.1016	1.15	1.61	5084.9
14	27.339	70.70	53.96	103	157	0.4197	0.0681	1.1016	1.15	1.75	5291.2
15	27.339	70.70	53.96	101	155	0.4197	0.0681	1.1016	1.12	1.73	5257.4
16	27.345	69.98	53.96	99	149	0.4197	0.0682	1.0999	1.10	1.66	5150.8
17	27.345	69.98	53.96	97	138	0.4197	0.0682	1.0999	1.08	1.53	4957.0
18	27.345	69.98	53.96	99	136	0.4197	0.0682	1.0999	1.10	1.51	4921.0
19	27.354	70.70	53.78	95	123	0.4170	0.0681	1.1009	1.06	1.37	4681.9
20	27.354	70.70	53.78	102	75	0.4170	0.0681	1.1009	1.13	0.83	3655.9

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AVG.STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
165.9 CFM	1.039E+05	0.0176	1.12 INW	1.48 INW	4866 FPM

TABLE D-17: OBSERVATIONS AND COMPUTATIONS FOR CONVEYING CHARACTERISTICS FOR UREA AT 2875 r.p.m.
Fan - full open. Rate of Flow - 1.84 lb/min.

TRAV. POINT	BAROMET. PRES.	D.BULB TEMP.	WETBULB TEMP.	O.ST. PRES.	O.VEL. PRES.	SAT.VP. PRES.	DENSITY AIR	COR.FAC. DENSITY	CR.ST. PRES.	CR.VEL. PRES.	VELOCITY OF AIR
	(IN.HG)	(F)	(F)	(MM)	(MM)	(IN.HG)	(LB./C.FT)		(INW)	(INW)	(FPM)
1	27.489	70.88	56.12	109	92	0.4540	0.0684	1.0967	1.21	1.02	4041.5
2	27.489	70.88	56.12	111	125	C.4540	0.0684	1.0967	1.23	1.39	4710.8
3	27.489	70.88	56.12	108	151	0.4540	0.0684	1.0967	1.20	1.67	5177.6
4	27.451	70.70	55.40	111	173	0.4423	0.0683	1.0976	1.23	1.92	5544.3
5	27.451	70.70	55.40	108	156	0.4423	0.0683	1.0976	1.20	1.73	5264.8
6	27.451	70.70	55.40	107	148	0.4423	0.0683	1.0976	1.19	1.64	5128.0
7	27.427	70.70	55.58	106	159	0.4452	0.0683	1.0987	1.18	1.76	5317.7
8	27.427	70.70	55.58	106	154	0.4452	0.0683	1.0987	1.18	1.71	5233.4
9	27.427	70.70	55.58	105	145	0.4452	0.0683	1.0987	1.17	1.61	5078.2
10	27.407	70.88	54.5C	107	102	0.4281	0.0682	1.0994	1.19	1.13	4260.6
11	27.407	70.88	54.50	108	91	0.4281	0.0682	1.0994	1.20	1.01	4024.3
12	27.407	70.88	54.50	109	108	0.4281	0.0682	1.0994	1.21	1.20	4384.1
13	27.339	70.70	53.96	107	143	0.4197	0.0681	1.1016	1.19	1.59	5049.7
14	27.339	70.70	53.96	107	153	0.4197	0.0681	1.1016	1.19	1.70	5223.3
15	27.339	70.70	53.96	107	155	0.4197	0.0681	1.1016	1.19	1.73	5257.4
16	27.345	69.98	53.96	104	145	0.4197	0.0682	1.0999	1.16	1.61	5081.2
17	27.345	69.98	53.96	104	138	0.4197	0.0682	1.0999	1.16	1.53	4957.0
18	27.345	69.98	55.96	103	129	0.4197	0.0682	1.1003	1.14	1.43	4793.3
19	27.354	70.70	53.78	102	117	0.4170	0.0681	1.1009	1.13	1.30	4566.3
20	27.354	70.70	53.78	104	74	0.4170	0.0681	1.1009	1.16	0.82	3631.5

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AVG.STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
164.9 CFM	1.032E+05	0.0176	1.18 INW	1.46 INW	4836 FPM

TABLE D-18: OBSERVATIONS AND COMPUTATIONS FOR CONVEYING CHARACTERISTICS FOR UREA AT 2875 r.p.m.
Fan - Full open. Rate of Flow - 4.09 lb/min.

TRAV. POINT	BAROMET. PRES.	D.BULB TEMP.	WETBULB TEMP.	O.ST. PRES.	O.VEL. PRES.	SAT.VP. PRES.	DENSITY AIR	COR.FAC. DENSITY	CR.ST. PRES.	CR.VEL. PRES.	VELOCITY OF AIR
	(IN.HG)	(F)	(F)	(MM)	(MM)	(IN.HG)	(LB./C.FT)		(INW)	(INW)	(FPM)
1	27.489	70.88	56.12	137	87	0.4540	0.0684	1.0967	1.52	0.96	3930.1
2	27.489	70.88	56.12	139	117	0.4540	0.0684	1.0967	1.54	1.30	4557.6
3	27.489	70.88	56.12	142	146	0.4540	0.0684	1.0967	1.57	1.62	5091.2
4	27.451	70.70	55.40	139	155	0.4423	0.0683	1.0976	1.54	1.72	5247.9
5	27.451	70.70	55.40	141	147	0.4423	0.0683	1.0976	1.56	1.63	5110.7
6	27.451	70.70	55.40	136	140	0.4423	0.0683	1.0976	1.51	1.55	4987.5
7	27.427	70.70	55.58	137	144	0.4452	0.0683	1.0987	1.52	1.60	5060.7
8	27.427	70.70	55.58	135	149	0.4452	0.0683	1.0987	1.50	1.65	5147.8
9	27.427	70.70	55.58	135	139	0.4452	0.0683	1.0987	1.51	1.54	4972.0
10	27.407	70.88	54.50	139	89	0.4281	0.0682	1.0994	1.54	0.99	3979.8
11	27.407	70.88	54.50	133	89	0.4281	0.0682	1.0994	1.48	0.99	3979.8
12	27.407	70.88	54.50	121	100	0.4281	0.0682	1.0994	1.34	1.11	4218.6
13	27.339	70.70	53.96	122	141	0.4197	0.0681	1.1016	1.36	1.57	5014.3
14	27.339	70.70	53.96	120	153	0.4197	0.0681	1.1016	1.34	1.70	5223.3
15	27.339	70.70	53.96	121	155	0.4197	0.0681	1.1016	1.35	1.73	5257.4
16	27.345	69.98	53.96	116	143	0.4197	0.0682	1.0999	1.29	1.59	5046.0
17	27.345	69.98	53.96	116	136	0.4197	0.0682	1.0999	1.29	1.51	4921.0
18	27.345	69.98	53.96	116	129	0.4197	0.0682	1.0999	1.29	1.43	4792.7
19	27.354	70.70	53.78	116	114	0.4170	0.0681	1.1009	1.29	1.27	4507.3
20	27.354	70.70	53.78	115	73	0.4170	0.0681	1.1009	1.28	0.81	3606.9

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AVG.STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
161.3 CFM	1.010E+05	0.0177	1.43 INW	1.40 INW	4732 FPM

APPENDIX E

Mitre Bend Characteristics

TABLE E-1: OBSERVATIONS AND COMPUTATIONS FOR MITRE BEND FRICTION AT 2875 r.p.m. Fan - Full open.

Measuring Station - Upstream

TRAV. POINT	BAROMET. PRES.	D.BULB TEMP.	WETBULB TEMP.	O.ST. PRES.	O.VEL. PRES.	SAT.VP. PRES.	DENSITY AIR	COR.FAC. DENSITY	CR.ST. PRES.	CR.VEL. PRES.	VELOCITY OF AIR
	(IN.HG)	(F)	(F)	(MM)	(MM)	(IN.HG)	(LB./C.FT)		(INW)	(INW)	(FPM)
1	27.531	69.98	51.62	160	78	0.3852	0.0687	1.0916	1.76	0.86	3712.6
2	27.531	69.98	51.62	154	124	0.3852	0.0687	1.0916	1.70	1.37	4681.0
3	27.531	69.98	51.62	165	150	0.3852	0.0687	1.0916	1.82	1.65	5148.4
4	27.531	69.98	51.62	163	163	0.3852	0.0687	1.0916	1.80	1.80	5366.8
5	27.531	69.98	51.62	163	145	0.3852	0.0687	1.0916	1.80	1.60	5061.8
6	27.519	69.98	51.62	156	143	0.3852	0.0687	1.0921	1.72	1.58	5027.9
7	27.519	69.98	51.62	157	150	0.3852	0.0687	1.0921	1.73	1.66	5149.5
8	27.519	69.98	51.62	157	146	0.3852	0.0687	1.0921	1.73	1.61	5080.4
9	27.519	69.98	51.62	155	138	0.3852	0.0687	1.0921	1.71	1.52	4939.2
10	27.519	69.98	51.62	150	96	0.3852	0.0687	1.0921	1.66	1.06	4119.6
11	27.501	70.70	50.90	165	77	0.3750	0.0686	1.0939	1.82	0.85	3692.6
12	27.501	70.70	50.90	164	110	0.3750	0.0686	1.0939	1.81	1.22	4413.5
13	27.501	70.70	50.90	165	137	0.3750	0.0686	1.0939	1.82	1.51	4925.4
14	27.501	70.70	50.90	164	156	0.3750	0.0686	1.0939	1.81	1.72	5255.9
15	27.501	70.70	50.90	161	152	0.3750	0.0686	1.0939	1.78	1.68	5188.1
16	27.498	70.70	50.90	157	139	0.3750	0.0686	1.0940	1.74	1.54	4961.5
17	27.498	70.70	50.90	156	130	0.3750	0.0686	1.0940	1.72	1.44	4798.2
18	27.498	70.70	50.90	157	111	0.3750	0.0686	1.0940	1.74	1.23	4433.7
19	27.498	70.70	50.90	157	101	0.3750	0.0686	1.0940	1.74	1.12	4229.3
20	27.498	70.70	50.90	153	70	0.3750	0.0686	1.0940	1.69	0.77	3520.9

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AVG.STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
159.7 CFM	1.000E+05	0.0178	1.76 INW	1.37 INW	4685 FPM

TABLE E-2: OBSERVATIONS AND COMPUTATIONS FOR MITRE BEND FRICTION AT 2875 r.p.m. Fan - Full open.

Measuring Station - Downstream

TRAV. POINT	BAROMET. PRES. (IN.HG)	D.BULB TEMP. (F)	WETBULB TEMP. (F)	O.ST. PRES. (MM)	O.VEL. PRES. (MM)	SAT.VP. PRES. (IN.HG)	DENSITY AIR (LB./C.FT)	COR.FAC. DENSITY	CR.ST. PRES. (INW)	CR.VEL. PRES. (INW)	VELOCITY OF AIR (FPM)
1	27.531	69.98	51.62	97	63	0.3852	0.0687	1.0916	1.07	0.69	3336.5
2	27.531	69.98	51.62	95	96	0.3852	0.0687	1.0916	1.05	1.06	4118.7
3	27.531	69.98	51.62	99	103	0.3852	0.0687	1.0916	1.05	1.14	4266.2
4	27.531	69.98	51.62	95	118	0.3852	0.0687	1.0916	1.05	1.30	4566.3
5	27.531	69.98	51.62	102	118	0.3852	0.0687	1.0916	1.12	1.30	4566.3
6	27.519	69.98	51.62	95	127	0.3852	0.0687	1.0921	1.05	1.40	4738.3
7	27.519	69.98	51.62	98	110	0.3852	0.0687	1.0921	1.08	1.21	4409.8
8	27.519	69.98	51.62	98	103	0.3852	0.0687	1.0921	1.08	1.14	4267.2
9	27.519	69.98	51.62	94	88	0.3852	0.0687	1.0921	1.04	0.97	3944.2
10	27.519	69.98	51.62	92	66	0.3852	0.0687	1.0921	1.02	0.73	3415.8
11	27.501	70.70	50.90	95	56	0.3750	0.0686	1.0939	1.05	0.62	3149.0
12	27.501	70.70	50.90	96	73	0.3750	0.0686	1.0939	1.06	0.81	3595.4
13	27.501	70.70	50.90	95	74	0.3750	0.0686	1.0939	1.05	0.82	3619.9
14	27.501	70.70	50.90	97	105	0.3750	0.0686	1.0939	1.07	1.16	4312.0
15	27.501	70.70	50.90	97	117	0.3750	0.0686	1.0939	1.07	1.29	4551.7
16	27.498	70.70	50.90	97	137	0.3750	0.0686	1.0940	1.07	1.51	4925.7
17	27.498	70.70	50.90	98	116	0.3750	0.0686	1.0940	1.08	1.28	4532.5
18	27.498	70.70	50.90	97	111	0.3750	0.0686	1.0940	1.07	1.23	4433.7
19	27.498	70.70	50.90	96	98	0.3750	0.0686	1.0940	1.06	1.08	4166.0
20	27.498	70.70	50.90	92	68	0.3750	0.0686	1.0940	1.02	0.75	3470.3

RATE OF FLOW	REYNOLDS NUMBER	FRICTION FACTOR	AVG.STATIC PRESSURE	AVG.VELOCITY PRESSURE	AVERAGE VELOCITY
140.4 CFM	8.793E+04	0.0184	1.06 INW	1.06 INW	4119 FPM

APPENDIX F

Rheological Properties of Fertilizers

TABLE F-1: FERTILIZER PROPERTIES

FERTILIZER: Common Name Ammonium Sulphate Chemical Name $(NH_4)_2\ SO_4$

WEIGHT PER CUBIC FOOT: Poured 70.053 lb/cu.ft

ANGLE OF REPOSE: 26.8°

PARTICLE SIZE:

Mesh	Size of Opening	Weight of Material Retained	Per Cent of Material Retained	Multiplied by
4	0.185	0.00	0.00	6=
8	0.093	7.85	3.14	5= 15.70
14	0.046	204.50	81.80	4= 327.20
28	0.0232	37.20	14.88	3= 44.64
48	0.0166	0.18	.07	2= 0.14
100	0.0058	0.23	.09	1= 0.09
Pan		0.10	.04	0= 0.00
		Totals	100.00	387.77

Fineness Modulus = $\frac{387.77}{100}$ =3.88

Average Particle Dia. = $0.0041(2)^{F.M.} = .0041(2)^{3.88} = 0.060$ inch.

SPECIAL CHARACTERISTICS:

pH Highly Acidic

Abrasive Fair to Moderate

Hygroscopic yes

Corrosive yes

Combustible no

Explosive no

TABLE F-2: FERTILIZER PROPERTIES

FERTILIZER: Common Name Ammonium Sulphate Chemical Name $(NH_4)_2\ SO_4$

WEIGHT PER CUBIC FOOT: Poured 69.828 lb/cu ft.

ANGLE OF REPOSE: 27.4°

PARTICLE SIZE:

Mesh	Size of Opening	Weight of Material Retained	Per Cent of Material Retained	Multiplied by	
4	0.185	0.00	0.00	6=	
8	0.093	14.55	5.82	5=	29.10
14	0.046	203.85	81.54	4=	326.16
28	0.0232	31.25	12.50	3=	37.50
48	0.0166	0.17	0.07	2=	0.14
100	0.0058	0.08	0.03	1=	0.03
Pan		0.10	0.04	0=	
		Totals	100		392.93

Fineness Modulus = $\frac{392.93}{100}$ = 3.93

Average Particle Dia. = $0.0041(2)^{F.M.} = 0.0041(2)^{3.93}$ = .062

SPECIAL CHARACTERISTICS:

pH highly acidic

Abrasive fair to moderate

Hygroscopic yes

Corrosive yes

Combustible no

Explosive no

TABLE F-3: FERTILIZER PROPERTIES

FERTILIZER: Common Name Ammonium Sulphate Chemical Name $(NH_4)_2\ SO_4$

WEIGHT PER CUBIC FOOT: Poured 69.728 lb/cu.ft

ANGLE OF REPOSE: 27.0°

PARTICLE SIZE:

Mesh	Size of Opening	Weight of Material Retained	Per Cent of Material Retained	Multiplied by
4	0.185	0.00	0.00	6= 0.00
8	0.093	7.92	3.17	5= 15.85
14	0.046	199.30	79.72	4= 318.88
28	0.0232	42.35	16.94	3= 50.82
48	0.0116	0.18	0.07	2= 0.14
100	0.0058	0.15	0.06	1= 0.06
Pan		0.10	0.04	0= 0.00

Totals

Fineness Modulus $= \frac{385.75}{100} = 3.86$

Average Particle Dia. $= 0.0041(2)^{F.M.} = .0041(2)^{3.86} = 0.059$ inch

SPECIAL CHARACTERISTICS:

pH Highly Acidic

Abrasive Fair to moderate

Hygroscopic yes

Corrosive yes

Combustible no

Explosive no

TABLE F-4: FERTILIZER PROPERTIES

FERTILIZER: Common Name Urea Chemical Name $CO(NH_2)_2$

WEIGHT PER CUBIC FOOT: Poured 48.07 lb/cu. ft

ANGLE OF REPOSE: 22.8°

PARTICLE SIZE:

Mesh	Size of Opening	Weight of Material Retained	Per Cent of Material Retained	Multiplied by	
4	0.185	0.00	0.00	6=	
8	0.093	205.72	82.29	5=	411.45
14	0.046	43.57	17.43	4=	69.72
28	0.0232	0.50	0.20	3=	0.60
48	0.0116	0.15	0.06	2=	0.12
100	0.0058	-	-	1=	
Pan		0.08	0.03	0=	
		Totals	100.00		481.89

Fineness Modulus $= \frac{481.89}{100} = 4.82$

Average Particle Dia. $= 0.0041(2)^{F.M.} = .0041(2)^{4.82} = 0.116$ inch

SPECIAL CHARACTERISTICS:

pH Acidic

Abrasive Low to Moderate

Hygroscopic yes

Corrosive yes

Combustible no

Explosive no

TABLE F-5: FERTILIZER PROPERTIES

FERTILIZER: Common Name Urea Chemical Name $CO(NH_2)_2$

WEIGHT PER CUBIC FOOT: Poured 48.70 lb/cu.ft

ANGLE OF REPOSE: 23.1°

PARTICLE SIZE:

Mesh	Size of Opening	Weight of Material Retained	Per Cent of Material Retained	Multiplied by	
4	0.185	0.00	0.00	6=	
8	0.093	204.42	81.77	5=	408.85
14	0.046	45.22	18.09	4=	72.36
28	0.0232	0.23	0.09	3=	0.27
48	0.0116	-	-	2=	
100	0.0058	0.08	0.03	1=	0.03
Pan		0.08	0.03	0=	
		Totals	100.00		481.51

Fineness Modulus $= \frac{481.51}{100} = 4.82$

Average Particle Dia. $= 0.0041(2)^{F.M.} = .0041(2)^{4.82} = 0.115$

SPECIAL CHARACTERISTICS:

pH Acidic

Abrasive Low to Moderate

Hygroscopic yes

Corrosive yes

Combustible no

Explosive no

TABLE F-6: FERTILIZER PROPERTIES

FERTILIZER: Common Name Urea Chemical Name $CO(NH_2)_2$

WEIGHT PER CUBIC FOOT: Poured 49.32 lb/cu.ft

ANGLE OF REPOSE: 22.9°

PARTICLE SIZE:

Mesh	Size of Opening	Weight of Material Retained	Per Cent of Material Retained	Multiplied by	
4	0.185	0.0	0.0	6=	
8	0.093	203.42	81.37	5=	406.85
14	0.046	46.28	18.51	4=	74.04
28	0.0232	0.15	0.06	3=	0.18
48	0.0116	-	-	2=	
100	0.0058	0.08	0.03	1=	0.03
Pan		0.08	0.03	0=	
		Totals	100.00		481.10

Fineness Modulus $= \frac{481.10}{100} = 4.81$

Average Particle Dia. $= 0.0041(2)^{F.M.} = .0041(2)^{4.81} = 0.115$

SPECIAL CHAR[illegible]RISTICS:

pH Acidic

Abrasive Low to Moderate

Hygroscopic yes

Corrosive yes

Combustible no

Explosive no