PNEUMATIC CONVEYING TESTS WITH DIFFERENT DRY GRAINS

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FOR

MY MOTHER AND FATHER

"THEY FURNISH SHADE TO OTHERS
WHILE STANDING IN THE SUN
THEMSELVES."

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF GRAPHS

INTRODUCTION

In 1975 the government of Saudi Arabia announced it would build three flour and feed mill plants inside its borders. Saudi Arabia is universally recognized by the West as the largest oil exporter in the world. The country is totally dependent on imports of food stock and other commodities to feed, clothe and industrialize its people. The three plants, with a total capacity of 25,000 cwt (100 lbs.)/24 hrs., will allow the government to process all of its grain imports instead of being dependent on processing outside the country as is presently the case. The decision to build its own milling plants is seen as a major technological move of a developing country.

One innovative feature of the flour and feed mills in Saudi Arabia is that pneumatic conveyors will be used throughout its operation. Europe and England began using pneumatic conveying equipment in milling operations in the early 1900's. William Cramp, an American engineer, is considered the "father" of pneumatic systems in the United States of America. His 1925 paper established the mathematical basis for air conveying systems which are still used. However, pneumatic systems in milling operations were not adopted in the United States because it was believed they were more expensive than the mechanical conveyors then in use. So it was that Europeans became the largest developers of pneumatic conveyors for handling food stock. Even to the present, American milling engineers consider the use of pneumatic conveyors as an "art" as well as an engineering feat or accomplishment.

Swtizerland dominated the manufacture of pneumatic conveyor for milling conveyance operations; Anton Meyer, one of the best-known manufacturers of pneumatic conveyors in Europe, established the first milling plant in 1944 which used pneumatic conveying exclusively. Apparently influenced by this decision, General Mills announced the following year it was establishing a milling plant in Los Angeles which would also use pneumatic conveyors for handling all mill stock and finished flour.

Research in pneumatic conveying systems for transporting grain has been conducted since as early as 1920 (1). Stoess (36) and Kraus (28) say its use in moving food stock is an art. Both agree there is as yet "no universal pneumatic conveyor...to handle all materials," nor is there an "universally applicable empirical formula for designing such systems."

> The basic reason for the diversity of data on the pneumatic transportation of solids is the variety of the materials that can be conveyed... by a broad range of air velocities at various material-to-air loadings...(Which are) a function of the particle-size spectrum and of the density, shape and physical characteristics of the material ...(and) direction of flow-horizontal or vertical. (28)

Stoess (36) adds that attempts to discover a universal formula has not yet met with success. Companies involved in manufacturing pneumatic conveyors for milling operations are reluctant to share their research. The result or empirical data is a field rapidly coming into its own, but with insufficient research literature available for millers who are considering using pneumatic conveyors in their operations. Kraus (28) says that prospective clients should know their needs before entering into a contract. "Thus the purchaser must know what equipment he needs to accomplish a definite objective and must be able to interpret the results of the vendor's test" designed to meet his specifications.

The use of pneumatic systems for transporting solids is not new. The present trend of mill operators to use the system in transporting grain and its by-products in their plants is different. Pneumatic conveyors have been used early in this century by grain farmers, but the system fell into disuse because they believed mechanical conveyors more economical and energy efficient. There was also a question of possible health hazards connected with the pneumatic conveyors, although documentation for this possibility was never made. The end result is that practical knowledge about pneumatic conveyors is limited and difficult to obtain.

THE PROBLEM

Research shows that pneumatic conveying systems have been used in milling operations since the early 1900's in Europe and the United States of America. Yet there is still considerable debate and conflicting information about building or designing these systems, and whether or not pneumatic conveyors are more economical or efficient than mechanical conveyors. Additionally, there is the lack of public information available to the plant superintendent or head miller who has to decide what type of pneumatic conveying system to use to transport grains in the milling plants. Among the many facets of information the head miller should be able to call upon are:

1) the cost of installing and operating a pneumatic system;

2) its energy consumption;

3) the efficiency of a particular system over other mechanical and pneumatic systems;

4) the benefits of pneumatic systems relating to sanitation and processing advantages;

5) the physical effects of the pneumatic conveying on the conveyed materials; and

6) the advantages of having a high cost pneumatic conveying system.

Our theoretical head miller would be faced with the problem of determining which are the most efficient and effective pneumatic conveying systems for transporting whole grains. The gravity of this problem area is underscored when we examine what resources are presently available for solving the problem.

There is little public information on the various types of pneumatic systems used in grain milling plants available by governments, universities, or research centers. Manufacturers of pneumatic conveying systems used in milling operations are reluctant to make their research public, fearing its application by competitors to improve their own products.

The systems presently in use have been designed for commercial operations and privately financed for that purpose. General Mills, in 1948, installed their first pneumatic mill. At the present time, approximately 65% of wheat milling plants in the United States use pneumatic conveyors.

The result of this reluctance by industry to make research available as public information is that there are only small depositories of objective research on the effects of various types of whole grains conveyed pneumatically. The implications of the problem increases for developing countries, such as Saudi Arabia, which are rapidly industrializing. These countries have neither the experience nor the factual information which would give them an indication of what problems to expect from certain grains under specific pneumatic conveying systems.

OBJECTIVE

The present study was instituted to provide needed objective information on pneumatic conveying systems which at present is unavailable. It is limited to the study of whole grain in pneumatic conveying systems. While no mill superintendent or government agent is likely to duplicate the exact conditions under which this research was carried out, a method and comparative tables have been provided which will aid others in adding to the body of information on pneymatic conveying systems.

Pneumatic conveying tests with different whole grains have been conducted at Kansas State University. These results will be examined to determine the effects of various grains when conveyed by positive and negative pressure systems. The knowledge gained in this research will definitely help to solve future technical problems and carry effective solutions when a decision is made for expansion.

REVIEW OF LITERATURE

DEFINITION

Pneumatic conveying has a broad definition. Stoess (36) described it as a simple tool to transport dry bulk materials (whole grains) by air movement through a pipe.

TYPES OF SYSTEMS

There are two types of pneumatic conveyors: positive pressure system, and negative pressure (or suction) system. In the positive pressure system, air is introduced into the conveying pipe with pressure above atmospheric (normal) 14.7 PSI. In negative pressure, air is introduced into the conveying pipe by developing a pressure below atmospheric at the intake or pick-up station.

Kice (27) explained well the positive pressure when using air lock injector or a venturi feeder (Fig. 1c, 1d). Stock is fed by air-lock into the conveying pipe against a considerable air pressure without undue loss of air. While utilizing the venturi principle, stock is introduced into the pressure line at a point of induced negative pressure. A negative pressure is developed in the throat of the venturi when air passes through it at high velocity and converts back to positive pressure in the expanding-out section. Stock falls into the throat of the venturi at negative pressure, but flows through the pipe under positive pressure.

Kice (27) continued, saying that air is moved in the conveying pipe by either centrifugal fan or displacement blower at the delivery point, a case usually used. The displacement blower permits the system to handle more stock with less air through a smaller pipe diameter. Thus, the smaller air quantity reduces the dust problem at the discharge point. This eliminates the need for dust separator and air-lock other than using the receiving bin as a settling chamber.

Similarly, negative pressure (Fig. 1a, 1b) operates either with stock passing through the fan or dropping out of the fan or blower. In the first case, it is limited to materials that neither damage the fan nor are damaged by the fan or blower.

Positive displacement blower and light centrifugal fan would not be recommended because separation of air from stock is required by either a cyclon or a filter. Usually negative pressure is powered by centrifugal fan. In the second case, the air mover is located after the material and air dust separation equipment (cyclon) so that stock is discharged out of the conveying pipe ahead of the fan or blower. Because the separator operates under negative pressure, a sealed air-lock is required at its outlet.

Kice (27) and Cereal Millers Handbook (9) explain the idea of pneumatic conveying. Actually, as any fan or blower removes air, it creates a partial suction at the inlet which is negative pressure, because it is less than atmospheric 14.7 PSI absolute. Since the atmospheric at the open end of the pipe is

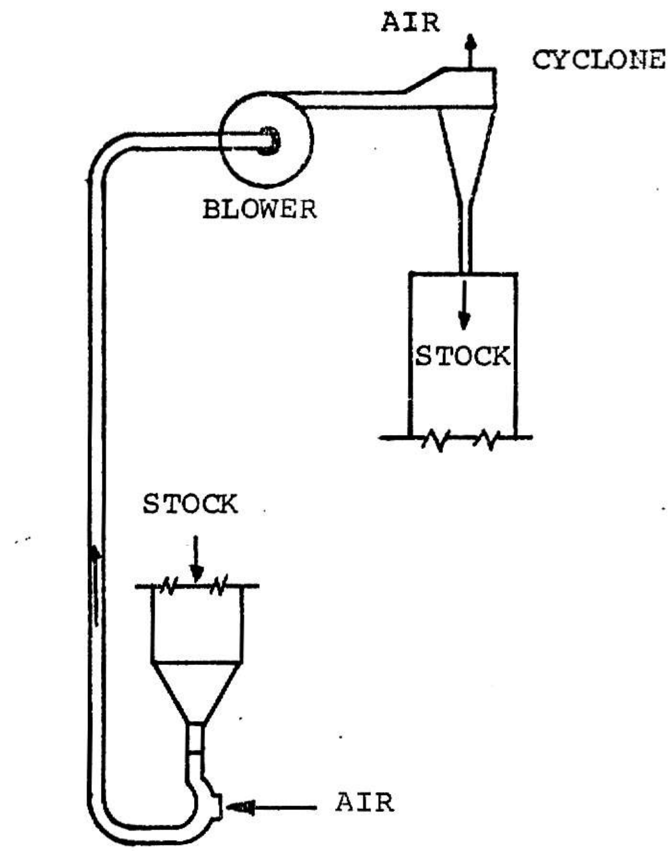


Fig.1(a) NEGATIVE PRESSURE WITH STOCK PASSING THROUGH THE FAN

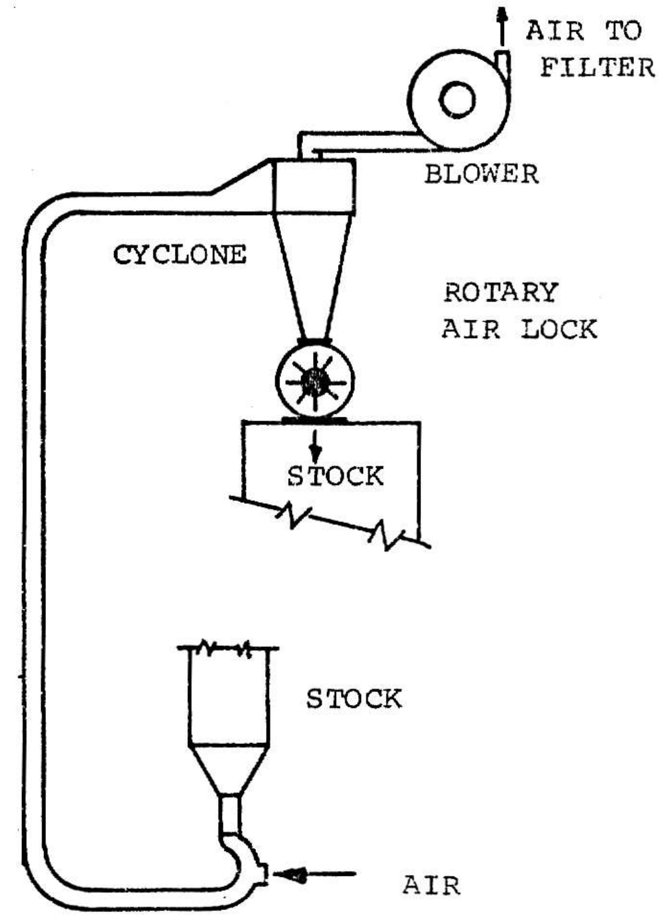


Fig.1 (b) NEGATIVE PRESSURE WITH STOCK DROPPING OUT AHEAD OF THE FAN

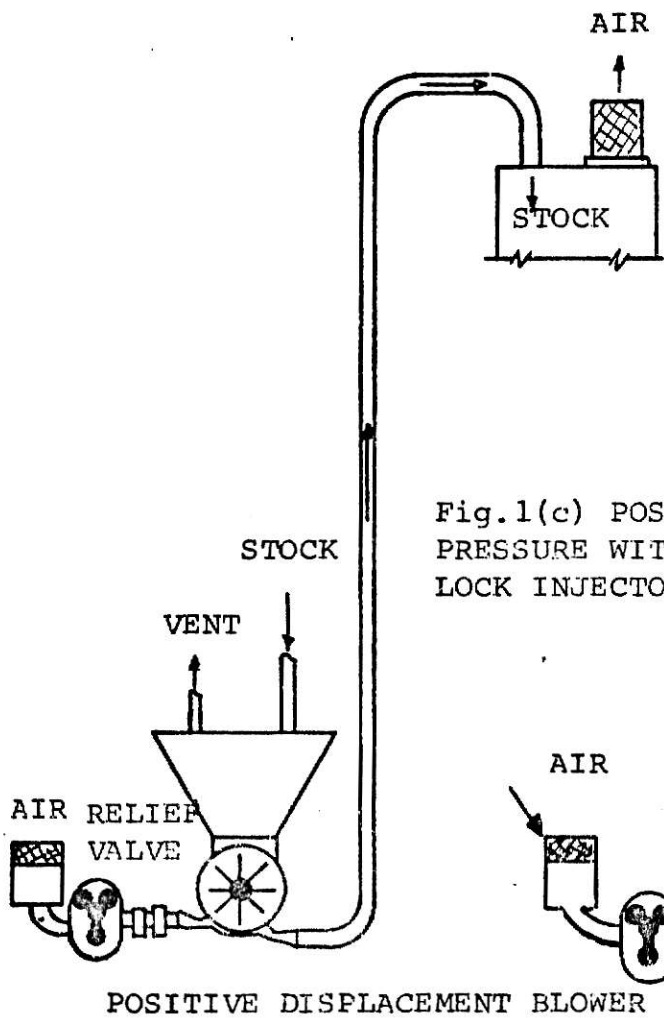


Fig.1(c) POSITIVE PRESSURE WITH AIR-LOCK INJECTOR

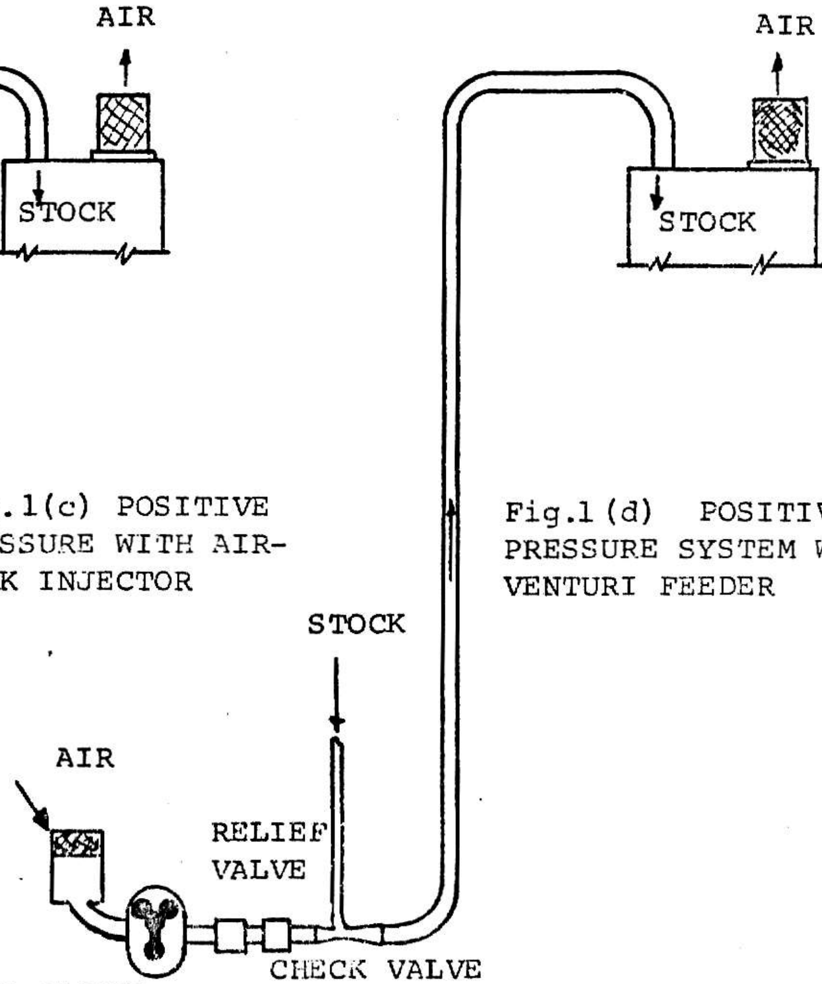


Fig.1 (d) POSITIVE PRESSURE SYSTEM WITH VENTURI FEEDER

Fig. 1

greater than it is at the end of the air mover, air is pushed through the pipe toward the fan or blower by the amount of the pressure difference at its inlet. Stock can ride along with the moving air. In either case, therefore, stock is carried by the air that is being pushed, whether the blower or fan is used to produce negative or positive pressure.

BASIC PRINCIPLE OF PNEUMATIC CONVEYING

Nichols (31) stated that the fundamental principle of pneumatic conveying is overcoming the effect of gravity by the force of the moving air. Kice (27) pointed out that having air pressure differential between the inlet and the outlet is necessary to transport material through a horizontal or vertical pipe. This difference must be equal to or greater than the sum of all resistances, part of which are due to the air flow and part to the material flow.

Fairchild (16) mentioned that in order to obtain an upward movement of stock in a pneumatic tube, the velocity of the conveying air must be greater than the terminal or floatational velocity of the stock particles.

TERMINAL VELOCITY

When a kernel of grain falls through still air, it accelerates, and quickly reaches a speed at which the effect of air resistance prevents further increase in the rate of its fall,

then maintains a constant speed relative to the air (27). This speed is known as the terminal velocity of the kernel.

Abbott (1) reported that terminal velocity of a particle depends largely upon the size, specific gravity and physical shape of the conveyed material.

Jun (26) added that if the speed of air is increased beyond the terminal velocity, a condition will be reached where the relative velocity of the kernel with respect to the speed of the conveying air is exactly equal to the absolute velocity of the air. The speed of the air at this point is referred to as the floatation velocity of the kernel. At the floating velocity, the kernel will cease to move downward, remaining suspended in mid-air. If the speed of air is increased beyond that of the kernel's floatation velocity, it will commence to rise and accelerate in the desired direction.

FLOATATION VELOCITY

Floatation velocity is the suspension of a kernel of grain in the moving air. The force is exerted by the moving air counterbalancing the force of gravity on the conveyed kernel. Thus, if the velocity of the moving air exceeds the floatation velocity of the kernel, the kernel tends to move. This is true, whether the conveying system runs horizontally or vertically. Therefore, if the kernels of grain are flowing upward in a high velocity air stream, kernels will move upward with a velocity equal to the difference between the air conveying velocity and the stock motion velocity (26).

CLASSIFICATION OF PNEUMATIC CONVEYING BY PRESSURE RANGE

Kice (27) stated that logical classifications for pneumatic conveying systems fall in three categories related to the normal operating range of the air moving device used:

1) low pressure systems

   single stage centrifugal: up to 2/3 PSIG

2) medium pressure systems

   high speed centrifugal: 2/3 to 1 1/2 PSIG

   multi-stage centrifugal: 1 1/2 to 4 PSIG

3) high pressure systems

   single stage positive displacement: 4 to 10 PSIG

   two-stage positive displacement: 10 to 20 PSIG

LOW PRESSURE SYSTEMS

According to Abbott (1), the low pressure-negative conveying systems originated in Britain. The principle feature of this system is the reduction in the number of elbows and horizontal pipes. Stoess (36) said that it is also categorized by limiting air supply and feeding mechanism. Rotary positive blowers of lobe type are used primarily to activate the system (1). He continues by noting the work done by the moving air is mainly confined to lifting the stock through vertical pipes. Thus the horsepower required for conveying is lower than that needed by high pressure systems.

From the supply bins, the stock falls into a mechanical device known as a "diffuser" which throws stock upward into the vertical pneumatic pipe, thus cutting down on losses due to acceleration of particles. The change in direction caused by the diffuser eliminates two 90° elbows and most horizontal pipes in the system. But such elimination has some disadvantages, in that the system becomes less flexible with regard to the layout of equipment, loss in space because of spouting on the floor, and mechanical diffusers. The cyclones are positioned with vertical entry requiring extra height in the building. The recommended design overload capacity is 10%.

Stoess (36) states the system is used in plant processing, car unloading, and conveying to several outlets from a single pickup point. It conveys dry, pulverized, crushed, granular, or fibrous materials.

Nagel (30) disagreed with Abbott (1) on the low power consumption of the so-called "low pressure" system. He argues this is not factual and his research shows a larger pipe has been used which results in larger amounts of air. And, in greater detail, all sorts of different combinations are possible in pneumatic conveying. Any amount of material can be conveyed in large or small pipes, he said. The important thing is in deciding what pressure to use.

HIGH PRESSURE, OR POSITIVE CONVEYING SYSTEM

Stoess (36) defines high-pressure systems as use of high air pressure and small amounts of air. According to Abbott (1), in the high pressure system, the stocks are conveyed from the supply bins through horizontal to vertical pipes placed along the walls of the building. This provides greater flexibility in the design of the mill and in the location of equipment. Conveying through horizontal pipes with three 90° elbows requires a relatively high air velocity to prevent stock from precipitating.

Another disadvantage of high-pressure systems is the possibility of choking in any part of the system. This requires opening up lines for unchoking and cleaning out the horizontal sections. As a rule, a high pressure system must be designed to handle a 20% overload capacity.

COMPARISON BETWEEN HIGH AND LOW PRESSURE SYSTEMS

High pressure positive systems are theoretically more efficient than low pressure negative systems if they are properly designed and are leak tight (9).

Leaks are much more critical in high pressure systems, not only because more air will leak through a hole of a given size at the higher pressure, but of the less air available for leaks. For example, if either of these systems can handle a load of 200 lbs/min. for typical pipe size and pressures compared for a short time, then the low pressure system, using 1000 CFM to convey 200 lbs./min. of stock, would be operating at what is called "air to solid ratio" of 5 CFM/lb. of stock. For the high pressure system, a 100 CFM will have a ratio of 1/2 CFM/lb. of stock. This last is high and seldom exists because of leakage and other difficulties associated with the systems.

Systems that use less than one CFM per one lb. of stock are referred to as "dense" loading, sometimes called "fluidization." In general, light loading works with low pressure systems, medium loading with medium pressures, and dense loading with high pressure systems (27).

There are many cases where a low pressure system is preferred because of the larger volume of air it requires for conveying and for additional purposes, such as removing heat from roll stands to flush out moisture from grain or flour, and cleaning stock from dust.

Likewise, there are many cases when high pressure systems are used to permit operation with less air. So, the amount of care and planning in the design, construction and installation of pneumatic conveying systems should increase in proportion to the cube of the pressure at which they will operate.

COMPONENTS OF POSITIVE-PRESSURE SYSTEM

The pressure-conveying system is generally used as a single lift conveying. The layout of its parts is somewhat different from that used for negative systems. It consists of the following major parts:

(a) air movers...centrifugal or positive displacement blowers

(b) feeding mechanism parts

(c) pipeline, connection and fittings

(d) receiving units

(a) Kice (27) reported that either a centrifugal or a displacement blower can be used to power positive pressure systems, but when material to air ratio is big, a positive displacement blower is usually selected. There are several items attached to its inlet and outlet. There is an air inlet to protect the close clearance rotors from the input air dust, and a muffler to reduce the noise level produced by the blower. At its outlet, there is a pressure relief valve and gage to prevent excessive pressure in lines; also a check valve to prevent stock from blowing back into the blower when the system is shut down. The above items are not necessarily required by the centrifugal blower. It is claimed that positive displacement blowers deliver constant air volume and assure uniform air velocity (30).

(b) The system's feeding mechanism is one of the critical points for successful conveying. It is a very vital part of the whole system. Therefore, before we select the type of feeding device, it is advisable to know the physical characteristic of the material to be passed through the feeder, as well as the volume of the material and the pressure differential across it. All this information is necessary to determine the size and speed of the feeder, so as to give a uniform feed (36). Although many types of air-lock feeder devices have been developed, the rotary air-lock is more practical than any other type of feeder. It essentially consists of an air-sealed star wheel with material buckets designed to suit the characteristics of the material to be conveyed (28). The jet-under type air-lock permits air connections to run perpendicular to the shaft which avoids interference with the drives. The stock is air-borne immediately as it drops out of the pocket (27).

(c) For the system pipeline, steel and aluminum are recommended. Leakage in a positive system is a great problem (27). Leakage cuts down a system's efficiency to a high degree. Therefore, the system pipeline must withstand the pressure developed.

(d) The receiving terminals are the area where positive pressure systems overcome the high cost of suction systems, in that moving grain from one point to a different destination does not require suction vessels when handling dust-free whole grains or granular materials (9). The discharge point is often a cyclone or a collection type with an atmospheric exhaust vent on top and a simple spouting connection at its bottom.

CHARACTERISTICS OF POSITIVE-PRESSURE SYSTEM

In this system a high velocity air stream is established in the conveying pipe by the air discharged from a positive displacement or centrifugal blower through an injection fitting. It is generally applied when material, delivered to one or more points, is located at a considerable distance from the source of supply. No special structural receiving requirements are imposed by the use of a positive system other than the need for switching valves.

The positive-pressure system has the inherent defect of absorbing a considerable amount of power for moving air. The power required to supply air to the system far exceeds the power required to move the material to its destination mechanically.

The amount of air leakage lost through an air lock should not exceed 20% (2).

Positive-pressure systems are suitable for unloading material and is a little more efficient than the negative system. A rotary airlock is needed at the inlet, but not necessarily at the outlet point (27).

The cost advantage over vacuum systems occurs when conveying from one location to numerous discharge points; negative system requires a vacuum vessel at each outlet, plus a rotary valve to form an air seal at the product discharge.

Maximum operation pressures are as high as 10-12 PSIG, when rotary air-lock seals are placed at its inlet (20).

COMPONENTS OF NEGATIVE PRESSURE SYSTEM

Usually any single lift negative pressure system consists of the following major parts: (a) material feeding device; (b) air intake; (c) pipes, connections and fittings; (d) receiving units; (e) air/dust separator units; and (f) air movers, positive displacement blower or centrifugal fan (27).

(a) While a rotary air lock is not necessary at the system inlet, a regulating valve is used for non-continuous flow, but a metered feeding device is needed when feeding is done from a head of material. This device controls the volume of material flow to the air stream into the pipeline. For uniform material flow and minimum air leakage into the system, an air-tight metered device is recommended. Full blending of material and air is essential to reduce resistance of air and to provide efficient acceleration of the mixture (36).

(b) An air intake pipe should precede the material input to the system and the pipe cross section should be covered with some type of screen to eliminate foreign objects which might be sucked up with the air.

(c) Aluminum pipes can be used when soft stock is to be conveyed, but abrasive stock requires the use of steel pipes. Ordinary sheet metal elbows wear quickly at the section joints, causing more resistance than smoothed elbows. Rough joints tend to break up the stock and add resistance to the system. Longer radius elbows cost more, but last longer and reduce abrasion of stock, besides minimizing resistance. Screwed joints, short radius elbows and fittings are unsuitable. For maximum success in conveying, the system line should have as few elbows as possible.

(d) Receiver-separators used on suction systems are rather large units requiring access platforms.

(e) Most negative systems in grain handling are designed so that stock does not enter the blower, but passes through pneumatic aspirator lift and/or the cyclone collector (27). They are the most important parts of the system. The Miag pneumatic lift aspirator is mostly used in the cleaning house (18). It separates grain from air as much as possible, which allows the material to spread out from the moment it enters the bottom. This assures that the air velocity in the spreading zone is adjustable to an extent that efficient separation between small and heavy kernels (as well as from dust) can be made. In the absence of pneumatic aspirator lift in the cleaning house, the air/material separation unit is a cyclone receiver with a conical section sufficient to permit the material to discharge through a rotary air-lock. The air-lock should work at a rate at least twice the rate of incoming material from the system pipeline. When dustless material is conveyed, one cyclone is enough to successfully finish the separation (36).

(f) One of the major parts of the negative pressure is the air stream generator. Normally, two types are used: the high pressure centrifugal fan, or a single or two-stage positive displacement blower (18).

From the discharge at the top of the air/material separator units, clean air should be emitted and piped on to the inlet of the exhauster (36).

The positive displacement blower is usually driven through a multiple V-belt driven by an electric motor. A suitable silencer is installed as close as possible to the exhaust discharge so as to minimize the noise level from the machine. The discharge from the blower is released into the room.

CHARACTERISTICS OF NEGATIVE PRESSURE (SUCTION SYSTEM)

There is general consensus among such authorities as Gerchow, Kice, Kraus and Stoess that the negative conveying system offers many supplementary jobs during its operation:

1) It conveys material from one or several pick-up points to one single delivery destination. It can, by adding equipment, enable the system to deliver materials to several points;

2) The system is ideal for the unloading process, i.e., from box cars, vehicles, ships (barges), and for conveying between processes inside the mill plant and cleaning house;

3) It is more self-cleaning than any other moving system;

4) It is a dust-free collection system; any possible leakage before the fan is released in and not out, and therefore housekeeping expenses are greatly reduced;

5) It is excellent for controlling mechanical heat from grinding operations. Moisture is removed through evaporative cooling and sensible heat exchange from solids to the air. This increases the capacity for grinding or sifting;

6) The system is very efficient for heating or cooling conveyed materials by using heat exchangers (added at its inlet) to provide the desired temperature;

7) Systems of length to 1500 feet have been installed and successfully operated;

8) Its feeding mechanism is somewhat simpler than positive pressure. However, a careful consideration (metered feed to the system) is needed when feeding is done from a head of material in conveying from a multiplicity of pick-up points;

9) System control requirements are somewhat less than required for positive pressure systems;

10) The suction system for conveying whole grains is less efficient than positive pressure. The amount of air and the conveying lines on the suction system are of larger size than those used on positive system of the same capacity; and

11) It requires complete receiver-separations used to separate material from dust and air.

MECHANICAL DAMAGE TO GRAINS IN PNEUMATIC CONVEYING

Physical damage to grains (hard red winter wheat, yellow dent corn and sorghum) from impact and abrasion was analyzed from laboratory tests of pneumatic conveying. The purpose of the experiments was to determine the effects of the air velocity, conveying distance and grain types on damage to all conveyed grains during pneumatic conveying. The importance of controlling the amount of grain kernel damage during handling may be significant in the marketing grade and the selling price. Because handling grains by pneumatic systems became quite common recently in grain processing (and especially in transferring or transporting within the grain industry), broken kernels and fine grain material results in a reduction in economic value of the grain when it is marketed (11).

Converse added that damage evaluation in a pneumatic conveying system was done by Segler, whose experiments were to investigate the influence of air velocity, grain size, grain moisture content, grain temperature and conveying pipe size on grain damage.

Also, Gasterstde was the first to announce the occurrence of damage to grain when it is conveyed with too high air velocity, Converse said. Alden (2) pointed out that for a given pipe diameter, the material-handling capacity increases as the cube of the velocity. For wheat, a range of air velocity of 5000 to 7000 feet per minute was recommended.

Bilanski and co-workers published the terminal velocities of various grain. For wheat, the terminal velocity was 29.5 feet per second. Person and Sorenson found that the minimum air velocities for conveying ranged from approximately 3000 fpm to 4700 fpm, depending on the grain capacity required. Bilanski attempted to determine some basic knowledge of the energies and forces involved in damaging the grain during conveying. He predicted that the history of the grain kernels would affect its damage resistance (11).

Chung (10) made a comprehensive study of the damage to corn from pneumatic conveying. He selected as variables--moisture content, size and shape of kernel, air velocity, and the distance of the conveying system--to determine corn damage from pneumatic conveying.

> The effect of size and shape was greater on the 20 percent moisture corn than on the 12 percent moisture corn; however, the effects of size and shape were small. (Ibid.)

Breakage was caused by both air velocity of the conveying system and the distance the corn was conveyed, he reported. For 12 percent moisture corn, the increase in breakage was smaller. Broken-kernel damage in both 12 and 20 percent moisture corn, when conveyed at increased air velocities (varying from 2960 to 7200 fpm) and distances of 200, 800 and 1600 feet, increased the amount of broken kernels in about the same proportion as occurred for breakage. Pneumatic conveying of corn caused less than 5 percent broken-kernel damage in the 20 percent moisture corn, even at the highest air velocity (7200 fpm) and the longest conveying distance (1600 ft.). In tests with the 12 percent moisture corn, the use of the highest velocity and longest conveying distance caused about 70 percent broken-kernel damage.

For corn at both moisture contents, Chung continued, the number of small cracks in kernels increased proportionally with the increase in air velocity and conveying distance. For the 12 percent moisture corn conveyed at the highest air velocity (7200 fpm), the number of small cracks decreased rapidly following four repeated runs (a total of 800 ft. of conveying distance). The decrease in small cracks was in direct proportion to the increase in broken kernels. For corn of either moisture contents, large cracks accounted for only a small percent of the total damage, Chung reported.

The relationships between total damage and conveying air velocities, and between total damage and conveying distances, were differentiated graphically for the three conveying distances and the two corn moisture contents tested, he found. They showed that the increase in total damage to corn at each moisture content was generally high for the first 200 feet of conveying distance, but decreased rapidly as the conveying distance increased.

An analysis of the relationship between total damage and conveying air velocity revealed a difference in damage characteristics for the two moisture levels studied. The total damage from conveying was much higher in the 12 percent moisture corn than in the 20 percent moisture corn. For the latter, the rate at which total damage increased was almost proportional with the increase in air velocity, regardless of the conveying distance, Chung reported.

Successive handling of the high-moisture content corn with pneumatic conveying at the highest air velocity does not cause excessive damage. However, he said, with 12 percent moisture corn, the total damage rate began to increase sharply at 5400 fpm.

Any pneumatic conveying system should be operated with the amount of damage permissible to satisfy the grade requirements for corn and other grains. If pneumatic conveying is operated improperly, the pneumatic conveying can cause serious damage to the conveyed grain (10).

ADVANTAGES OF PNEUMATIC CONVEYING

As the use of pneumatic conveying systems has increased in the milling industry, it was found to have certain advantages over the conventional systems. Several sources--Stoess (36), Auer (4), Horn (23), Schumacher (35), Kraus (28), Day Company (12), and Gehle (18)--have listed these advantages:

1) It provides for more efficient use of plant space. The space requirements for installing pneumatic conveying systems are reduced by as much as one-tenth that needed for mechanical conveying equipment, resulting in proportional savings in building costs, and access space for control and maintenance purposes.

2) The automatic operations reduce manpower requirements, sometimes by as much as 30 percent, because of the automatic operation. Critics say this is offset through the increased cost of training personnel.

3) It improves the working environment for the personnel involved, in that less dust results from air conveying systems.

4) Infestation and stock molding is reduced throughout the cleaning house, since there are fewer spots where stocks can stagnate and become insect breeding zones.

5) It offers greater safety to employees than does the mechanical types of bulk conveyors.

6) Higher capital investment cost recovery because of the longer life efficiency of the system.

7) Fire hazards and dust explosion are greatly reduced by the use of pneumatic conveying.

8) The need for other dust control systems is less when compared to those recommended for mechanical handling systems.

9) The compact arrangement of pneumatic equipment helps to ensure as short a shutdown time as possible.

10) It eliminates the straight line conveying (36), transfer points, crowdedness, and interference--all of which are characteristics of the mechanical conveying systems.

11) Housekeeping costs are substantially reduced because materials are totally conveyed in a closed system, thus eliminating spillage and leakage.

DISADVANTAGE OF PNEUMATIC CONVEYING

Pneumatic conveyors have disadvantages; and these should be considered when making a decision regarding their installation. It is important that advanced planning be done (to the last detail) in close cooperation with the milling engineers and operators.

These problems were cited as major in pneumatic systems:

1) Initial capital investment is higher than for other types of conveyors.

2) Conveyance is in only one direction.

3) Conveying distance may limit the use of pneumatic conveyors.

4) Unless designed for such purpose, friable materials can not be conveyed.

5) Material's physical characteristics need to be studied carefully before conveying; they should be classed as dry and relatively free flowing.

6) There is a higher power consumption demand than the conventional systems. Conveying cost increases disproportionately with added grain conveyed because of the increased power consumption need.

7) There is a loss in flexibility of operation as compared to the mechanical systems. The higher power cost of the pneumatic system usually results in a system that is designed with a limited overload capacity.

8) It is less adaptable to flow changes and to capacity increase without adding new machines. A well-designed system will not permit such disadvantage.

9) Pneumatic conveying systems for handling bulk material are not competitive with mechanical handling systems in either first cost or operating cost.

10) A malfunction anywhere in the system sometimes necessitates shutting down the entire system.

HORIZONTAL - VERTICAL CONVEYING

According to Jun (26), when a particle is being conveyed horizontally within a short time interval, it will precipitate to the bottom of the duct wall. The length of time for this precipitation will depend entirely on the weight of the particle and, because of the effect of gravity on the particle and its natural trajectory, the diameter of the duct used. The particle falls into the low velocity area of the duct and effectively ceases to convey; thus, it is no longer suspended in the air stream. To provide greater moving force at the lower wall of the duct, it is necessary to increase the mean velocity of the air.

A mean velocity of 60 to 70 percent greater than the terminal velocity of the grain (2800-2900 FPM) is necessary to provide horizontal conveying. For grain handling, horizontal conveying speeds range from 3500 to 4500 PRM.

Nicols (31) states that the force exerted by the air in an upward direction is of local nature only and is quite transitory. Upward air movements are due to turbulence and to the tendency of the following air to revolve. Turbulence is greatly increased in a duct when solid material is carried along by the air stream.

The losses of pressure in horizontal conveying is greater than vertical, because extra force is needed to overcome the friction.

As shown in this section, horizontal conveying requires more power than vertical conveying.

Nagel and Segler (30) noted their disagreement with reports that vertical conveying requires less power than horizontal conveying. They stated that most specialists agreed that in vertical conveying, the power requirements are higher.

Gasterstadt said that power requirements are made up of several items:

a) pressure needed for overcoming pipe friction in a straight line;

b) pressure needed for overcoming additional resistance in bends;

c) pressure needed for accelerating the feed; and

d) pressure needed for lifting vertical conveying.

Pressures from (a) through (c) are required equally in vertical and horizontal conveying, but for vertical conveying, pressure from (d) requires more power. Segler states regarding this point that in vertical conveying, "the resistance figures for the area in question is nearly twice as high as it is in horizontal conveying."

Although more energy is needed to transport a pound of material through a given distance vertically than for the same distance horizontally, there is little tendency to clog a vertical pipe, whereas settlement can occur in the bottom of a horizontal pipe. If such settlement takes place, a higher air velocity is needed to dislodge the pile of material. In practice, it is customary to produce similar air velocities in vertical and horizontal conveying ducts (See Figs. 2a, 2b, 2c, and 2d) (31).

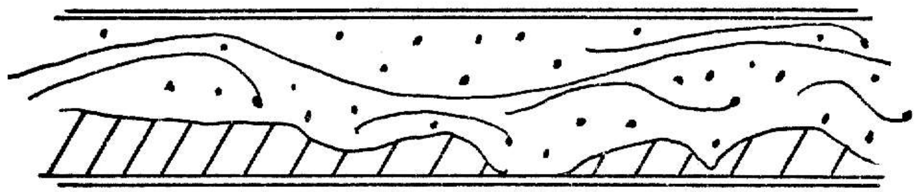


Fig. 2 (a) BEHAVIOR OF AIR MOVEMENT IN HORIZONTAL PNEUMATIC CONVEYING

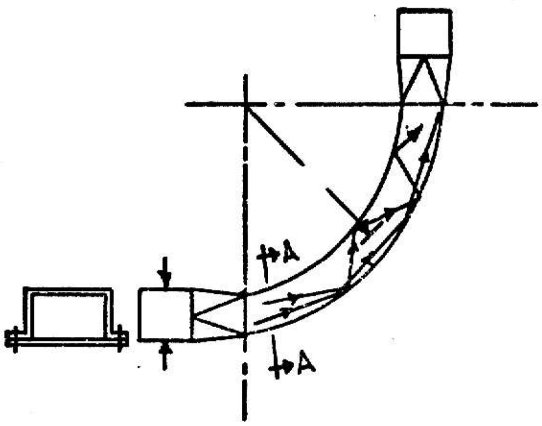


Fig. 2 (b) GRAIN CONVEYING AROUND AN ELBOW

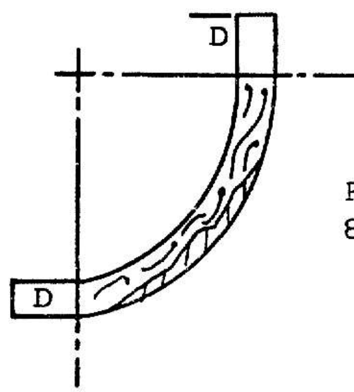


Fig. 2 (c) SOFT FINE STOCK CONVEYING AROUND AN ELBOW

- FITTINGS -

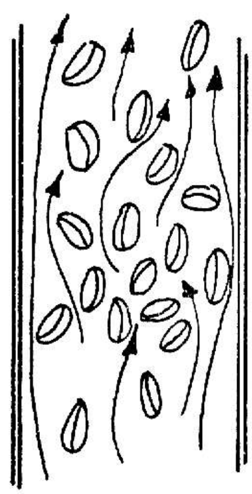


Fig. 2 (d) AIR MOVEMENT PATH THROUGH GRAIN IN A VERTICAL PIPELINE

Fig. 2

SOLID-TO-AIR RATIO

Jun (26) reported single pneumatic systems are operating at mixtures of two lbs. of material per one of air. Currently positive or negative pressure systems are designed to convey at ratios up to 4, 5 and 6 lbs. of materials per one lb. of air, depending on the nature of the material being conveyed. Generally speaking, the less dense the material to be conveyed, the less quantity of air required. Conversely, the denser the material, the more air pressure is needed, and the lower the air-load ratio will be.

Kice (27) worked with air-to-solid ratios to compare high and low pressure conveying systems. He illustrated the difference between the two systems in their air/solids ratio. The lowest ratios of solids-to-air are encountered in handling dusts and undesirable atmospheric contaminants. These are found in mill dust control systems, bucket elevators, moving air streams (such as in the cleaning house), in purifiers, or roll suction systems. A dense mixture of solids and air is found in pneumatic conveying systems.

CONVEYING VELOCITIES OF WHOLE GRAINS

Jun (26) also reported that the floatation velocity of the wheat (as empirically determined) is 2800-2900 FPM. The velocity required to support the weight of whole kernel of corn varies from 3300 to 3500 FPM, he added.

Nicols (31) said the approximate duct velocity for clean air needed for conveying wheat or corn is 5000-6000 FPM for either horizontal or vertical transmission.

The critical suspension velocities of vertical air stream for wheat and corn (all grain lifted) are (31):

wheat	1500 FPM	specific gravity of wheat = 1.27
corn	2200 FPM	or = 0.038 grams

For every material, there is a terminal and floatation (suspension) velocity, reported Nagel (30). Besides these velocities, there is a velocity of motion (conveying velocity) which is a little above the floatation velocity.

In coarser material, the velocity is greater than for fine stocks. This deviation depends on the difference between the velocity of air and the terminal velocity of stock. Nagel added that the term "choking velocity" does not exist and is misleading. However, there is a choking limit of air conveying velocity. This depends on the loading figure which it must not exceed, and on the pipe diameter and velocity of motion. It also depends on whether there are many bends in the conveying pipe line, and on the type of conveying, i.e., vertical or horizontal (30).

The power requirements are unfavorable when a system is near the choking point, because the relative velocity between air and stock is higher, thus adding more to the frictional losses.

Nagel does not agree with conveying stock near the safety margin because of the expense of additional personnel needed for removing stocks if the system chokes (30).

AIR FLOW CHARACTERISTICS

When a unit mass of air or mixture of air and material (grain) conveys pneumatically through a pipe, Alden reports, there are two distinct pressures acting on the flow simultaneously (2). One is known as "Static" pressure; the other is the "Velocity" pressure. Their algebraic sum is called "total" or "head" pressure.

STATIC PRESSURE

This is sometimes called the "friction" or "resistance," he said (2). It is the pressure exerted on the inner surface walls of the duct to overcome the resistance against material flowing. It acts equally in all directions of flow. As he reported, it is the perpendicular force per unit area tending to expand or compress the flowing media. (See also Fan Engineering (15).) It is equivalent to the potential energy of a unit volume of the flowing media and exists by virtue of the material flowing density and the degree of compression. It has a positive or negative value, depending on the location of blower.

VELOCITY PRESSURE

Alden said the pressure required to accelerate the flowing material from rest is velocity pressure. Velocity pressure acts only in the direction of the flow, and always has a positive value, regardless of the location of the blower (15). It also is the force per unit area equal to the kinetic energy of a unit volume of flowing material and exists by virtue of the flowing material density and the air velocity.

MANOMETERS READING

Vertical U-Tube

This is a simple, vertical U-tube manometer made from glass tubing with 3/4" to 1/4" bore (25,15). When partially filled with water and calibrated to the zero level, the gage pressure is then determined by connecting one leg to the appropriate probe and exposing the other end to atmosphere. Static pressure is determined by placing the probe cross section strictly tangential to the measuring hole. The difference between the water columns in the U-tube is the static pressure shown in inches gage (5, 15) (Fig. 3a).

Impact Tube

This is an excellent instrument (Fig. 3b) because of the insensitivity in its design and arrangement. It is a U-tube, but the principle of applying it is different from that used for measuring static pressure. The probe need not be cut exactly square and free from burrs, nor be pointed exactly in the direction of the flow. The pressure gage connected to the impact tube shows a pressure which equals the sum of the static gage pressure and the velocity pressure in the main duct. Therefore, subtracting static pressure measured by a separate U-tube gives the velocity pressure in that duct.

Pitot Tube

This is a combination of static pressure and impact tube (25). It is an instrument forming two centric tubes joined in a faired end (Figs. 3e, 3c). The inner tube is the impact tube; the outer tube picks up the static pressure through a group of very small and smooth holes drilled at some distance back from the main head of the pitot tube. Each tube is connected to a gage pressure; one reads the static pressure, the other reads the total pressure of the flowing material into the duct. The differential gage connected to both tubes will read the velocity pressure directly (Figs. 3c, 3e).

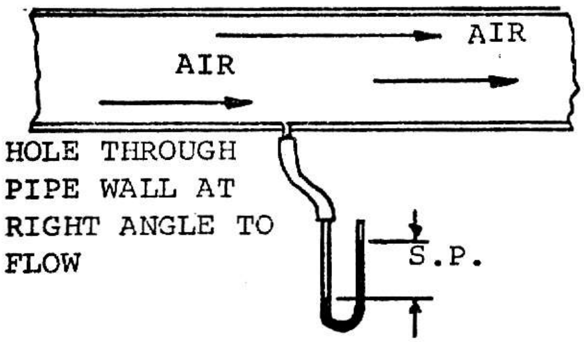


Fig. 3 (a) MEASUREMENT OF STATIC PRESSURE (SP)

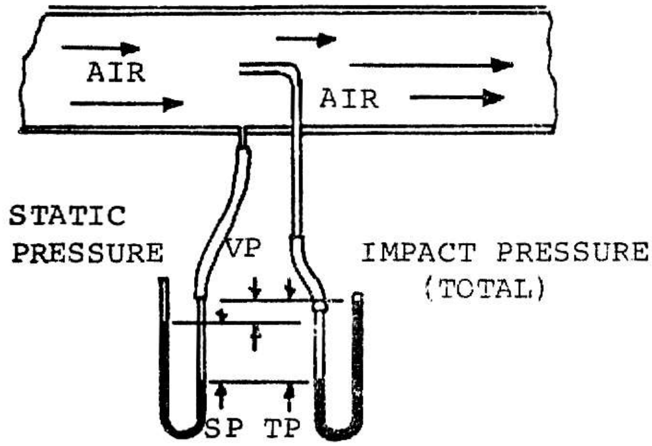


Fig. 3 (b) TOTAL PRESSURE = SP + VP

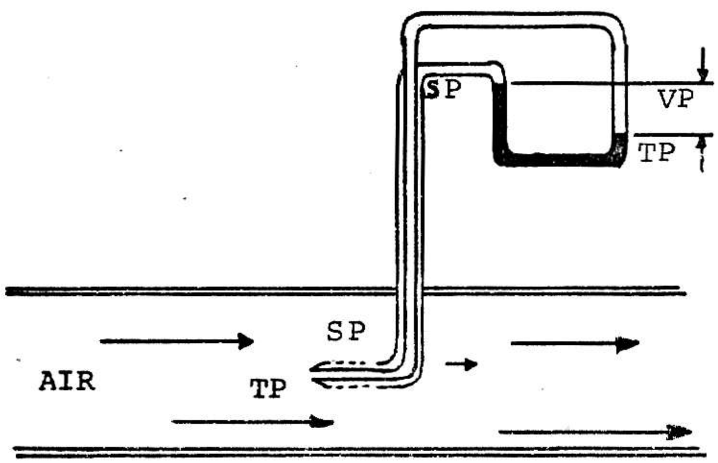


Fig. 3 (c) STANDARD PITOT TUBE MEASURE VELOCITY PRESSURE INCH H_2O

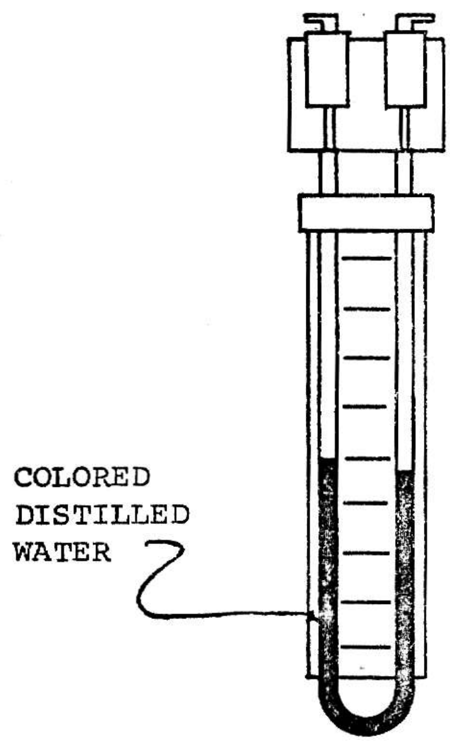


Fig. 3 (d) U-TUBE MANOMETER

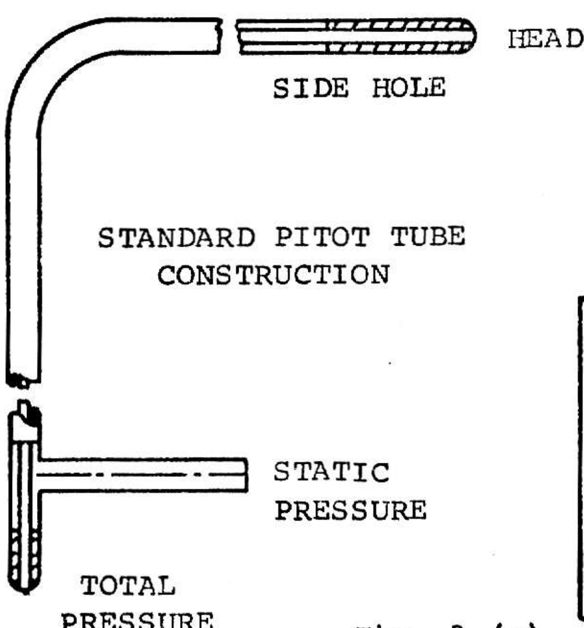


Fig. 3 (e)

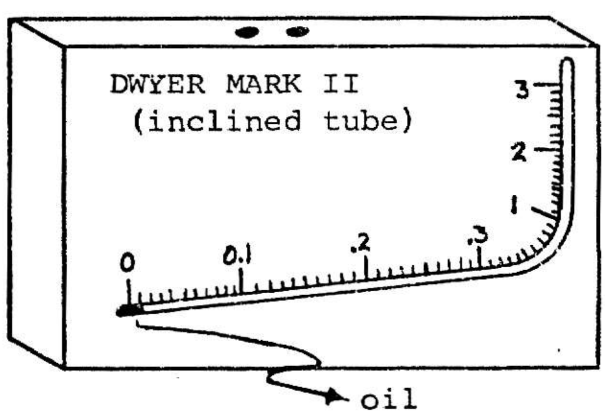


Fig. 3 AIR FLOW MEASUREMENTS (MANOMETERS)

MATERIALS AND METHODS

In the summer of 1976, experiments with pneumatic conveying of whole grains---hard red winter wheat, yellow dent corn and sorghum---were conducted on positive and negative pressure systems at the Kansas State University Cleaning House. (Table No. shows the initial physical characteristics of the grains.)

MATERIALS AND EQUIPMENTS PREPARATION

One hundred bushels of each of the above grains were cleaned by the millerator machine (see Appen.) to remove foreign objects such as sticks, papers, straw, etc. The semi-clean grain was stored in a supply bin.

Equipment

- manometers
- tachometer
- flashlight
- sealing tape
- measuring tape
- drum (to measure flow rate)
- sling psychrometer
- glass thermometer
- sealed clean cans (for sampling)
- scale

Figure 3 shows the manometers used to measure the static and velocity pressures of the flow at different locations of the system. The clean and graduated U-tube manometer is filled with distilled colored water. One end is connected to a probe 1/8" in diameter; and the other to an atmosphere. A Dwyer Mark II inclined tube is filled with red gage oil, 0.86 specific gravity. The two ends of the molded plastic tube are connected to a standard pitot tube by two probes 1/8" in diameter. These manometers are installed at different locations. One U-tube is connected after the blower output. Another is located 3.0 feet after the air is mixed with grain. The inclined manometer with the pitot tube and another U-tube are at 5.7 feet from the discharge point. All manometers are levelled (with a leveling device) and calibrated to zero. All the measuring holes on the system are 1/8" diameter, drilled smooth in a straight line, either vertical or horizontal, away from any joints or elbows so as to assure accurate measurements or pressures.

- The environmental conditions, including the input, the output discharge area, and the outside atmosphere are recorded by using the sling psychrometer.

- The electrical energy input to the system is measured from the control panel by a GE Tong ampere and voltage meter (Fig. 16).

- The temperature of air inside the pipeline is measured by a glass thermometer (Fig. 9).

- A tachometer measures the RPM of the blower and air-lock.

Inspection

There are major areas in the system which must be checked before starting up. The receiver-separator units and the discharge bin must be empty; the feeding mechanisms and the metering device should be working in a satisfactory condition; checks of the air lock and the blower RPM are made; examination for loose or leaking joints in the system pipeline are made; the clamp band coupling must be tight, and the pipeline must be free from any material.

Before beginning the experiment, enough samples of the conveyed grain is made to determine its physical characteristics. Repeat tests after the grain has been conveyed are also performed.

The same preparation for every experiment is made, except in the case of negative pressure system. The measuring holes and manometers are located in different locations on the system pipeline (see Figs. 4, 19).

A U-tube and an inclined tube manometer with pitot tube are installed at 10.5 feet from the pick-up point. Another U-tube and pitot tube are located 1.0 feet before the discharge point.

NOTE: Each experiment is repeated three times to measure feed rate, amperage used, static pressures at points I, II and III, velocity pressure at point II, voltage from energy input, motor HP, pressure loss and efficiency.

A permanent magnetic separator, corrugated feed roll or spout type, is preferred to be installed on the input of the system supply bin to insure removal of metal objects which might seriously damage or plug the pneumatic pipeline and cause choking up the system.

PRESSURES MEASUREMENT

One of the most important factors in the testing of pneumatic conveying system's condition is studying the material flowing measurements into the system.

STATIC PRESSURE is measured by U-tube manometer at right angles to the direction of flow. In order to avoid the influence of the material velocity and eliminate errors in reading, the pressure hole (1/16"-1/8" in diameter) is most important in measuring. It should be smooth and entirely free from burrs in its inner surface (Figs. 11, 12, 13, 20, 24).

VELOCITY PRESSURE is more difficult to measure because it can not be separated from the static pressure which accompanies it. Pitot tube and impact tube are two pressure manometer methods that could be used to check readings taken. It must be measured in the center of direction of flow, and is never uniform across the pipe section. Presumably the velocity pressure should be constant all across the pipeline (12) (Figs. 14, 20, 25).

TOTAL GAUGE PRESSURE. The "impact" or "dynamic" pressure is the algebraic sum of the static and velocity pressures (Fig. 3b).

SAMPLE PHYSICAL CHARACTERISTICS TESTS ON GRAIN

All samples of grains were analyzed, both before and after every experiment, to determine the effect of air conveying on the physical characteristics of the grain conveyed.

The following tests were applied to the grain samples:

- moisture
- test weight
- pearling value
- grain size test
- 1000 kernel weight
- tempering
- density
- angle of repose

MOISTURE

Moisture content of samples were determined by using Weston grain moisture meter and Motomco moisture meter.

TEST WEIGHT

Determinations were made with a quart kettle using a beam scale, according to the standard method outlined by USDA. Results were expressed by weight in pounds per Winchester bushel.

PEARLING VALUE

Twenty grams of grain with all foreign material and broken kernels removed is kept for one minute in a Strong Scott

Laboratory Barley Pearler equipped with No. .30 grit stone and a 10-mesh screen made of wire .041 inches in diameter (Tyler Code "FIJÖR"). Pearling value is percent of the original sample remaining over a 20-wire after pearling (Fig. 18).

1000 KERNEL WEIGHT

The weight in grams of 1000 kernels of grain was determined with an electronic seed counter, using a 40g sample from which all foreign material and broken kernels have been removed (Fig. 18).

GRAIN SIZE TESTS

Two hundred grams of grain are placed on the top sieve of a stock of three Tyler standard sieves (numbers 7,9) and pan. The stack of sieves is placed in a RO-TAP sifter and sifted for one minute. The percent remaining on each sieve is then determined.

TEMPERING

Tempering was accomplished by adding the exact amount of water to the grain in the tempering device to give it the desired moisture content. Tempering was done only for hard red winter wheat at 16.5% moisture for 24 hours, 48 hours and 72 hours.

DENSITY

The density was determined with a Beckman Air Psycnometer, using a 14.4 gram sample.

$$\text{density} (\rho) = \frac{14.4 \text{ grams}}{\text{volume (CC)}}$$

ANGLE OF REPOSE

A smooth pipe, 3 inches in diameter and 3 feet high, open from both ends, stands on different concentric circles. Two thousand grams of grain is poured into the smooth pipe, then lifted slowly without shaking it. The natural shape of the grain will determine its angle of repose. Using the leveling device, the height of the cone and its radius will be used to calculate the angle of repose.

$$\tan(\gamma) = \frac{\text{height}}{\text{radius}}$$

DESCRIPTION AND PROCEDURE OF PNEUMATIC CONVEYING SYSTEMS

Positive Pressure System

The pneumatic systems used at K.S.U. for these experiments are positive and negative systems. The positive-pressure system consisted of a positive displacement blower with constant speed (1570 RPM) (Fig. 8), a rotary air lock feeder (26 RPM), a conveying pipe (Fig. 15), and a cyclone separator (Fig. 17). Figure 4 shows a schematic diagram of the system. The positive displacement blower has the capacity to deliver air at a maximum pressure of 10 PSIG (pounds per square inch gage) above normal.

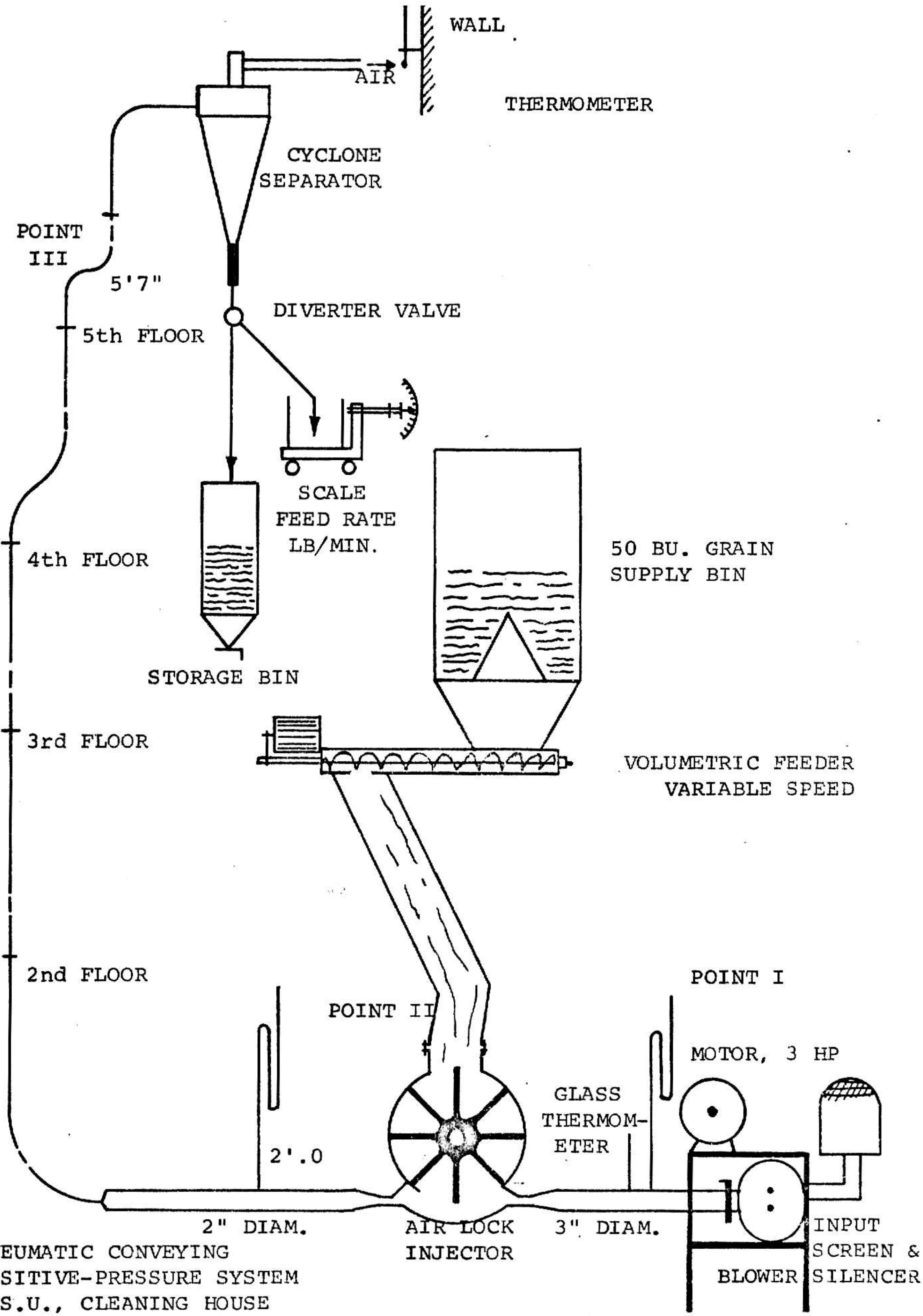
Grains (hard red winter wheat, yellow dent corn and sorghum) were introduced separately into the system from the bin by a volumetric variable speed feeder (Fig. 6) to the rotary air-lock feeder. The flow rate of grains was found by diverting the flow of grain (Fig. 7) to an empty drum for one minute. The conveying pipe and elbows were aluminum with 1.89 inch inside diameter. The total length of the conveying pipe from the feeder to the receiving cyclone separator was 60 feet, also four 90° elbows, each having a 28-64 inch radius.

When the system was ready for an experiment to be run, the positive system was turned on without any flow of grain. All the pressure measurements (Figs. 11, 12, 13, and 14) were recorded on the sheet provided. The flow of grain began with a small feed rate. This was controlled by the variable speed device (Fig. 6) at the end of the screw feeder under the supply bins (Fig. 5). Every time the load was increased, all the necessary information was obtained. This continued until the system was saturated, and no more load could be conveyed. Tables 1-4 indicates the different feed rates of grains (hard red winter wheat, yellow dent corn, and sorghum) conveyed by the same positive pressure system, due to the variety of the physical characteristics of the three grains.

The positive-pressure blower is noisy. Any air leakage in the fittings at the blower air output or at the feeding mechanism can hardly be heard. After a few experiments were conducted with dry HRWW and corn, it was found, while checking the air lock RPM, that a high pressure of air was leaking from the blower output pipe. This instigated a check for other possible leaks in the system pipeline. All leaks were sealed. Similar experiments were conducted again, using the same grains--dry HRWW and corn--to see how much leaks (particularly close to the blower air output) affect the conveying capacity of grain.

Due to such an incident, we studied six grain treatments for positive system as follows:

dry hard red winter wheat	leak
dry yellow corn	leak
dry hard red winter wheat	no leak
tempered red winter wheat	no leak
dry yellow corn	no leak
dry sorghum	no leak



PNEUMATIC CONVEYING
POSITIVE-PRESSURE SYSTEM
K.S.U., CLEANING HOUSE
Scale 1/8" = 1'; 1" = 30"

Fig. 4

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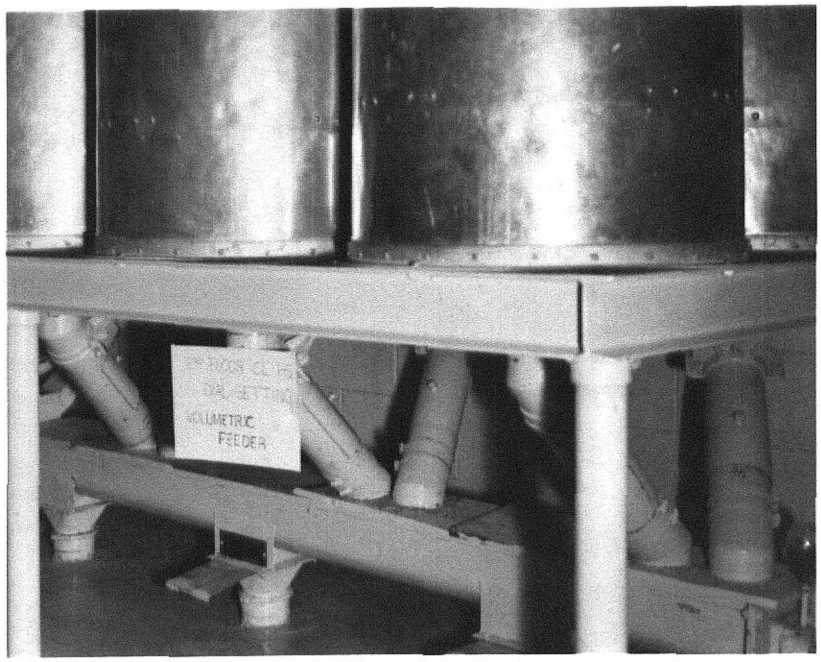


Fig. 5 Positive System Grain Supply Bins

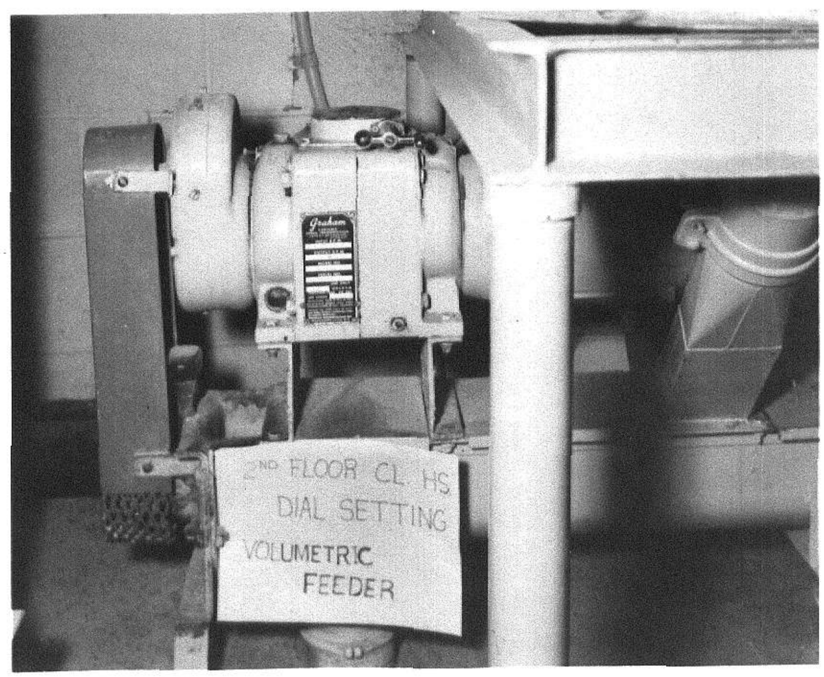


Fig. 6 Variable Speed Drive on 1/2 Pitch 4" Screw Feeder

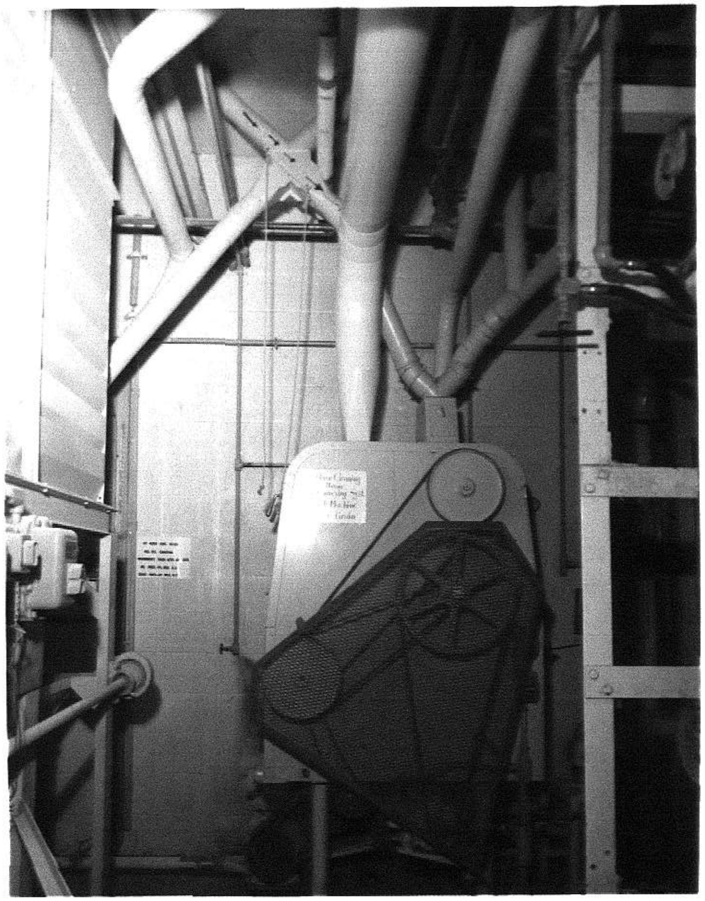


Fig. 7 Grain Flow to Positive System Pick up Point (Air Lock Feeder)

Fig. 8 Positive System, High Pressure Positive Displacement Blower

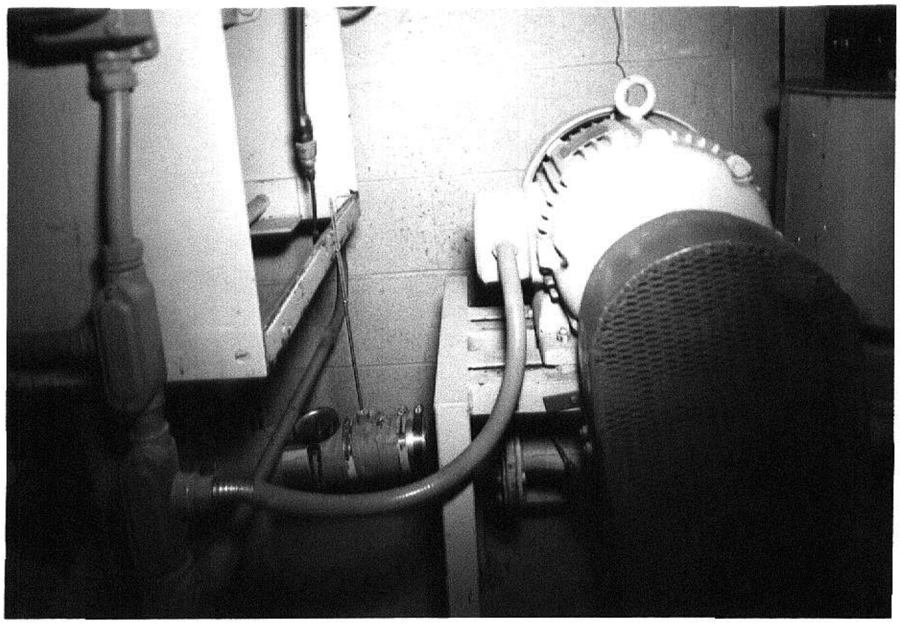


Fig. 9 Positive System Measuring Blower Output Air Temperature

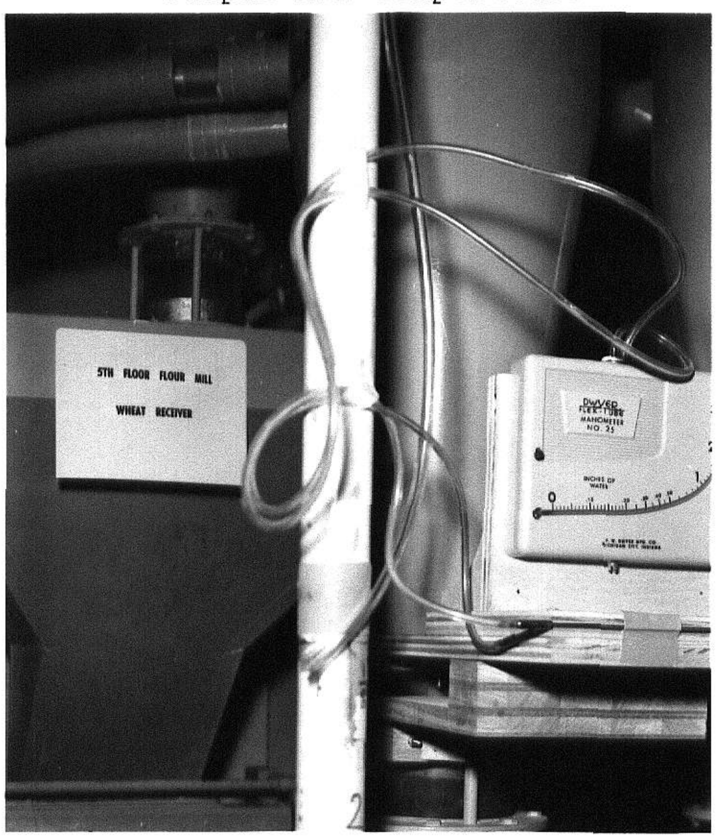


Fig. 10 Positive System Wheat Receiver from Brush Machine

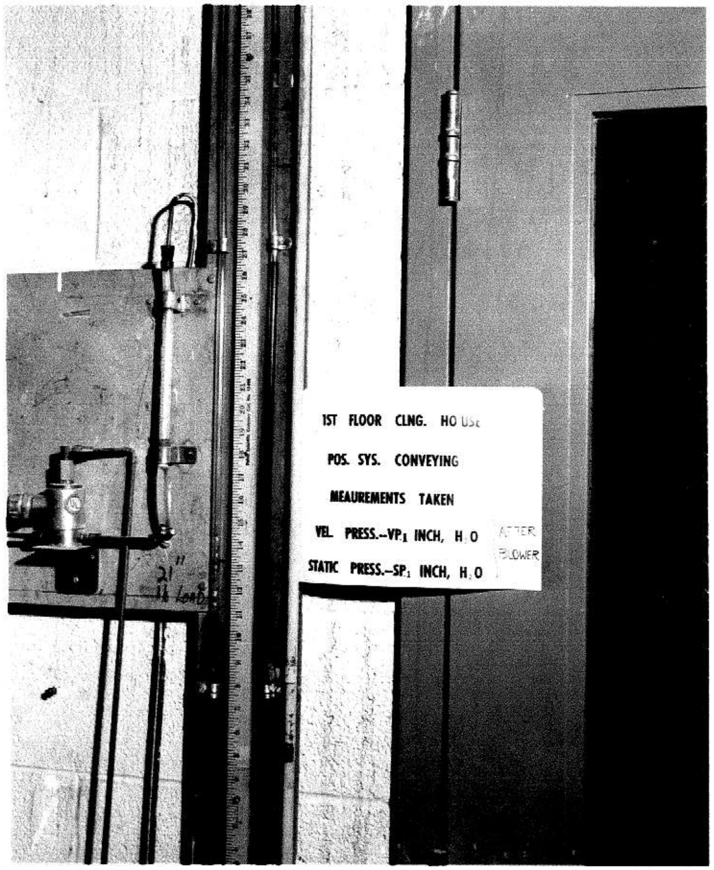


Fig. 11 Positive System Measuring Static Pressure at Point I

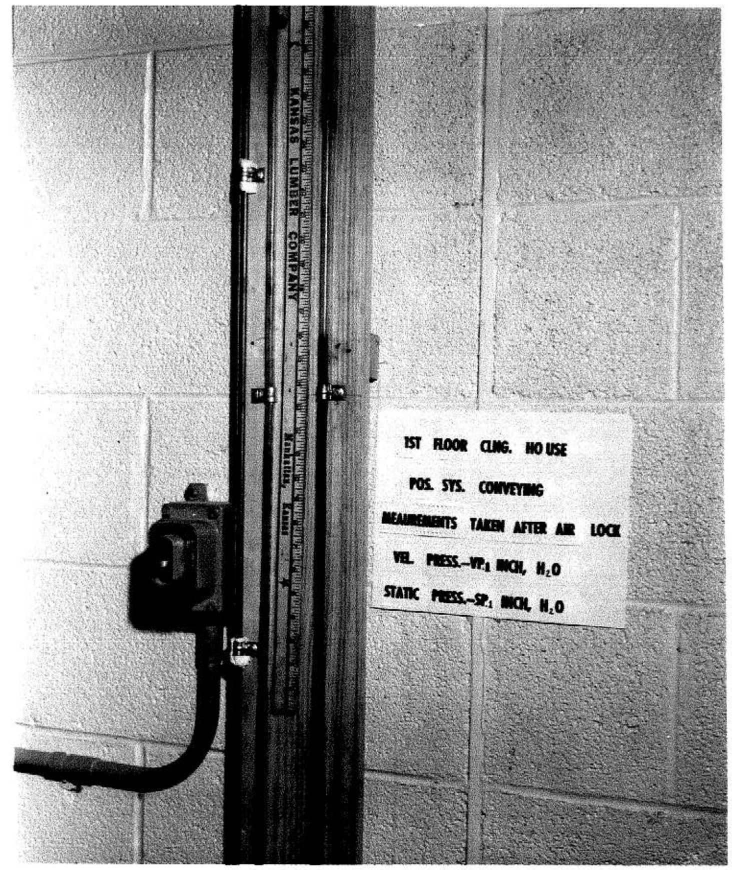


Fig. 12 Positive System Measuring Static Pressure at Point II

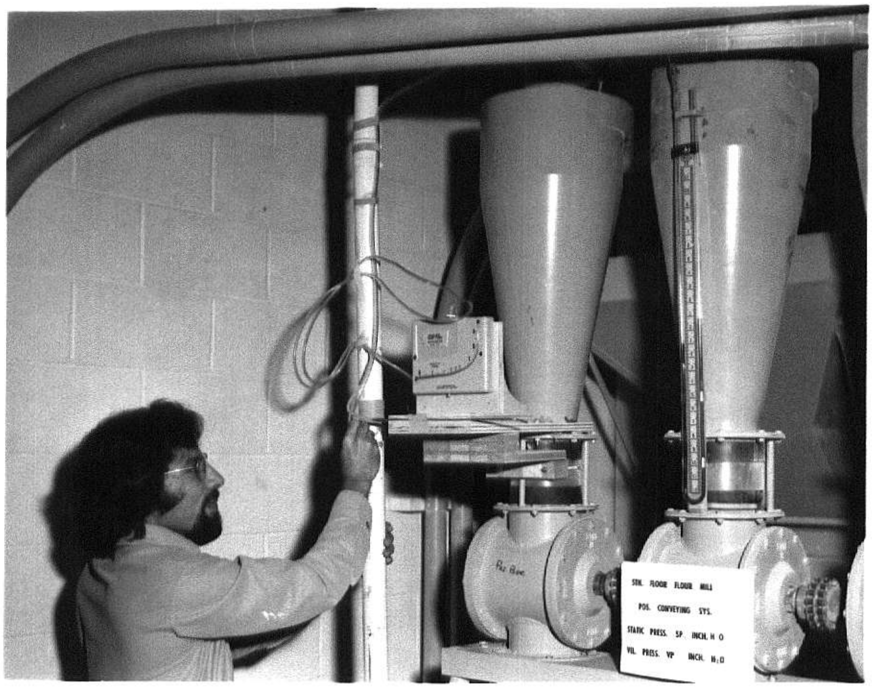


Fig. 13 Measuring Static Pressure at Point III, Positive System

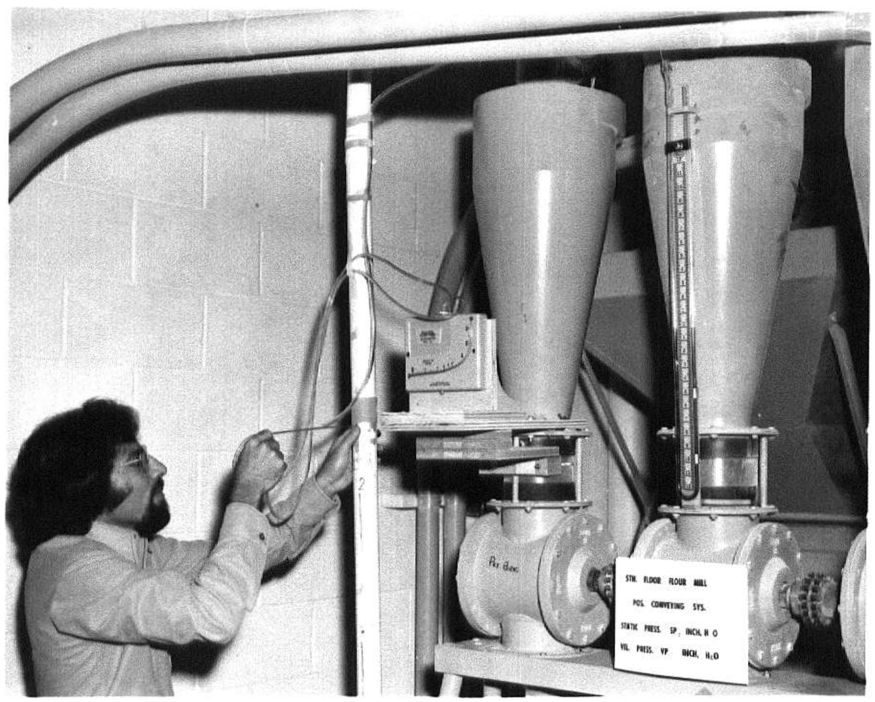


Fig. 14 Measuring Velocity Pressure at Point III, Positive System

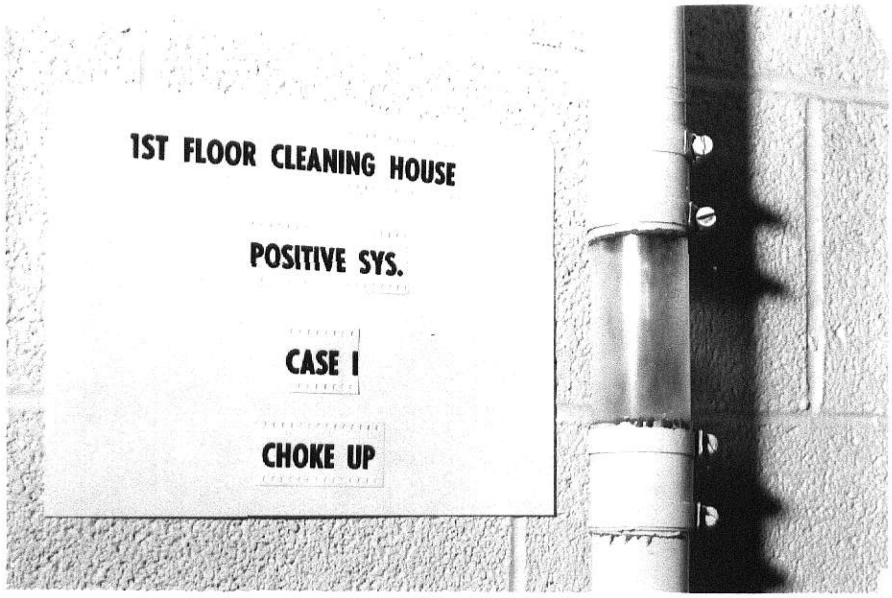


Fig. 15 Pneumatic Lift Before Choke Up

Fig. 16 Measuring Energy Input to System in Kilowatts

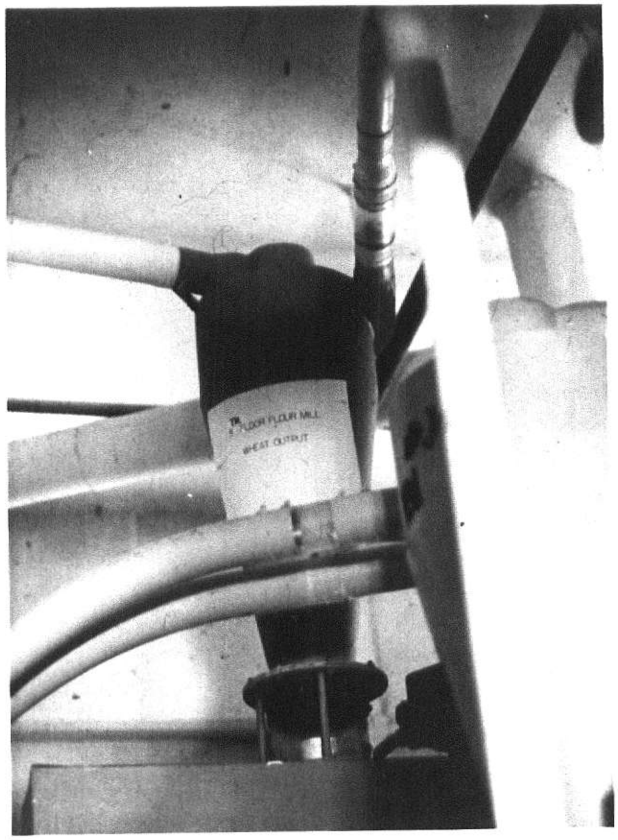


Fig. 17 Grain Discharge Point,
Positive System

Fig. 18 Grain Physical Characteristic Test

Negative Pressure System

Figure 19 shows a schematic diagram of a single negative pressure system installed at Kansas State University Cleaning House. It consists of the following parts:

a) air intake;

b) material intake (Fig. 20);

c) conveying pipeline (steel);

d) pneumatic aspirator (Fig. 21);

e) air/dust separation unit (Fig. 21); and

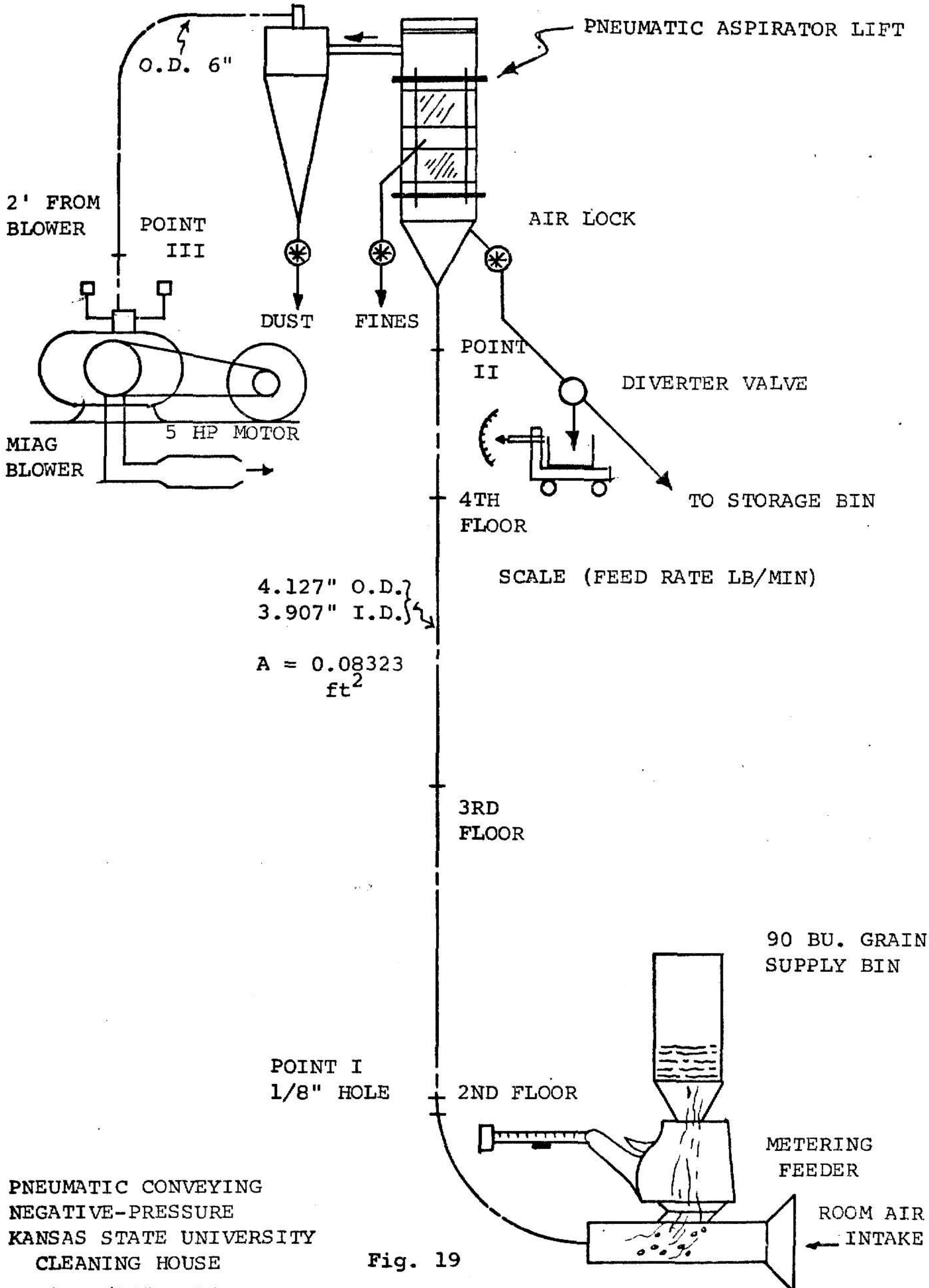
f) Lobe type positive displacement blower with exhauster (Figs. 22,23) develop 1.44 PSIG below atmospheric at heavy load.

Method of Conveying

Atmospheric air from the room was drawn into a 3.907 inch inside diameter steel pipe by the vacuum pressure developed by the blower at the far end of the system. One foot from the system inlet, grain dropped from a feeding device under the grain supply bin. Then, at two feet from the inlet, the input air and the dropped grain combined together in what is usually called the pick up area. The mixture of air and grain conveyed through a 45° elbow with a radius eight times the pipe diameter, then continued moving upward through a 40-foot vertical pipeline. The mixture entered vertically into the bottom of a MIAG pneumatic lift aspirator, spreading apart like a fountain-spray over the full circumference of the cone so that dust attached to the kernel's crease or skin was knocked off. After that, whole and broken kernels were separated from the conveying air. Air with dust passed through the long, streamlined cyclone, separating dust from air.

The grain discharged from the pneumatic lift aspirator through sealed rotary air locks to the cleaning machines. Broken kernels discharged from the other side of the aspirator lift through another sealed rotary air-lock to the supply bin. While acceptable cleaned air passed through the blower on to the silencer, dust settled down the cyclone and discharged through another rotary air-lock to the screening bin. All air-locks were sealed against loss of conveying air and vacuum to prevent air from being pulled in (Fig. 21).

Measurements of static pressure and velocity pressure at different points of the system are shown in Figs. 20, 24, 25. Measurement of feed rate of grain conveyed is shown in Fig. 26.



PNEUMATIC CONVEYING
NEGATIVE-PRESSURE
KANSAS STATE UNIVERSITY
CLEANING HOUSE
Scale 3/16" = 1'

Fig. 19

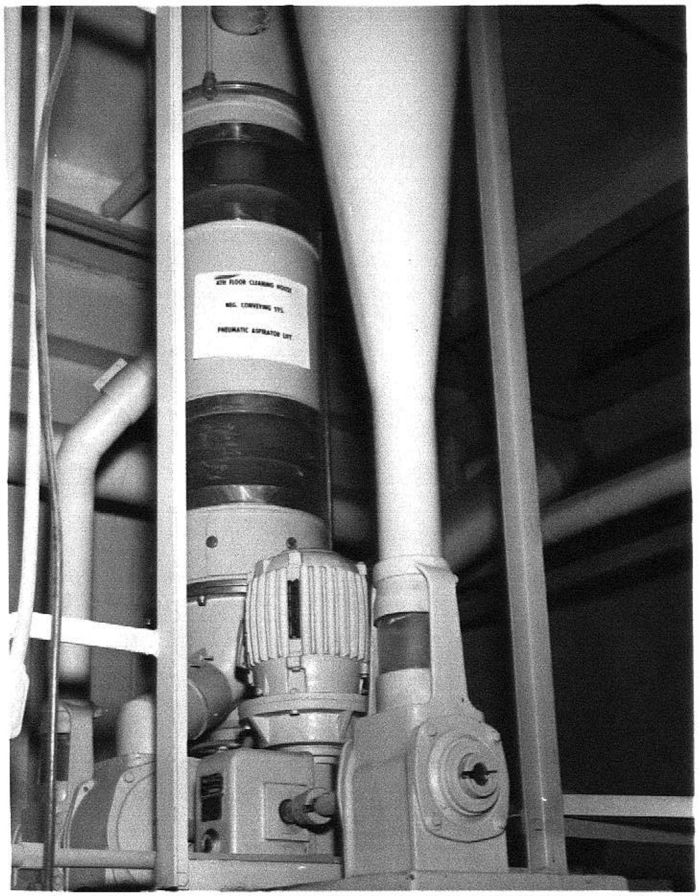


Fig. 21 Receiving Aspirator at End Separators of Suction System

Fig. 20 Pick Up Point of Suction System, Gage Pressures Measurements at Point I

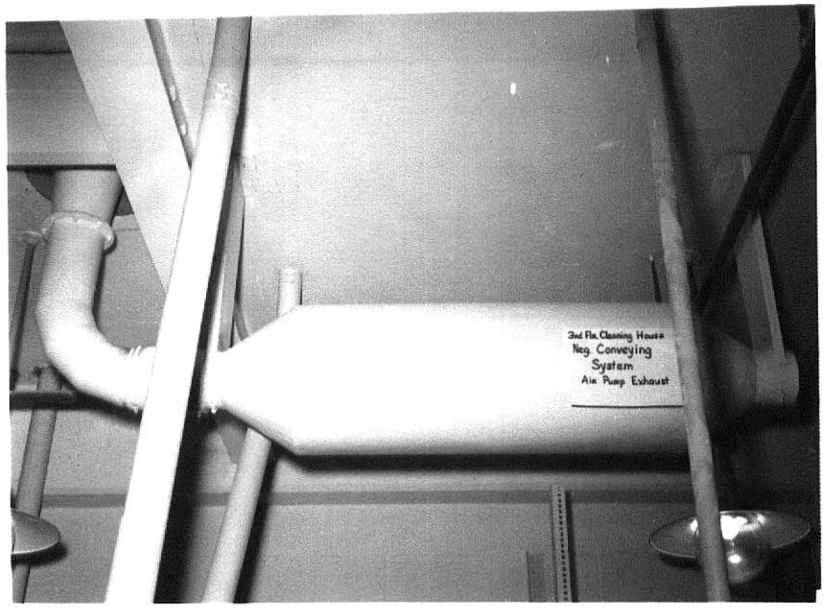


Fig. 23 Silencer - Negative System

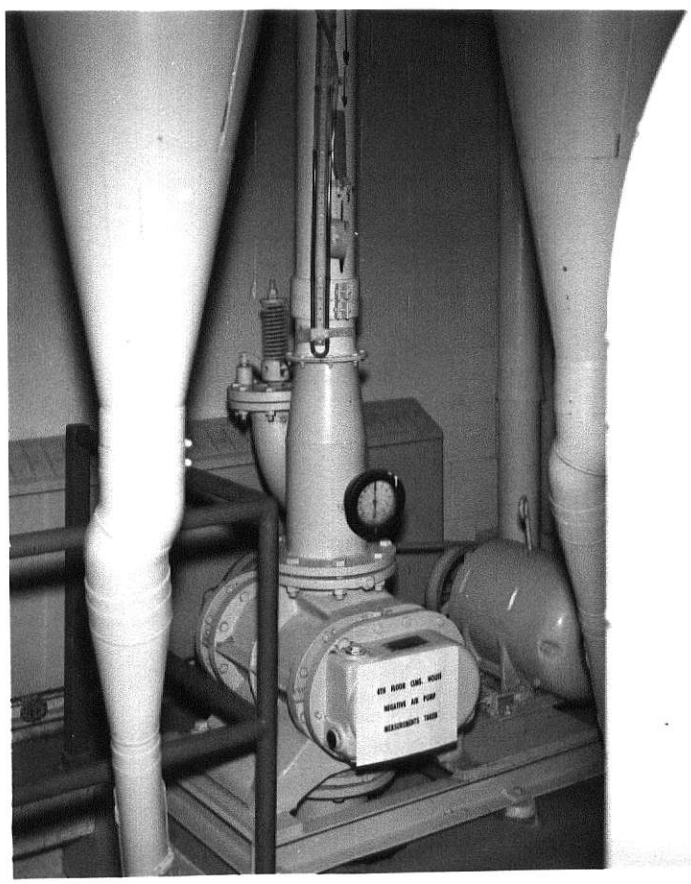


Fig. 22 Lobe Type Blower Negative System, Gage Pressures Measurements at Point III

Fig. 24 Measuring Static Pressure
Negative System Point II

Fig. 25 Measuring Velocity Pressure
Negative System Point II

Fig. 26 Measuring Flow Rate
Negative System

CALCULATIONS

Although the so-called "theory" of (air) pneumatic conveying of grain and mill production is still in the development stage, there is not yet any specific formula advised to be used for determining grain conveying treatments. Our calculation based on simple straight formulas to determine the following:

a	-	air conveying density	lbm/ft^3
b	-	volume rate of air flow	ft^3/min
c	-	weight rate of air flow	lbm/min
d	-	pressure drop between inlet and output points inch H_2O or (lb/ft^2)	
e	-	energy (electrical) input	kilowatts
f	-	output in terms	ft - lb/min
g	-	air horse power	ft - lb/min
h	-	motor horse power	hp
i	-	efficiency of conveying	(%)

(a) The manner in which the input air conveying is compressed directly or expanded affects the amount of the energy it can deliver or absorb. The high pressure system developed by the positive-displacement blower compresses air adiabatically - that is, without transfer of heat or energy input from the shaft work. In the expansion of air conveying through a pipeline, there is a negligible heat transfer and the expansion may be considered .

The combined gas law (perfect gas) equation is used to determine the density of the atmospheric air in the blower room and then at different points of the conveying pipeline to see how air input density changes because of rise of temperature and pressure from the input mechanical energy.

where $P = \rho RT$

P = pressure (absolute) lb/ft^2

R = gas constant for air = 53.34 ft-lbf/lbm-R°

T = absolute temperature R° = (F + 459.67)

ρ = air density lb/ft^3

* The average barometric pressure of Manhattan, Kansas, recorded by the Physics Department station, Kansas State University, for the year 1976, is 28.904 inch mercury.*

<u>NOTE</u> P_o = barometric pressure, inch HG x 0.49 x 144

where P_o = absolute atmospheric room pressure (lb/ft^2)

one inch of HG = 0.49 lb/in^2

one inch H_2O = 5.196 lb/ft^2

Therefore, the air densities were determined at different points in the conveying pipeline system with the different load (lb/min) conveyed.

$$\rho = \frac{P_o}{R \quad T_o} = \frac{P_o}{(53.34) \times (F° + 459.67)}$$

For determining the air densities, we need to determine first the total absolute pressures in these different points of the conveying pipeline at each certain load conveyed.

Total pressure gage inside the conveying pipeline = the static pressure + the velocity pressure.

Total absolute pressures in the conveying pipeline is at Point I.

$$P_1 = (VP_1 + SP_1) \times 5.196 + P_0$$

The same procedure is followed for determining ρ_2, ρ_3, and then P_2, P_3.

<u>NOTE</u>

Velocity pressure is always measured only at the discharge point III when the grain is conveyed. The velocity pressure is measured at points II and III when only air is flowing into the pipeline. Our calculation assumes that $VP_2 = VP_3$, since the conveying pipe diameter is constant. There was not a big difference between the values of VP_2 and VP_3.

From the velocity pressure measured in the pneumatic conveying test, the velocity (ft./min.) must be computed from the observed velocity pressure.

We start with definition of total head. It is the quantity which combines in a single term:

- the pressure head
- the velocity head
- the elevation head

$$\text{Total Head } (H_T) = \frac{P}{\rho} + \frac{V^2}{2g} + Z$$

where g = acceleration of gravity = 32.174 ft/sec^2
Z = elevation above datum (elevation head)
P/ρ = pressure head (potential energy)
$V^2/2g$ = velocity head (kinetic energy)

All terms have the dimension of length.

Kinetic energy = the work required to accelerate the body from zero velocity.

Potential energy = the work required to introduce the body from an absolute vacuum into the region where the pressure is.

Gravitational energy = the work required to lift the body from datum to the elevation Z.

$$\text{Velocity head} = \frac{V^2}{2g}$$

where V = Velocity ft./sec. and Velocity Head in ft.

If V expressed in FPM,

$$\text{Velocity Head} = \frac{V^2}{2g3600}$$

pressure equals the velocity head ft. x the density lbm./ft.^{3}. The velocity pressure (h_v) (lbm/ft^2) divided by 5,196 gives:

Velocity pressure in inch H_2O

$$h_v = \rho \frac{v^2}{2\ g\ 5.196}$$

where: v = velocity ft./sec.
h_v = inches of H_2O

With the velocity (v) expressed in (ft/min) we arrive at the common equation used for non-standard air condition:

$$h_v = \rho \frac{v^2}{2\ g\ \ 5.196 \times 3600} = \rho \frac{(\ V\ )^2}{(1096.5)}$$

$$V = 1097.56 \quad \frac{h_v}{\rho},$$

where ρ = density of air conveying
h_v = velocity pressure inch H_2O

For standard air

$$h_v = \frac{V^2}{2g \quad 5.196} = \frac{V^2}{16031918} = \left(\frac{V}{4007}\right)^2$$

$$V = 4007 \times \sqrt{h_v (\text{IN inch } H_2O)}$$

where

$$\rho = 0.075 \text{ lbm/ft}^3$$

where

V = velocity of air flow (ft/min)
h_v= velocity pressure. inch H_2O
ρ = density of standard air 0.075 = (lb/ft^3)

The air volume rate flowing in a pipe depends on the area of the pipe and the velocity at which the air flows. This relation can be expressed by the following basic equation:

$$Q = V \times A$$

where

Q = air volume rate flow ft^3/min (cfm)
V = air velocity ft/min (fpm)
A = area of the conveying pipe ft^2

A_1 = cross section area of positive conveying pipe = 0.01944 ft^2
A_2 = cross section area of the negative conveying pipe = 0.08325 ft^2

If the velocity (v) and volume rate of flow (Q) are known, the weight flow rate of conveying air (lb/min) can be determined.

$$G = Q \times \rho$$
$$= V \times A \times \rho$$

where G = weight rate of flow (lb/min)

To find the electrical energy input to the system in watts:

$$= \text{volts} \times \text{amps} \times \sqrt{3} \times \text{P.F.} \times \text{efficiency}$$

where

VOLTS = the measured voltage
AMPS = average amperes at the three phases
P.F. = power factor (guess) = 0.95
Efficiency = 0.85 for general purpose motor

$$\text{Mechanical energy} = \frac{\text{electrical energy}}{746} \quad \text{H.P.}$$

The energy output is the sum of the weight of grain (lbf./min.) times the total vertical height of the conveying pipeline expressed in (ft.-lbf./min.) plus the power that delivered to the conveyance air to maintain the air volumn flow rate through the system. The sum can be converted to watts.

System horsepower is the power that must be delivered to accelerate the conveying air to maintain flow at the rate Q through the system's resistance. Power to move and accelerate air is the sum of the total gage pressures at both inlet and outlet points.

$$(SP_3 + VP_3) - (SP_2 + VP_2) \times \frac{Q \times 33000}{6350}$$

But

$$VP_3 = VP_2 \quad \text{(assumed)}$$

$$= (SP_3 - SP_2) \times \frac{Q \times 33000}{6350}$$

$$\text{Output} = (SP_3 - SP_2) \times \frac{Q \times 33000}{6350} + \text{conveying distance (ft.)} \times \text{load conveyed (lb./min.)}$$

Conveying efficiency (includes fan efficiency, motor efficiency, and grain conveying) $= \frac{\text{energy output}}{\text{energy input}} \times 100$

<u>Calculation of losses (pressure drop) in the pneumatic systems</u>

When air flows through pipes and other fittings, it is subjected to a resistance or dragging force that tends to retard or stop the flow. These opposing forces are known as "friction" in the system. In both conveying systems, the friction is measured in inches of water gage. In general, the resistance offered to the mixture flow (air + grain) in a straight run of pipe varies with the size of the pipe, length of pipe and the velocity and flow rate. Thus, the small pipe offers greater resistance than the larger pipe. Long pipe offers greater resistance than the short pipe. The velocity (ft./min.) is the most important factor, since friction resistance varies with the square of the velocity.

There are different ways to calculate the total pressure drop in the conveying system due to the resistances encountered during conveying, as follows:

1 (a) In terms of inch water gage, by finding the difference of (SP_2 and SP_3) including the elbows (considered as straight line pipe).

<u>or</u> Applying Bernoulli equation to find (H_L) head losses including elbows as straight line pipe:

$$\frac{P_2}{\rho_2} + \frac{V_2^2}{2g} + \frac{G\ Z_2}{g_c} = \frac{P_3}{\rho_3}\ \frac{V_3^2}{g_c} + \frac{G\ Z_3}{g_c} + H_{L\ 2-3} + W_{x\ 2-3} - W_{r\ 2-3}$$

where

$H_{L\ 2-3}$ = loss of head (work) dissipated through friction between points 2 and 3

$W_{x\ 2-3}$ = work expanded between points 2 and 3

$W_{r\ 2-3}$ = work received between points 2 and 3

(b) it resolve into

$$g_c \ (SP_2 - SP_3) + \frac{(V_2^2 - V_3^2)}{2} + g \ (Z_2 - Z_3) + g \ H_{L \ 2-3} = 0$$

$$= \quad lbf/ft^2$$

$$g_c = \frac{ft - lbm}{sec^2 - lbf} = 32.174 \ \frac{lbm \ ft}{lbf \ sec^2}$$

v = ft/sec $\qquad$ g = ft/sec^2 = 32.174 ft/sec^2

now

$V_2 = V_3$ because $VP_2 = VP_3$ $\qquad$ $Z_2 = 0$

Therefore,

$$g_c \ (SP_2 - SP_3) + g \ Z_3 + g \ H_L = 0$$

$$H_L = \frac{\underline{g_c} \ (SP_2 - SP_3) - g \ Z_3}{g}$$

$$H_L = \frac{(SP_2 - SP_3)}{\rho \ av. \ 2-3} \times 5.196 - Z_3$$

Total pressure loss = H_L x $\qquad$ av. 2-3 $\qquad$ $lb./ft^3$.

TABLE NO. 1

PNEUMATIC CONVEYING, POSITIVE-PRESSURE SYSTEM
SEMI-CLEAN HARD RED WINTER WHEAT, 60.1 TEST WEIGHT, 11.0% MOISTURE CONTENT
POSITIVE DISPLACEMENT (SCHWITZER) BLOWER, 1570 RPM, 1.89" I.D. PIPE, SYSTEM LENGTH 75'
KANSAS STATE UNIVERSITY, CLEANING HOUSE

FR (lb/min)	VP_2 INCH H_2O	SP_1 INCH H_2O	SP_2 INCH H_2O	SP_3 INCH H_2O	D_0 lb/ft^3	D_2 lb/ft^3	D_3 lb/ft^3	V_2 ft/min	Q_{2} ft^3/min	G_2 lb/min	AVG AMPS	ENERGY INPUT KILO-WATTS	ENERGY OUTPUT ft-lb/min	EFF. %	MOTOR HORSE POWER HP	PRESS LOSS INCH H_2O
00.0	2.35	18.5	15.0	1.4	0.0694	0.0708	0.0695	6317	122.8	8.6	2.95	1.9	8747	15.4	2.9	13.6
22.4	1.73	37.4	32.8	2.6	0.0694	0.0733	0.0696	5330	103.6	7.4	3.21	2.1	14809	23.9	3.3	30.2
45.5	1.37	57.0	50.6	4.8	0.0693	0.0754	0.0701	4669	90.8	6.6	3.41	2.2	18555	28.2	3.5	45.8
69.8	1.08	82.2	73.3	7.6	0.0693	0.0781	0.0705	4083	79.4	5.9	3.68	2.4	22577	31.8	3.7	65.7
93.3	0.90	106.4	98.2	8.6	0.0692	0.0812	0.0707	3650	70.9	5.4	4.00	2.6	27217	35.3	4.1	89.6
115.8	0.65	126.1	117.7	11.4	0.0690	0.0836	0.0712	3057	59.4	4.6	4.21	2.7	25484	31.4	4.3	106.3

TABLE NO. 2

PNEUMATIC CONVEYING, POSITIVE-PRESSURE SYSTEM
SEMI-CLEAN HARD RED WINTER WHEAT (TEMPERED) 54.8 TEST WEIGHT, 16.65% MOISTURE CONTENT
POSITIVE DISPLACEMENT (SCHWITZER) BLOWER, 1570 RPM, 1.89" I.D. PIPE, TOTAL SYSTEM LENGTH 75'
KANSAS STATE UNIVERSITY, CLEANING HOUSE

FR. (lb/min)	VP_2 INCH H_2O	SP_1 INCH H_2O	SP_2 INCH H_2O	SP_3 INCH H_2O	D_o lb/ft^3	D_2 lb/ft^3	D_3 lb/ft^3	V_2 ft/min	Q_2 ft^3/min	G_2 lb/min	AVG AMPS	ENERGY INPUT KILO-WATTS	ENERGY OUTPUT ft-lb/min	EFF. %	MOTOR HORSE POWER HP	PRESS LOSS INCH H_2O
000.0	2.30	18.5	14.7	1.7	0.0697	0.0716	0.0706	6214	120.8	8.6	2.9	1.77	8169	15.4	2.7	13.0
21.5	1.89	31.3	26.6	2.8	0.0696	0.0727	0.0703	5600	108.9	7.8	3.0	1.80	11956	22.1	2.8	24.0
39.0	1.52	52.8	44.9	5.3	0.0697	0.0753	0.0707	4933	95.9	6.9	3.1	1.83	17154	31.9	2.8	39.6
60.6	1.38	70.0	60.5	6.5	0.0699	0.0779	0.0713	4611	89.6	6.7	3.3	1.90	21001	36.2	3.0	54.0
81.5	1.14	96.3	87.0	8.7	0.0698	0.0807	0.0717	4124	80.2	6.1	3.6	2.10	27535	43.5	3.3	78.3
95.5	0.97	117.1	105.0	9.8	0.0699	0.0829	0.0756	3750	72.9	5.8	4.1	2.50	29827	40.1	3.9	95.2
110.0	0.76	136.0	123.9	11.1	0.0705	0.0857	0.0724	3264	63.5	5.0	4.6	2.80	30492	36.9	4.3	112.8

TABLE NO. 3

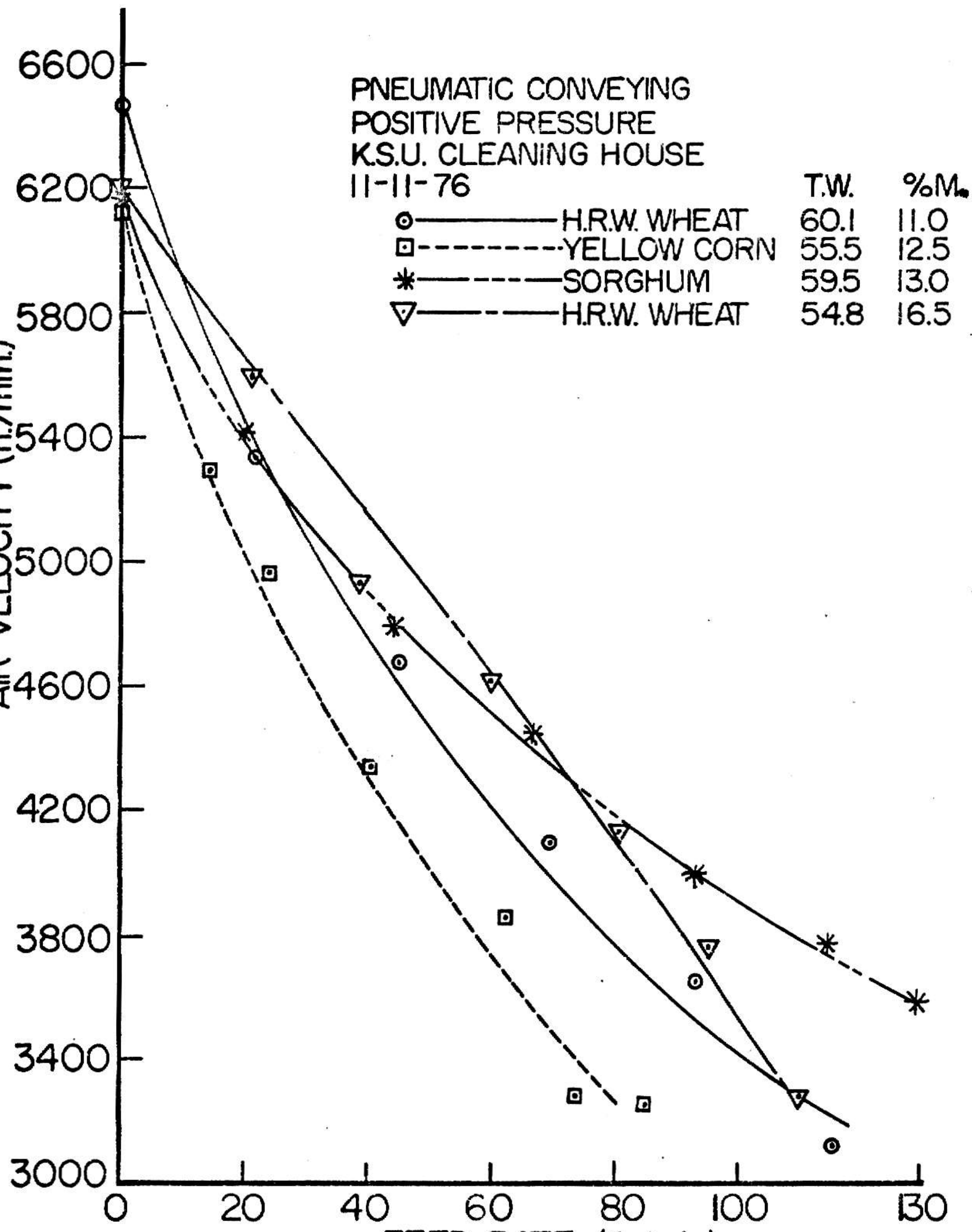
PNEUMATIC CONVEYING, POSITIVE-PRESSURE SYSTEM
SEMI-CLEAN YELLOW DENT CORN, 55.5 TEST WEIGHT, 12.5% MOISTURE CONTENT
POSITIVE DISPLACEMENT (SCHWITZER) BLOWER, 1570 RPM, 1.89" I.D. PIPE, TOTAL SYSTEM LENGTH 75'
KANSAS STATE UNIVERSITY, CLEANING HOUSE

FR. (lb/min)	VP_2 INCH H_2O	SP_1 INCH H_2O	SP_2 INCH H_2O	SP_3 INCH H_2O	D_0 lb/ft^3	D_2 lb/ft^3	D_3 lb/ft^3	V_2 ft/min	Q_2 ft^3/min	G_2 lb/min	AVG AMPS	ENERGY INPUT KILO-WATTS	ENERGY OUTPUT ft-lb/min	EFF. %	MOTOR HORSE POWER HP	PRESS LOSS INCH H_2O
00.0	2.26	18.8	15.3	1.65	0.0696	0.0726	0.0703	6123	119.0	8.5	3.02	1.93	8505	14.7	3.05	13.65
14.9	1.71	31.8	27.7	2.47	0.0696	0.0734	0.0691	5286	102.7	7.4	3.08	1.98	12516	21.0	3.13	25.24
24.4	1.53	41.5	36.5	3.10	0.0695	0.0747	0.0695	4964	96.5	6.9	3.13	2.02	15228	25.1	3.18	33.4
40.5	1.18	54.6	47.5	3.80	0.0695	0.0760	0.0698	4322	84.0	6.1	3.29	2.09	16459	26.5	3.26	43.7
62.4	0.95	73.0	65.5	4.10	0.0695	0.0770	0.0702	3848	74.8	5.5	4.90	3.08	19771	21.3	4.87	61.4
74.0	0.70	84.0	76.0	5.25	0.0695	0.0787	0.0703	3270	63.6	4.7	5.42	3.41	18501	18.1	5.38	70.75

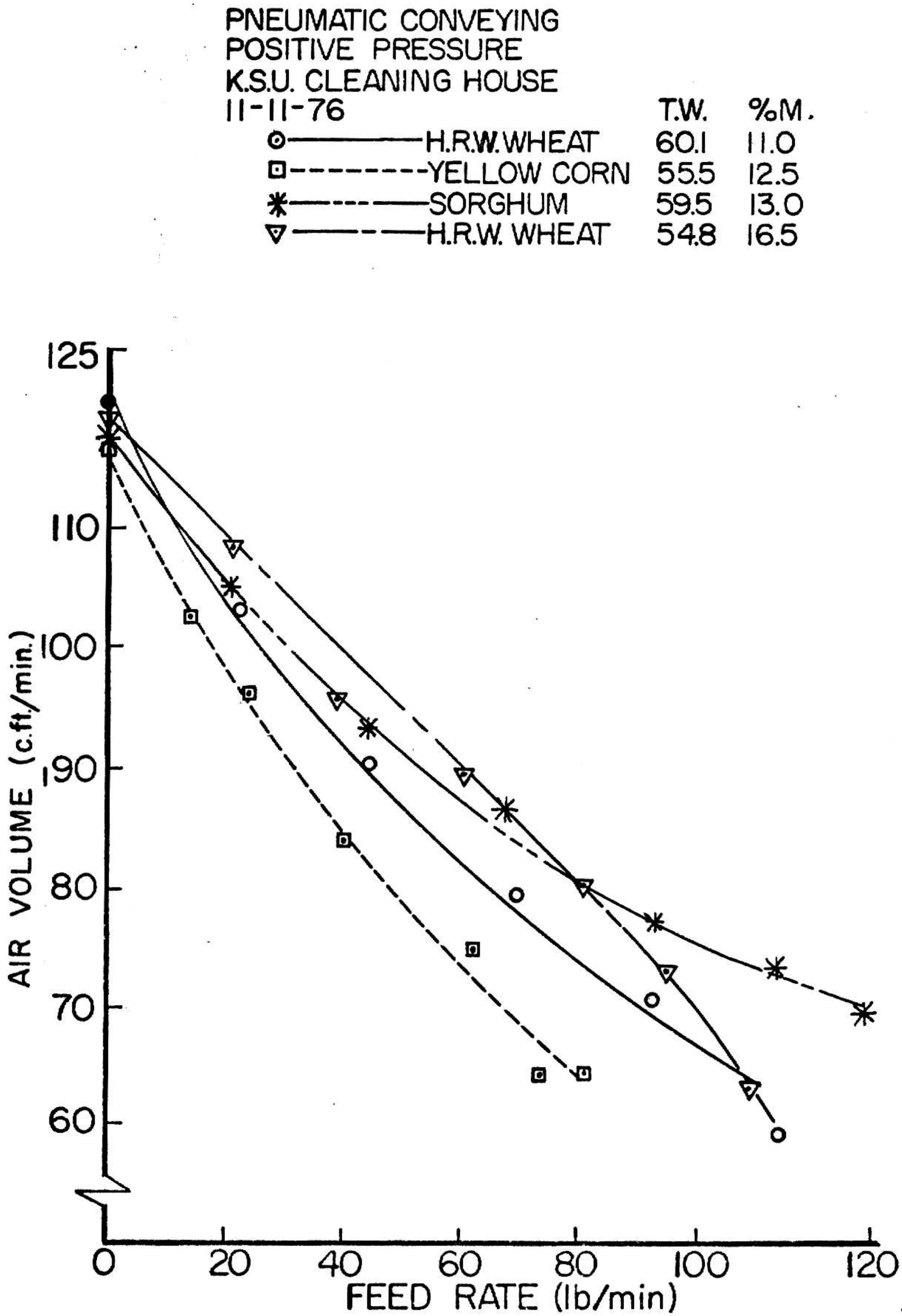
TABLE NO. 4

PNEUMATIC CONVEYING, POSITIVE-PRESSURE SYSTEM
SEMI-CLEAN SORGHUM, 59.5 TEST WEIGHT, 13.0% MOISTURE CONTENT
POSITIVE DISPLACEMENT (SCHWITZER) BLOWER, 1570 RPM, 1.89" I.D. PIPE, SYSTEM LENGTH 75'
KANSAS STATE UNIVERSITY, CLEANING HOUSE

FR (lb/min)	VP_2 INCH H_2O	SP_1 INCH H_2O	SP_2 INCH H_2O	SP_3 INCH H_2O	D_0 lg/ft^3	D_2 lb/ft^3	D_3 lb/ft^3	V_2 ft/min	Q_{2} ft^3/min	G_2 lb/min	AVG AMPS	ENERGY INPUT KILO-WATTS	ENERGY OUTPUT ft-lb/min	EFF. %	MOTOR HORSE POWER HP	PRESS LOSS INCH H_2O
00.0	2.30	18.1	13.1	1.3	0.0707	0.0723	0.0709	6153	119.6	8.6	3.02	1.96	7883	13.4	3.09	11.8
20.7	1.80	35.8	30.1	3.5	0.0707	0.0739	0.0714	5408	105.1	7.6	3.10	2.02	13091	12.5	3.19	26.6
44.7	1.45	52.7	43.9	4.5	0.0708	0.0757	0.0716	4796	93.2	6.9	3.32	2.15	16022	24.7	3.39	39.4
67.8	1.3	73.1	61.4	6.1	0.0708	0.0778	0.0719	4454	86.6	6.5	3.52	2.33	20306	29.7	3.60	55.3
93.2	1.10	95.8	84.0	8.1	0.0709	0.0808	0.0722	3983	77.4	5.9	3.94	2.44	24448	31.8	4.03	75.9
114.5	0.97	103.2	90.8	9.5	0.0709	0.0815	0.0724	3776	73.4	5.6	4.56	2.95	23397	25.9	4.66	80.3
129.5	0.90	117.5	106.5	9.3	0.0730	0.0846	0.0741	3577	69.5	5.5	4.22	3.31	26641	32.7	4.28	87.2

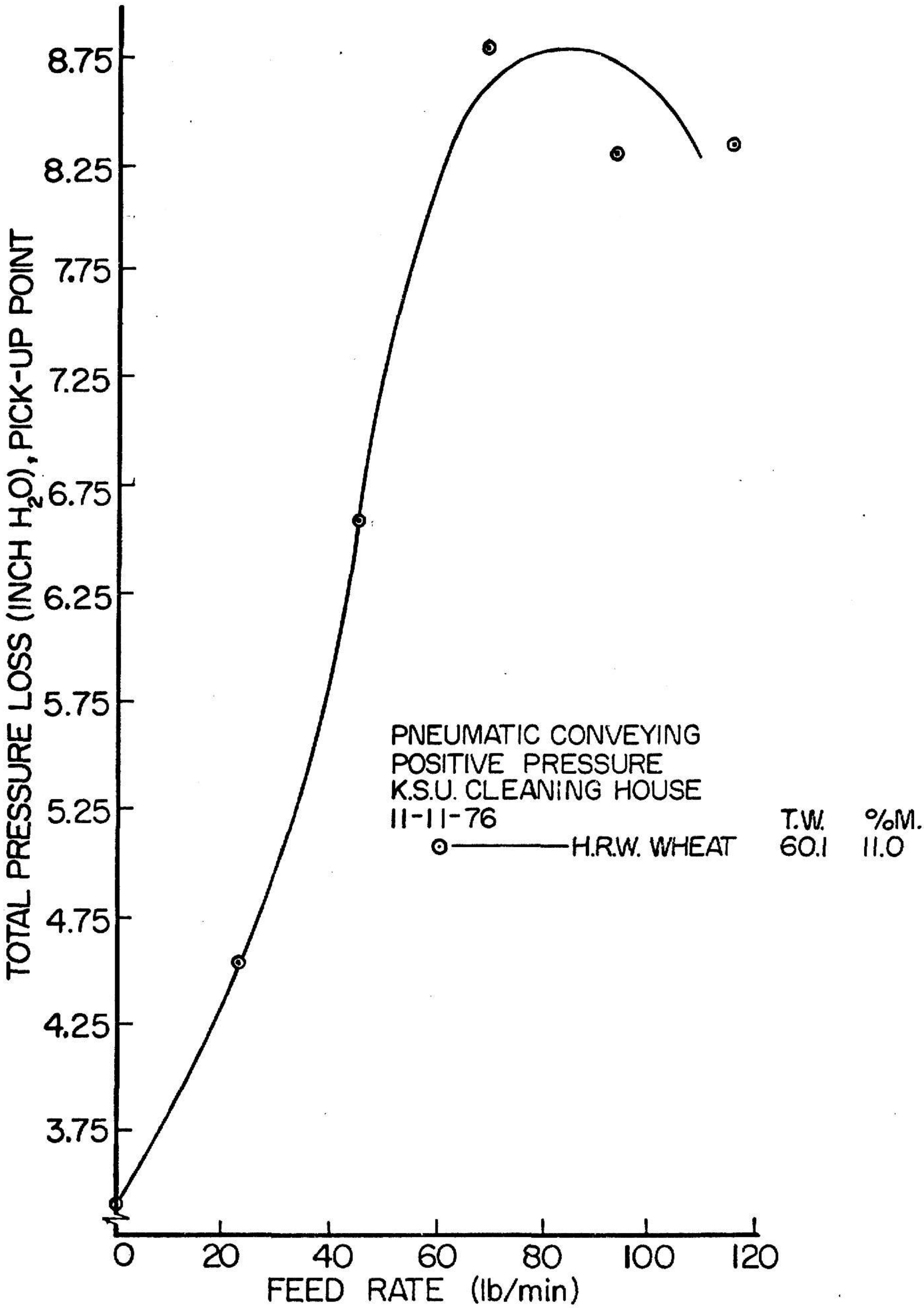

PNEUMATIC CONVEYING
POSITIVE PRESSURE
K.S.U. CLEANING HOUSE
11-11-76
T.W.
%M.
H.R.W. WHEAT 60.1 11.0
YELLOW CORN 55.5 12.5
SORGHUM 59.5 13.0
H.R.W. WHEAT 54.8 16.5
AIR VELOCITY (ft./min.)
6600
6200
5800
5400
5000
4600
4200
3800
3400
3000
0
20
40
60
80
100
130
FEED RATE (lb/min)

Graph 1

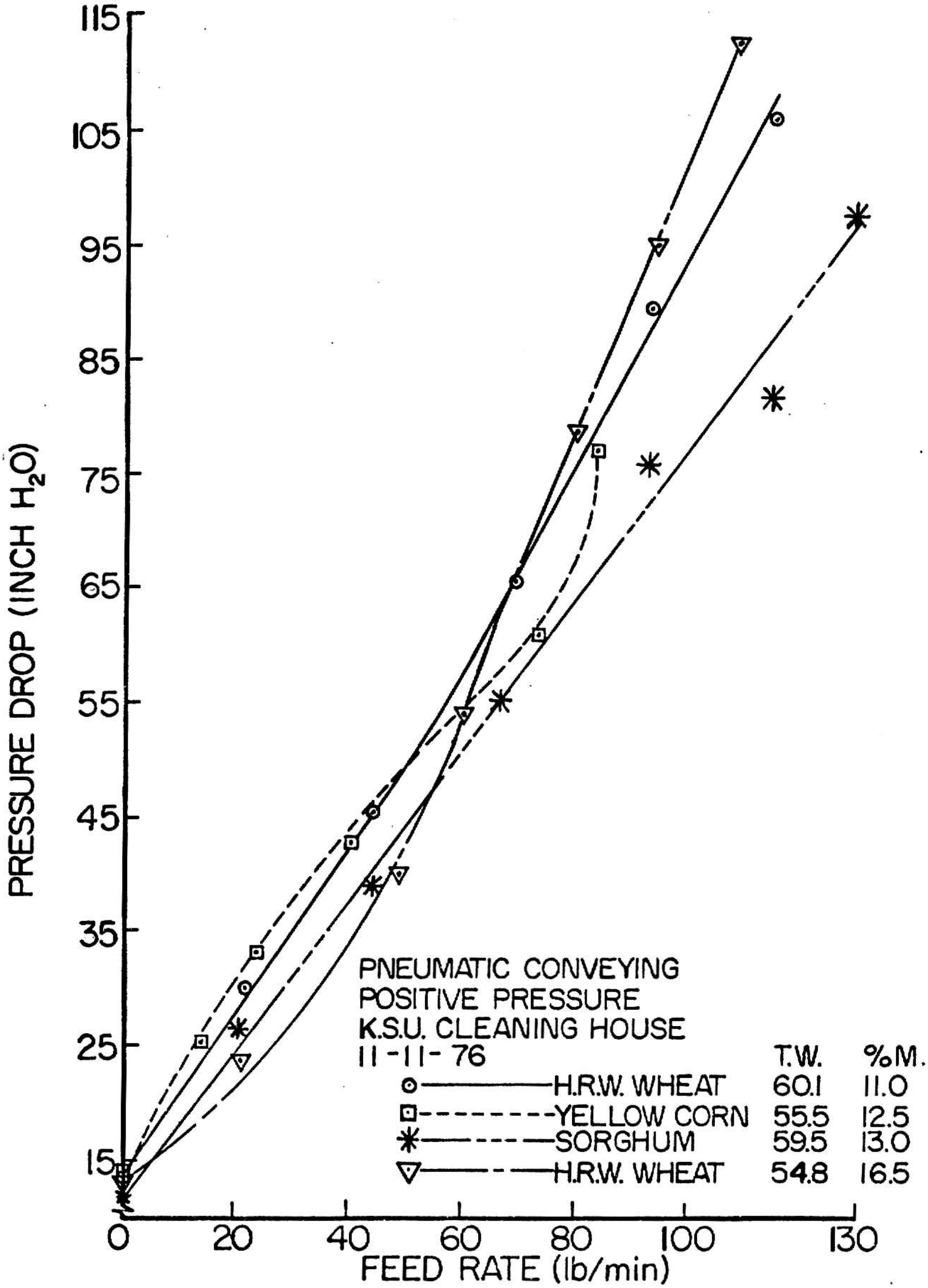


PNEUMATIC CONVEYING
POSITIVE PRESSURE
K.S.U. CLEANING HOUSE
11-11-76
T.W. %M.
H.R.W. WHEAT 60.1 11.0
YELLOW CORN 55.5 12.5
SORGHUM 59.5 13.0
H.R.W. WHEAT 54.8 16.5
125
110
100
90
80
70
60
AIR VOLUME (c.ft./min.)
0
20
40
60
80
100
120
FEED RATE (lb/min)

Graph 2

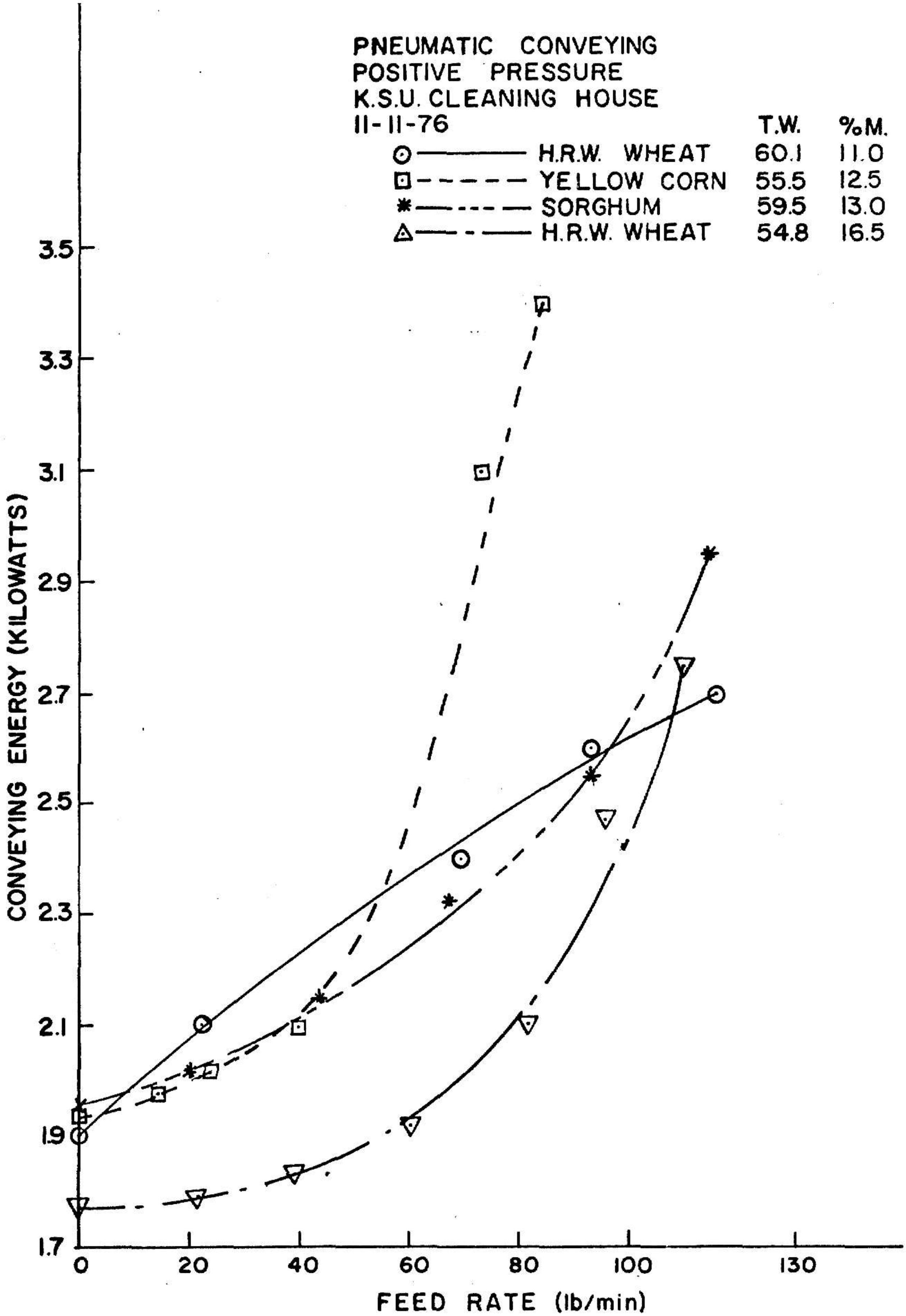

TOTAL PRESSURE LOSS (INCH H_2O), PICK-UP POINT
8.75
8.25
7.75
7.25
6.75
6.25
5.75
5.25
4.75
4.25
3.75
0
20
40
60
80
100
120
FEED RATE (lb/min)
PNEUMATIC CONVEYING
POSITIVE PRESSURE
K.S.U. CLEANING HOUSE
11-11-76
T.W. %M.
H.R.W. WHEAT 60.1 11.0

Graph 3

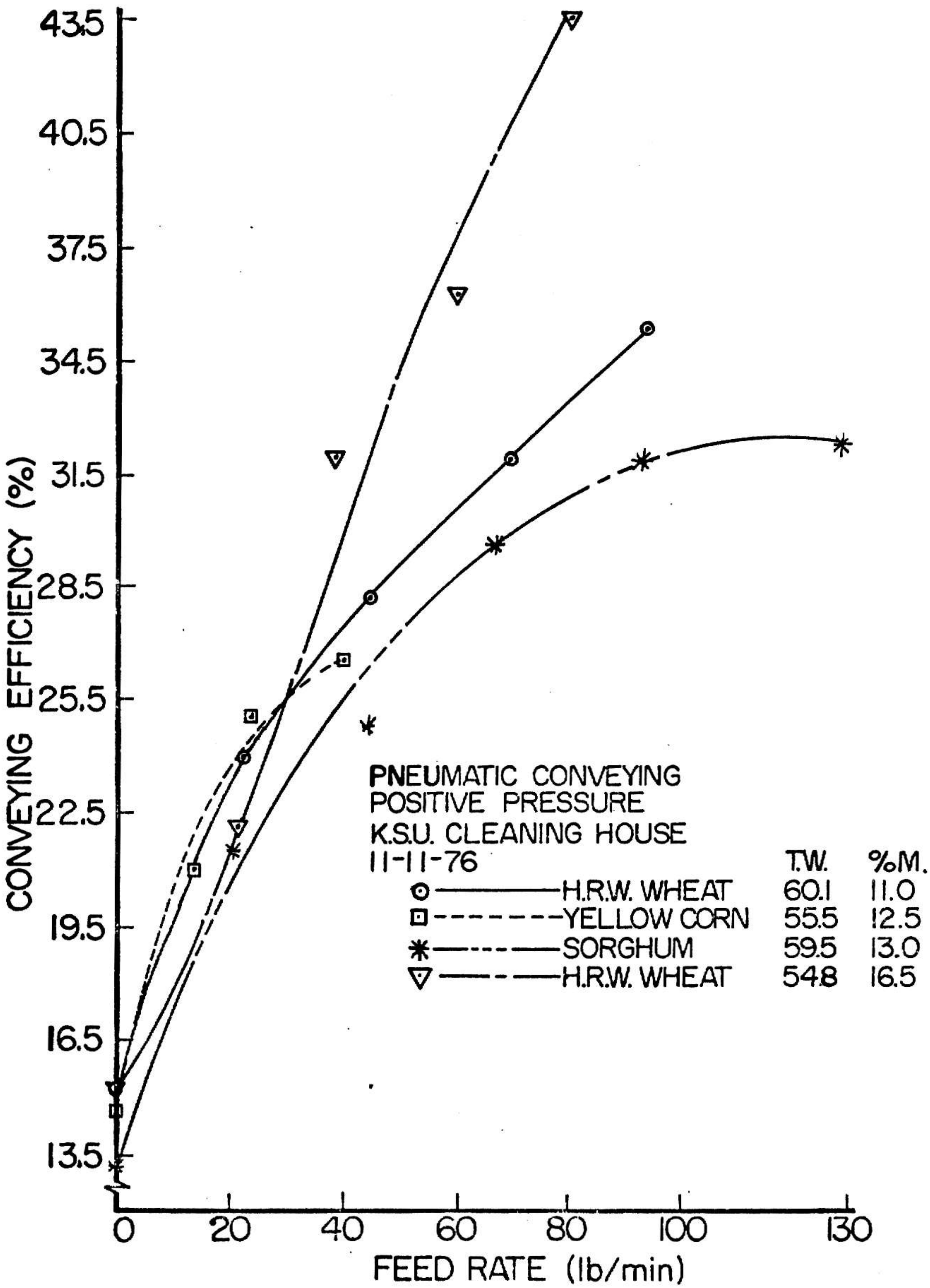


115
105
95
85
75
65
55
45
35
25
15
PRESSURE DROP (INCH H2O)
0
20
40
60
80
100
130
FEED RATE (lb/min)
PNEUMATIC CONVEYING
POSITIVE PRESSURE
K.S.U. CLEANING HOUSE
11-11-76
T.W.
%M.
H.R.W. WHEAT 60.1 11.0
YELLOW CORN 55.5 12.5
SORGHUM 59.5 13.0
H.R.W. WHEAT 54.8 16.5

Graph 4

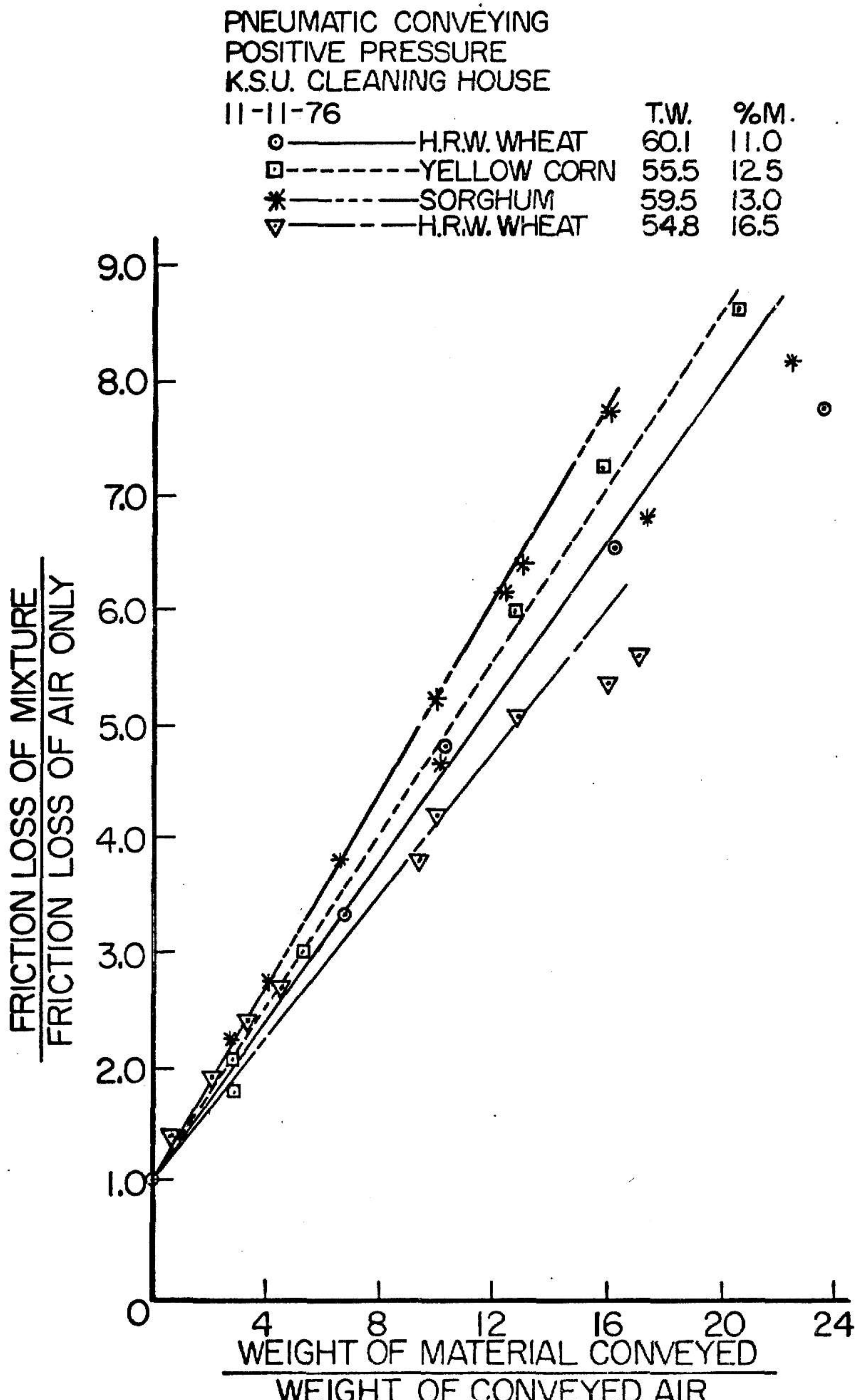

PNEUMATIC CONVEYING
POSITIVE PRESSURE
K.S.U. CLEANING HOUSE
11-11-76
T.W. %M.
H.R.W. WHEAT 60.1 11.0
YELLOW CORN 55.5 12.5
SORGHUM 59.5 13.0
H.R.W. WHEAT 54.8 16.5
CONVEYING ENERGY (KILOWATTS)
3.5
3.3
3.1
2.9
2.7
2.5
2.3
2.1
1.9
1.7
0
20
40
60
80
100
130
FEED RATE (lb/min)

Graph 5



CONVEYING EFFICIENCY (%)
43.5
40.5
37.5
34.5
31.5
28.5
25.5
22.5
19.5
16.5
13.5
0
20
40
60
80
100
130
FEED RATE (lb/min)
PNEUMATIC CONVEYING
POSITIVE PRESSURE
K.S.U. CLEANING HOUSE
11-11-76
T.W. %M.
H.R.W. WHEAT 60.1 11.0
YELLOW CORN 55.5 12.5
SORGHUM 59.5 13.0
H.R.W. WHEAT 54.8 16.5

Graph 6


PNEUMATIC CONVEYING
POSITIVE PRESSURE
K.S.U. CLEANING HOUSE
11-11-76
T.W. %M.
H.R.W. WHEAT 60.1 11.0
YELLOW CORN 55.5 12.5
SORGHUM 59.5 13.0
H.R.W. WHEAT 54.8 16.5
FRICTION LOSS OF MIXTURE / FRICTION LOSS OF AIR ONLY
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
4
8
12
16
20
24
WEIGHT OF MATERIAL CONVEYED / WEIGHT OF CONVEYED AIR

Graph 7

TABLE NO. 5

PNEUMATIC CONVEYING, NEGATIVE-PRESSURE SYSTEM
SEMI-CLEAN HARD RED WINTER WHEAT, 59.0 TEST WEIGHT, 11.0% MOISTURE CONTENT
POSITIVE DISPLACEMENT (MIAG) BLOWER, 1052 RPM, 3.907" I.D. PIPE, TOTAL SYSTEM LENGTH 40'
KANSAS STATE UNIVERSITY, CLEANING HOUSE

FR (lb/min)	VP_2 INCH H_2O	SP_1 INCH H_2O	SP_2 INCH H_2O	D_0 lb/ft^3	D_1 lb/ft^3	D_2 lb/ft^3	V_2 ft/min	Q_2 ft^3/min	G_2 lb/min	AVG AMPS	ENERGY INPUT KILO-WATTS	ENERGY OUTPUT ft-lb/min	EFF. %	MOTOR HORSE POWER HP	PRESS LOSS INCH H_2O
000.0	1.51	2.38	4.67	0.0691	0.0698	0.0701	5083	423	29.6	3.93	1.93	5033	6.6	3.99	-2.29
10.5	1.51	3.20	5.69	0.0691	0.0699	0.0703	5080	422	29.7	4.00	2.58	5881	7.6	4.06	-2.49
27.8	1.46	4.07	8.29	0.0691	0.0701	0.0707	4975	414	29.2	4.16	2.68	10252	12.8	4.22	-4.22
68.2	1.17	8.73	15.54	0.0691	0.0708	0.0720	4421	368	26.3	4.51	2.90	15821	18.2	4.58	-6.81
115.2	1.01	14.10	23.79	0.0691	0.0718	0.0735	4056	337	24.5	5.17	3.33	21711	21.8	5.25	-9.69
134.3	0.86	17.53	26.82	0.0691	0.0723	0.0740	3728	310	22.7	5.50	3.54	20537	19.5	5.58	-9.29
178.0	0.79	22.00	36.50	0.0690	0.0731	0.0757	3542	294	21.9	6.10	3.92	29545	25.0	6.19	-14.00

TABLE NO . 6

PNEUMATIC CONVEYING, NEGATIVE-PRESSURE SYSTEM
SEMI-CLEAN HARD RED WINTER WHEAT, TEMPERED, 53.0 TEST WEIGHT, 16.9% MOISTURE CONTENT
POSITIVE DISPLACEMENT (MIAG) BLOWER 1052 RPM, 3.907" I.D. PIPE, SYSTEM LENGTH 40'
KANSAS STATE UNIVERSITY, CLEANING HOUSE

FR. (lb/min)	VP_2 INCH H_2O	SP_1 INCH H_2O	SP_2 INCH H_2O	D_0 lb/ft^3	D_1 lb/ft^3	D_2 lb/ft^3	V_2 ft/min	Q_2 ft^3/min	G_2 lb/min	AVG AMPS	ENERGY INPUT KILO-WATTS	ENERGY OUTPUT ft-lb/min	EFF. %	MOTOR HORSE POWER HP	PRESS LOSS INCH H_2O
00.0	1.60	2.7	5.7	0.0704	0.0712	0.0716	5183	431.5	30.8	3.93	2.53	6906	9.10	3.99	-3.0
24.3	1.57	4.4	9.2	0.0704	0.0715	0.0723	5106	425.1	30.5	4.04	2.59	11785	15.1	4.09	-4.8
56.5	1.48	8.2	15.2	0.0704	0.0722	0.0733	4926	410.1	29.8	4.26	2.74	17069	20.7	4.32	-7.0
99.7	1.20	14.6	24.2	0.0704	0.0733	0.0750	4379	364.6	27.0	4.67	3.00	22228	24.7	4.74	-10.4
136.1	9.98	19.7	33.7	0.0704	0.0735	0.0767	3921	326.5	24.6	5.29	3.41	29300	28.6	5.37	-14.0
159.1	0.80	23.4	38.7	0.0702	0.0745	0.0774	3509	292.2	22.2	5.54	3.57	29963	27.9	5.63	-15.4

TABLE NO. 7

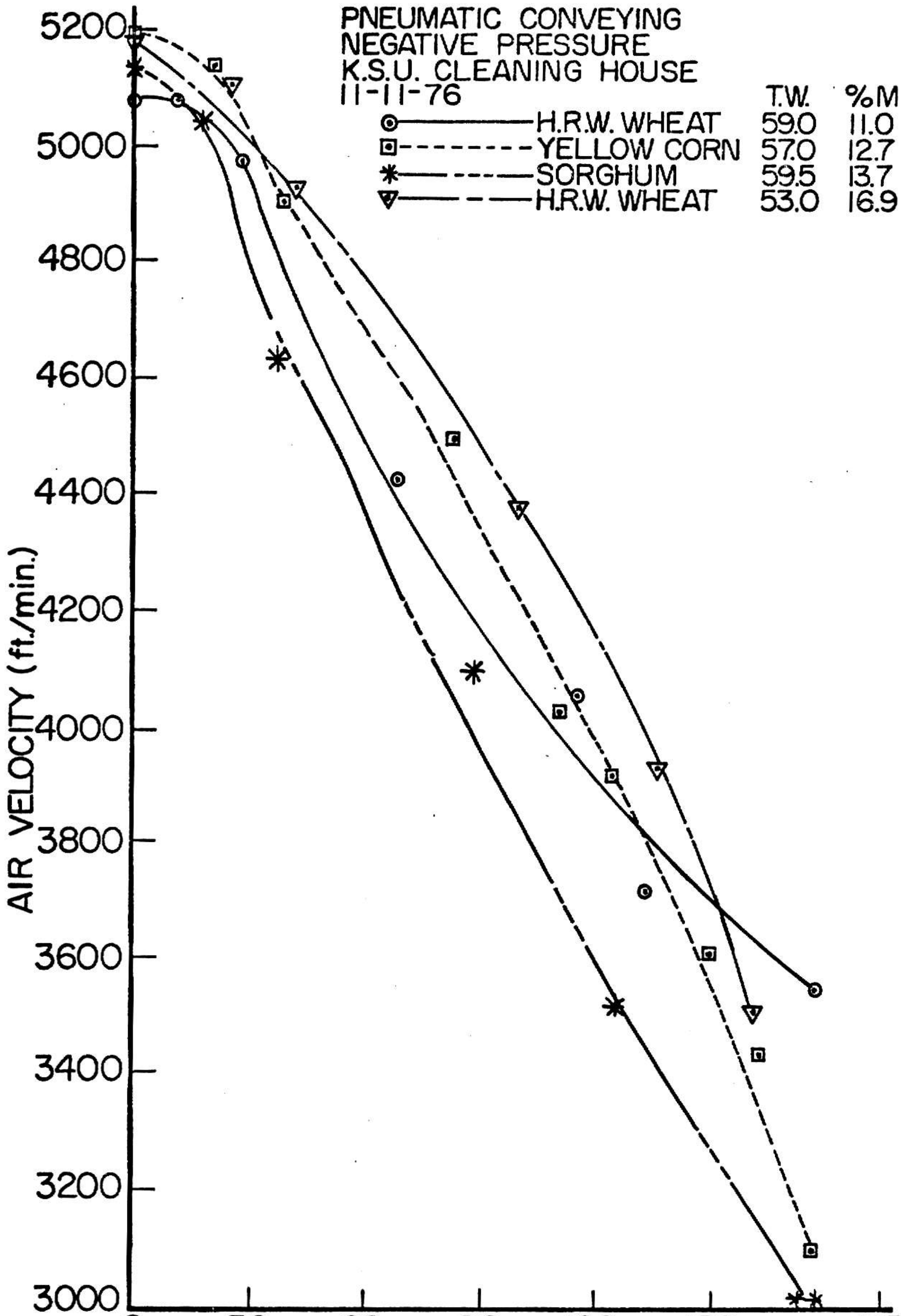
PNEUMATIC CONVEYING, NEGATIVE-PRESSURE SYSTEM
SEMI-CLEAN YELLOW DENT CORN, 57.0 TEST WEIGHT, 12.7% MOISTURE CONTENT
POSITIVE DISPLACEMENT (MIAG) BLOWER, 1052 RPM, 3.907" I.D. PIPE, TOTAL SYSTEM LENGTH 40'
KANSAS STATE UNIVERSITY, CLEANING HOUSE

FR. (lb/min)	VP_2 INCH H_2O	SP_1 INCH H_2O	SP_2 INCH H_2O	D_o lb/ft^3	D_1 lb/ft^3	D_2 lb/ft^3	V_2 ft/min	Q_2 ft^3/min	G_2 lb/min	AVG AMPS	ENERGY INPUT KILO-WATTS	ENERGY OUTPUT ft-lb/min	EFF. %	MOTOR HORSE POWER HP	PRESS LOSS INCH H_2O
000.0	1.16	2.73	4;97	0.0708	0.0716	0.0718	5197	432	31.0	3.91	2.54	4633	6.1	4.0	-2.24
19.50	1.59	3.77	8.00	0.0707	0.0716	0.0723	5145	428	30.8	3.93	2.54	10205	13.4	4.01	-4.23
45.8	1.45	5.00	9.57	0.0707	0.0718	0.0725	4903	408	29.5	4.22	2.74	11539	14.1	4.32	-4.57
82.9	1.24	7.55	15.25	0.0708	0.0724	0.0737	4491	373	27.3	4.33	2.81	18340	21.7	4.43	-7.70
108.8	1.01	11.20	19.87	0.0708	0.0730	0.0746	4029	335	24.8	4.57	2.97	19481	21.9	4.68	-8.67
124.2	0.96	13.27	23.75	0.0708	0.0734	0.0753	3909	325	24.2	4.7	3.05	22802	24.9	4.81	-10.48
149.0	0.82	15.57	27.50	0.0708	0.0738	0.0759	3610	300	22.9	5.11	3.32	24735	25.0	5.23	-11.93
162.7	0.74	17.25	30.25	0.0709	0.0745	0.0773	3089	257	19.5	5.63	3.67	27300	24.7	5.79	-15.00

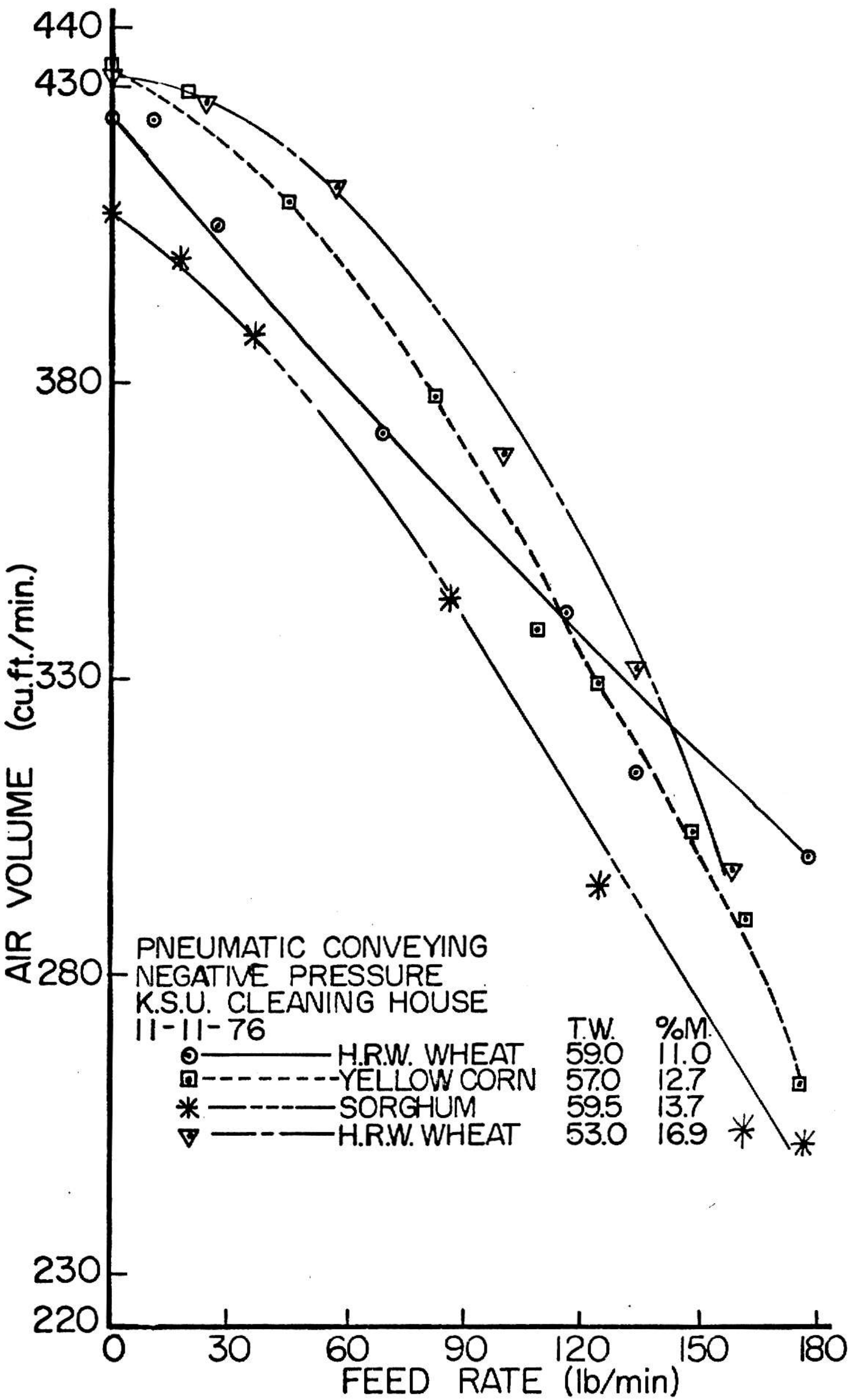
TABLE NO. 8

PNEUMATIC CONVEYING, NEGATIVE-PRESSURE SYSTEM
SEMI-CLEAN SORGHUM, 55.0 TEST WEIGHT, 11.0% MOISTURE CONTENT
POSITIVE DISPLACEMENT (MIAG) BLOWER 1052 RPM, 3.907" I.D. PIPE, TOTAL SYSTEM LENGTH 40'
KANSAS STATE UNIVERSITY, CLEANING HOUSE

FR. (lb/min)	VP_2 INCH H_2O	SP_1 INCH H_2O	SP_2 INCH H_2O	D_0 lb/ft^3	D_1 lb/ft^3	D_2 lb/ft^3	V_2 ft/min	Q_2 ft^3/min	G_2 lb/min	ENERGY INPUT KILO-WATTS	ENERGY OUTPUT ft-lb/min	AVG AMPS	EFF. %	MOTOR HORSE POWER HP	PRESS LOSS INCH H_2O
000.0	1.56	2.57	4.54	0.0696	0.0704	0.0707	5147	428	30.2	2.52	4402	3.85	5.82	3.98	-1.97
17.0	1.50	3.32	6.42	0.0696	0.0705	0.0709	5041	419	29.7	2.54	7452	3.88	9.75	4.01	-3.01
36.0	1.28	4.70	10.75	0.0697	0.0708	0.0718	4630	385	27.5	2.59	13604	3.98	17.49	4.08	-6.05
86.2	1.02	11.60	18.92	0.0696	0.0719	0.0732	4091	340	24.7	2.99	16460	4.58	18.25	4.74	-7.32
124.2	0.77	18.70	28.21	0.0696	0.0731	0.0749	3510	292	21.6	3.49	19426	5.34	18.69	5.52	-9.51
172.0	0.58	29.00	41.00	0.0697	0.0794	0.0772	3005	250	19.0	3.60	22601	7.33	15.77	7.52	-12.00
177.0	0.56	24.00	48.00	0.0696	0.0740	0.0784	2931	244	18.6	3.94	37961	6.00	32.02	6.22	-24.00

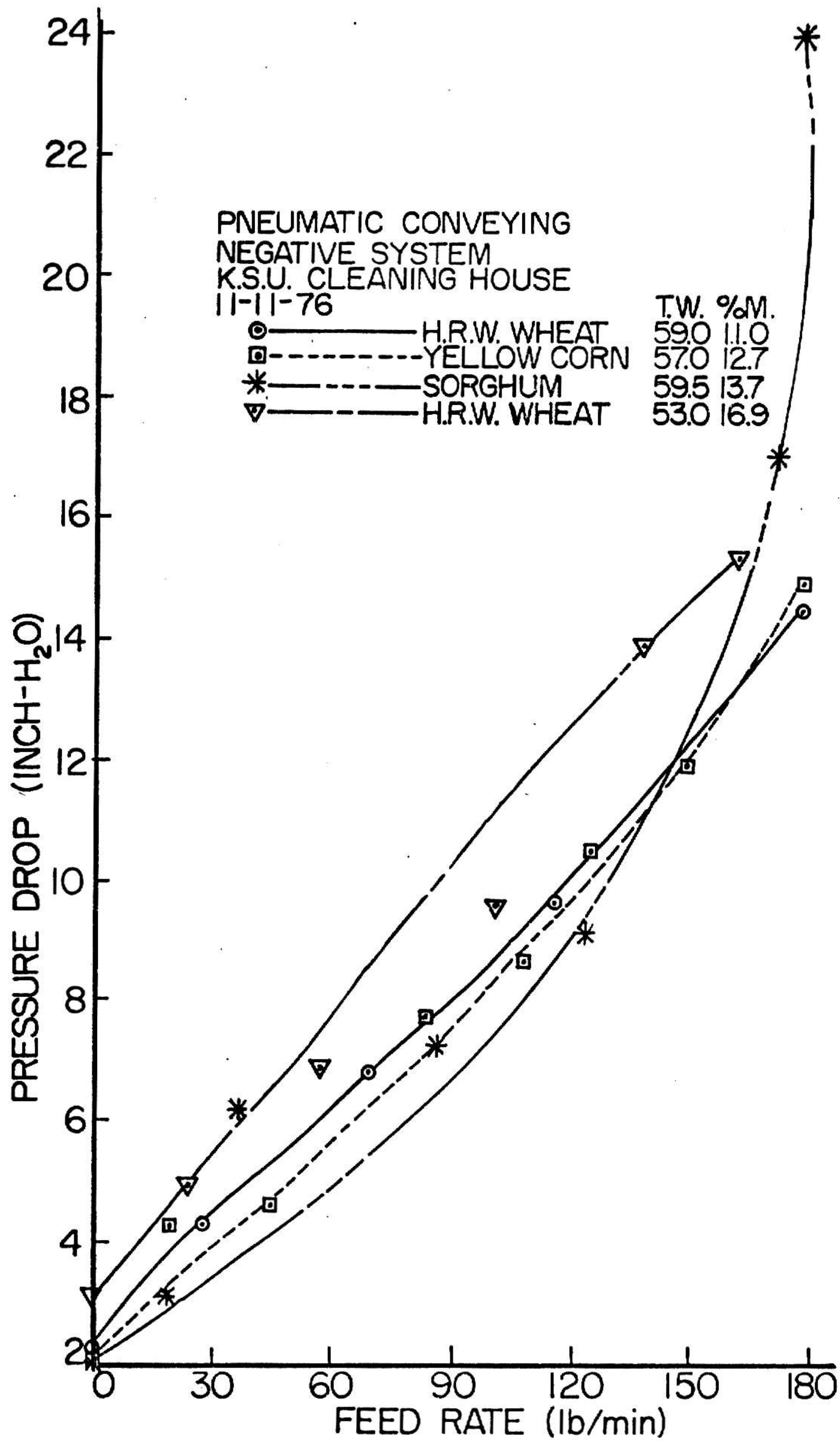

PNEUMATIC CONVEYING
NEGATIVE PRESSURE
K.S.U. CLEANING HOUSE
11-11-76
T.W. %M.
H.R.W. WHEAT 59.0 11.0
YELLOW CORN 57.0 12.7
SORGHUM 59.5 13.7
H.R.W. WHEAT 53.0 16.9
AIR VELOCITY (ft./min.)
5200
5000
4800
4600
4400
4200
4000
3800
3600
3400
3200
3000
0
30
60
90
120
150
195
FEED RATE (lb/min)

Graph 8

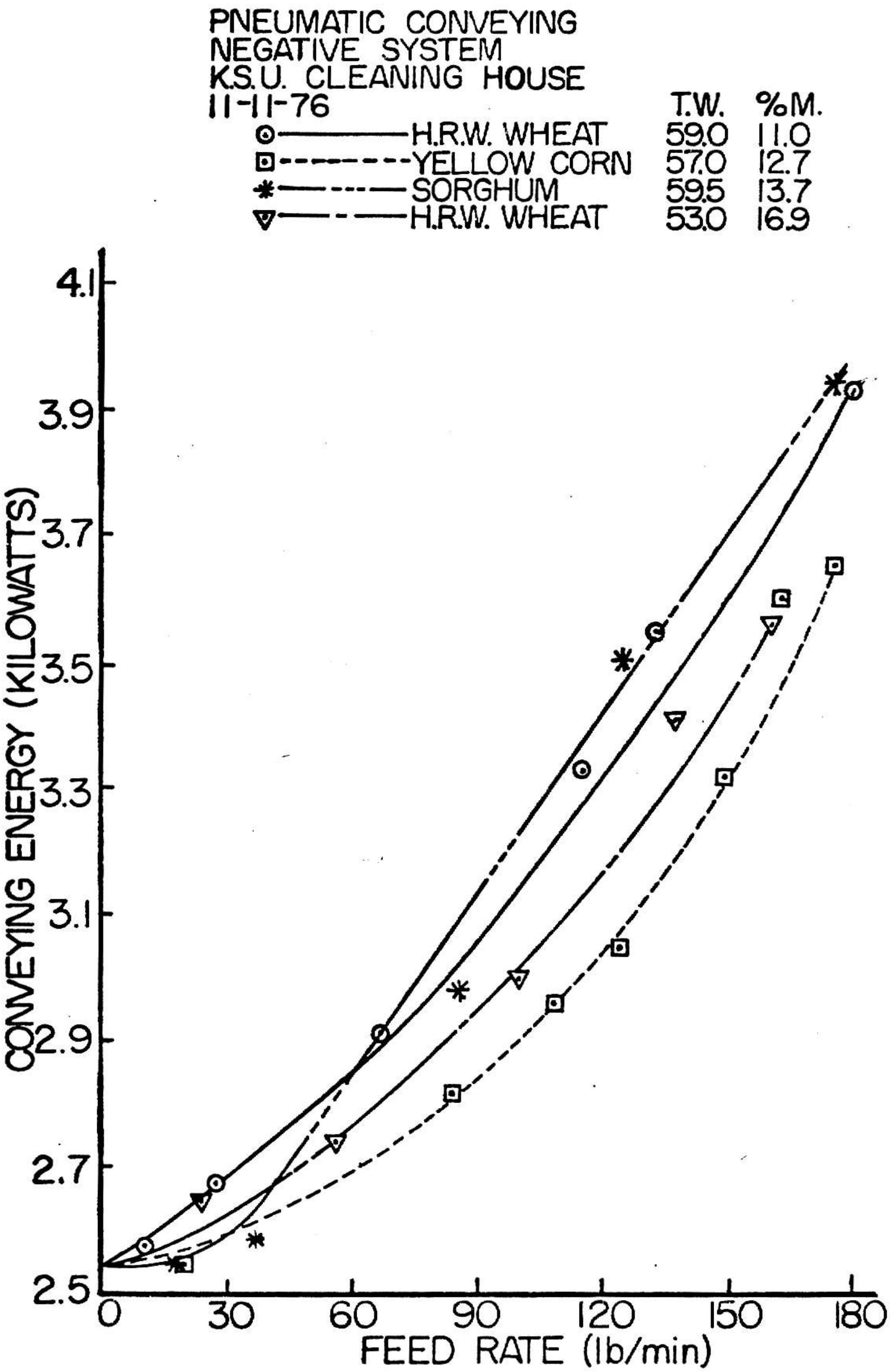


440
430
380
330
280
230
220
AIR VOLUME (cu.ft./min.)
0
30
60
90
120
150
180
FEED RATE (lb/min)
PNEUMATIC CONVEYING
NEGATIVE PRESSURE
K.S.U. CLEANING HOUSE
11-11-76
T.W. %M.
H.R.W. WHEAT 59.0 11.0
YELLOW CORN 57.0 12.7
SORGHUM 59.5 13.7
H.R.W. WHEAT 53.0 16.9

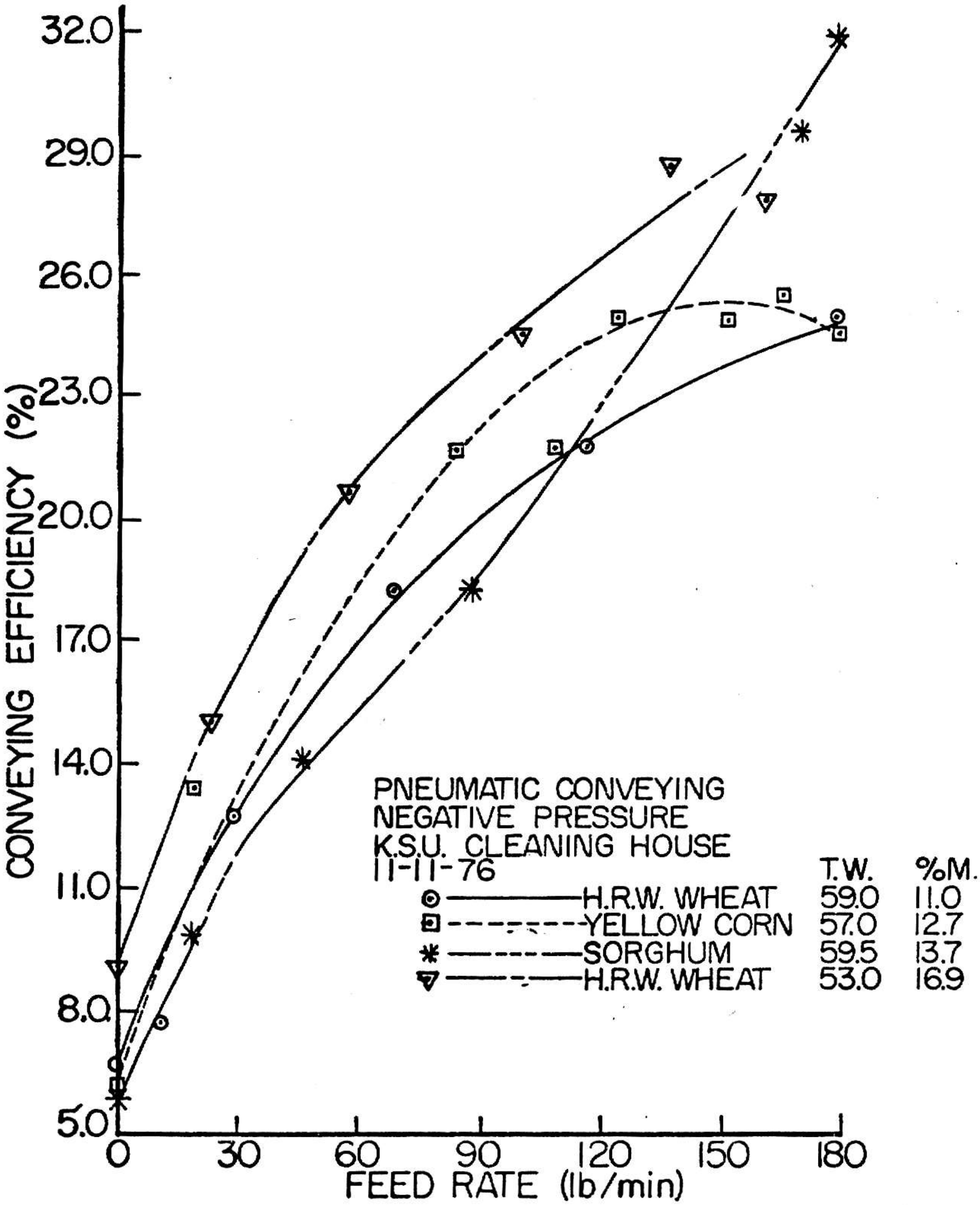
Graph 9


PNEUMATIC CONVEYING
NEGATIVE SYSTEM
K.S.U. CLEANING HOUSE
11-11-76
T.W. %M.
H.R.W. WHEAT 59.0 11.0
YELLOW CORN 57.0 12.7
SORGHUM 59.5 13.7
H.R.W. WHEAT 53.0 16.9
PRESSURE DROP (INCH-H2O)
FEED RATE (lb/min)
2
4
6
8
10
12
14
16
18
20
22
24
0
30
60
90
120
150
180

Graph 10

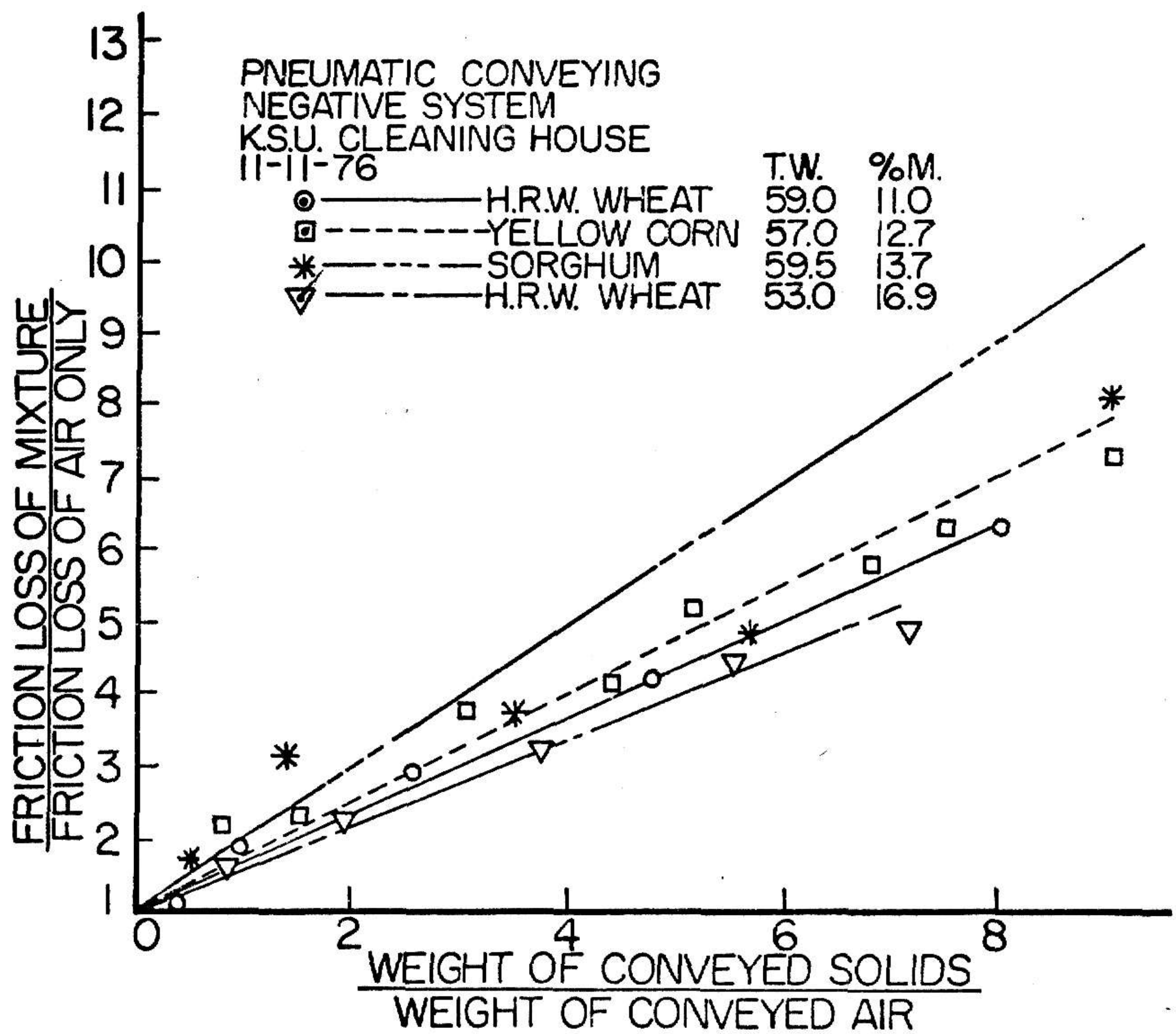

PNEUMATIC CONVEYING
NEGATIVE SYSTEM
K.S.U. CLEANING HOUSE
11-11-76
T.W. %M.
H.R.W. WHEAT 59.0 11.0
YELLOW CORN 57.0 12.7
SORGHUM 59.5 13.7
H.R.W. WHEAT 53.0 16.9
4.1
3.9
3.7
3.5
3.3
3.1
2.9
2.7
2.5
CONVEYING ENERGY (KILOWATTS)
0
30
60
90
120
150
180
FEED RATE (lb/min)

Graph 11



CONVEYING EFFICIENCY (%)
32.0
29.0
26.0
23.0
20.0
17.0
14.0
11.0
8.0
5.0
0
30
60
90
120
150
180
FEED RATE (lb/min)
PNEUMATIC CONVEYING
NEGATIVE PRESSURE
K.S.U. CLEANING HOUSE
11-11-76
T.W.
%M.
H.R.W. WHEAT 59.0 11.0
YELLOW CORN 57.0 12.7
SORGHUM 59.5 13.7
H.R.W. WHEAT 53.0 16.9

Graph 12



PNEUMATIC CONVEYING
NEGATIVE SYSTEM
K.S.U. CLEANING HOUSE
11-11-76
T.W. %M.
H.R.W. WHEAT 59.0 11.0
YELLOW CORN 57.0 12.7
SORGHUM 59.5 13.7
H.R.W. WHEAT 53.0 16.9
FRICTION LOSS OF MIXTURE / FRICTION LOSS OF AIR ONLY
WEIGHT OF CONVEYED SOLIDS / WEIGHT OF CONVEYED AIR

Graph 13

TABLE NO. 9

PNEUMATIC CONVEYING, POSITIVE-PRESSURE SYSTEM*
SEMI-CLEAN HARD RED WINTER WHEAT 60.1 TEST WEIGHT, 11.0 (%) MOISTURE CONTENT.
POSITIVE DISPLACEMENT (SCHWITZER) BLOWER 1570 RPM, 1.89" I.D. PIPE, TOTAL SYSTEM LENGTH 75'
KANSAS STATE UNIVERSITY, CLEANING HOUSE

FR. (lb/min)	VP_2 INCH H_2O	SP_1 INCH H_2O	SP_2 INCH H_2O	SP_3 INCH H_2O	D_0 lb/ft^3	D_2 lb/ft^3	D_3 lb/ft^3	V_2 ft/min	Q_2 ft^3/min	G_2 lb/min	AVG AMPS	ENERGY INPUT KILO-WATTS	ENERGY OUTPUT ft-lb/min	EFF. %	MOTOR HORSE POWER HP	PRESS LOSS INCH H_2O
00.0	1.8	15.3	12.4	1.4	0.0703	0.0711	0.0699	5519	107.3	7.6	2.99	1.97	6171	10.4	3.10	11.0
11.0	1.6	23.7	19.8	1.5	0.0703	0.0719	0.0695	5187	100.8	7.1	3.03	1.99	8844	14.7	3.15	18.3
20.5	1.3	30.5	26.3	1.9	0.0702	0.0728	0.0696	4657	90.5	6.4	3.08	2.03	10073	16.5	3.20	24.4
30.3	1.1	38.0	33.7	2.1	0.0701	0.0739	0.0695	4227	82.2	6.1	3.15	2.07	11411	18.3	3.27	31.6
39.3	0.9	49.8	45.3	2.4	0.0699	0.0757	0.0693	3726	72.4	5.3	3.27	2.14	13547	21.0	3.38	42.9
41.8	0.8	52.5	48.4	2.5	0.0699	0.0758	0.0693	3518	68.4	5.0	3.28	2.19	13452	20.8	3.39	45.9
44.3	0.7	57.0	52.5	2.5	0.0698	0.0762	0.0695	3467	67.4	4.9	3.35	2.19	14646	22.2	3.46	50.0
46.6	0.6	60.5	56.0	2.	0.0698	0.0765	0.0694	3118	60.6	4.4	3.40	2.22	13699	20.5	3.50	53.6

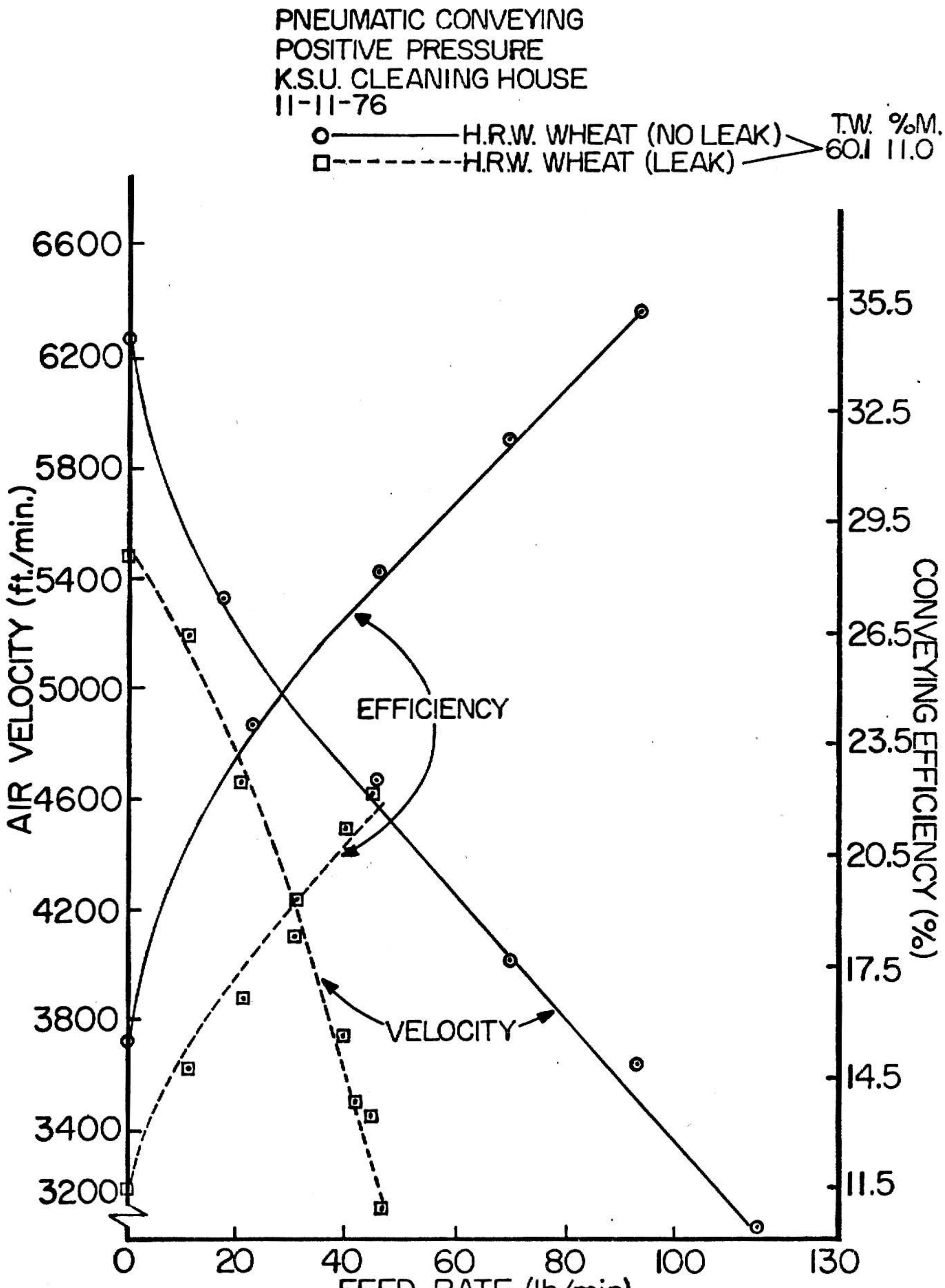
*BLOWER OUTPUT AIR LEAKS

TABLE NO. 10

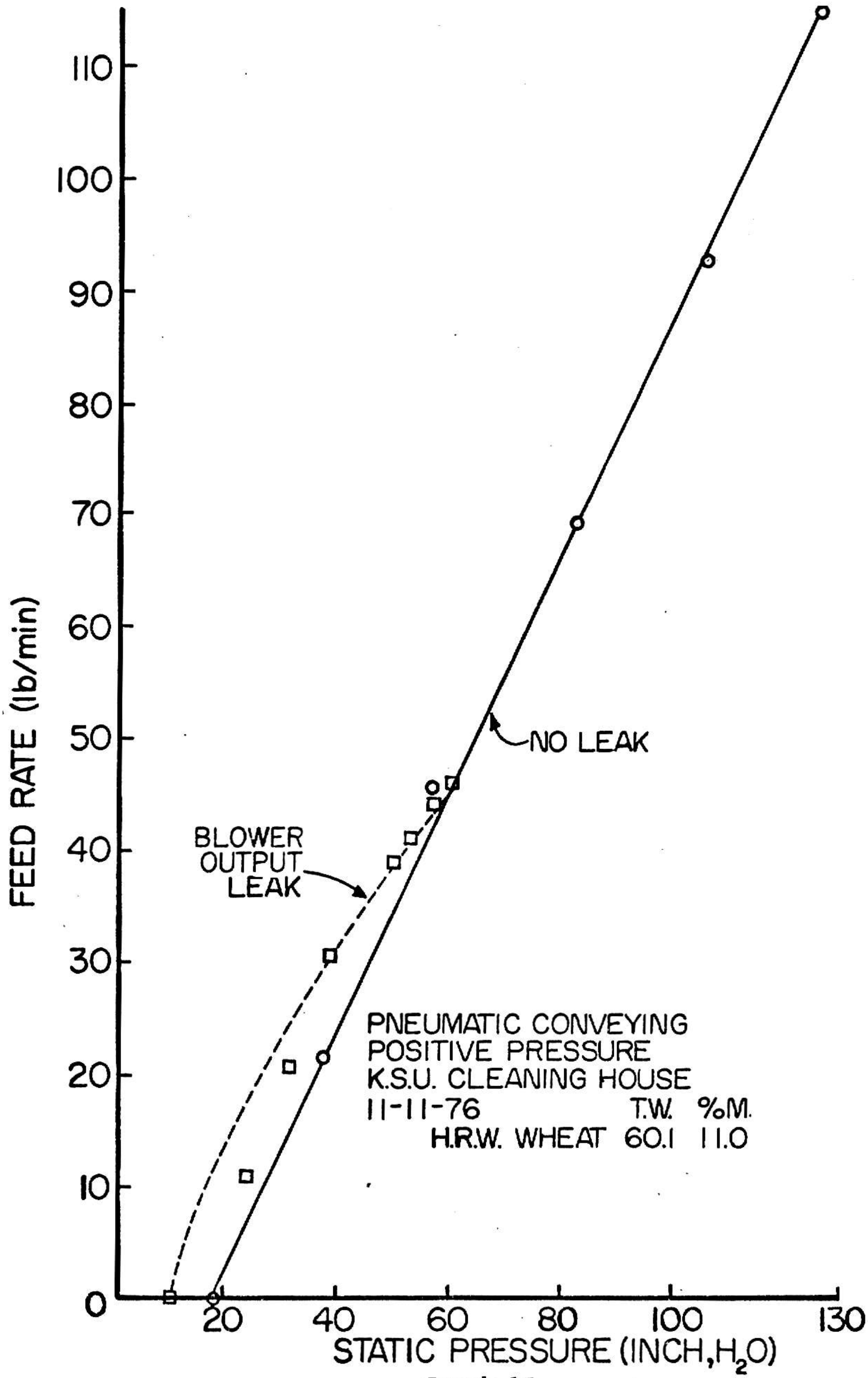
PNEUMATIC CONVEYING , POSITIVE-PRESSURE SYSTEM*
SEMI-CLEAN YELLOW DENT CORN, 55.8 TEST WEIGHT, 13.0% MOISTURE CONTENT.
POSITIVE DISPLACEMENT (SCHWITZER) BLOWER, 1570 RPM, 1.89" I.D. PIPE, SYSTEM LENGTH 75'
KANSAS STATE UNIVERSITY, CLEANING HOUSE

FR. (lb/min)	VP_2 INCH H_2O	SP_1 INCH H_2O	SP_2 INCH H_2O	SP_3 INCH H_2O	D_0 lb/ft^3	D_2 lb/ft^3	D_3 lb/ft	V_2 ft/min	Q_2 ft^3/min	G_2 lb/min	AVG AMPS	ENERGY INPUT KILO-- watts	ENERGY OUTPUT ft-lb/ min	EFF. %	MOTOR HORSE POWER HP	PRES LOSS INCH H_2O
00.0	1.78	15.2	12.5	1.4	0.0699	0.0717	0.0705	5473	106.4	7.6	2.93	1.89	6187	10.9	2.99	11.1
7.9	1.42	20.7	17.8	1.3	0.0699	0.0721	0.0704	4868	94.6	6.7	2.94	1.91	7543	13.1	3.02	16.3
16.0	1.18	26.8	22.9	1.6	0.0699	0.0721	0.0705	4432	86.2	6.1	3.06	1.98	8425	14.1	3.14	21.3
23.7	0.97	33.6	29.5	1.8	0.0699	0.0729	0.0705	4011	78.0	5.6	3.10	2.00	9530	15.8	3.17	27.7
32.4	0.87	39.4	35.5	2.3	0.0702	0.0736	0.0706	3771	73.3	5.3	3.15	2.05	10367	16.8	3.23	33.2
36.9	0.77	44.6	41.0	2.8	0.0702	0.0742	0.0707	3532	68.7	4.9	3.20	2.08	11051	17.7	3.29	38.2
40.1	0.70	48.0	44.0	2.9	0.0702	0.0745	0.0708	3361	65.4	4.7	3.23	2.10	11196	17.7	3.31	37.1
42.4	0.63	51.5	46.8	3.1	0.0702	0.0747	0.0709	3198	62.2	4.5	3.30	2.13	11118	17.4	3.42	49.2
45.2	0.53	56.3	52.7	3.5	0.0703	0.0754	0.0709	2907	56.5	4.1	3.33	2.17	11298	17.4	3.42	49.2
48.2	0.35	59.8	55.5	3.5	0.0708	0.0750	0.0708	2370	46.1	3.4	3.40	2.18	9014	13.8	3.44	52.0

*BLOWER OUTPUT AIR LEAKS


PNEUMATIC CONVEYING
POSITIVE PRESSURE
K.S.U. CLEANING HOUSE
11-11-76
H.R.W. WHEAT (NO LEAK)
H.R.W. WHEAT (LEAK)
T.W. %M.
60.1 11.0
AIR VELOCITY (ft./min.)
6600
6200
5800
5400
5000
4600
4200
3800
3400
3200
CONVEYING EFFICIENCY (%)
35.5
32.5
29.5
26.5
23.5
20.5
17.5
14.5
11.5
EFFICIENCY
VELOCITY
0
20
40
60
80
100
130
FEED RATE (lb/min)

Graph 14



FEED RATE (lb/min)
110
100
90
80
70
60
50
40
30
20
10
0
20
40
60
80
100
130
STATIC PRESSURE (INCH, H_2O)
NO LEAK
BLOWER
OUTPUT
LEAK
PNEUMATIC CONVEYING
POSITIVE PRESSURE
K.S.U. CLEANING HOUSE
11-11-76 T.W. %M.
H.R.W. WHEAT 60.1 11.0

Graph 15

TABLE NO. 11
PHYSICAL AND MECHANICAL PROPERTIES OF TESTED GRAINS
POSITIVE - PRESSURE SYSTEM
KANSAS STATE UNIVERSITY, EXPERIMENTAL LABORATORY

	HARD RED WINTER WHEAT (DRY)						HARD RED WINTER WHEAT (TEMPERED)						YELLOW DENT CORN		SORGHUM					
	Experiment 1		Experiment 2		Experiment 3		Experiment 1		Experiment 2		Experiment 3		Experiment 1		Experiment 1		Experiment 2		Experiment 3	
	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
TEST WEIGHT lb/bu	60.10	59.10	60.10	61.00	60.10	61.40	55.80	55.20	53.90	54.32	54.78	55.38	55.60	56.10	59.80	59.90	59.88	59.58	59.4	59.60
PEARLING VALUE %	73.50	76.00	73.50	73.50	73.30	73.40	73.40	74.20	74.90	72.20	71.90	70.04	---	---	---	---	----	---	---	---
GRAIN DENSITY gm/cc	1.43	1.35	1.43	1.42	1.40	1.41	1.38	1.30	1.38	1.39	1.37	1.38	1.29	1.31	1.37	1.38	1.38	1.39	1.38	1.39
GRAIN MOISTURE %	11.00	10.33	11.00	11.85	11.00	11.40	16.75	16.69	16.40	15.70	15.75	15.53	13.02	12.66	13.60	13.40	13.40	13.40	12.90	13.00
GRAIN TEMPERATURE F°	77.00	89.00	77.00	80.00	79.00	79.00	82.00	82.00	82.00	82.00	82.00	82.00	81.00	81.00	78.00	78.00	78.00	78.00	78.00	78.00
1000 KERNEL gms.	24.40	22.40	24.40	24.50	24.40	24.30	26.13	26.00	25.60	26.10	26.00	25.60	---	---	----	----	----	----	----	----
SIEVE ANALYSIS (gm) sieve 7 overs	44.75	40.50	44.75	46.50		43.75	555.16	56.00	54.66	56.50	57.00	58.00	---	---	74.00	86.66	74.00	84.33	84.9	88.5
sieve 9 overs	52.25	55.00	52.25	50.50		53.25	42.33	41.00	43.66	40.25	40.33	40.00	---	---	10.00	9.66	10.00	10.00	10.5	9.0
pan	3.00	4.50	3.00	3.00		3.00	1.16	2.00	1.83	1.50	2.00	1.50	---	---	15.33	2.33	15.33	5.00	5.2	2.7
ANGLE OF REPOSE (deg.)	22.20	21.30	22.20	21.10	22.20	21.50	25.70	24.40	27.50	26.40	---	---	25.80	23.00	32.30	27.00	32.00	28.60	27.3	26.90

TABLE 12

PHYSICAL AND MECHANICAL PROPERTIES OF TESTED GRAINS
NEGATIVE-PRESSURE SYSTEM
KANSAS STATE UNIVERSITY, EXPERIMENTAL LABORATORY

	H.R.W.WHEAT (DRY)		HARD RED WINTER WHEAT (TEMPERED)					
	Experiment 1		Experiment 1		Experiment 2		Experiment 3	
	Before	After	Before	After	Before	After	Before	After
TEST WEIGHT lb/bu	59.00	60.20	53.40	53.38	53.10	54.10	51.67	52.25
PEARLING VALUE %	71.50	72.80	74.30	75.20	73.20	73.60	75.00	74.70
GRAIN DENSITY gm./cc	1.38	1.43	1.37	1.38	1.39	1.39	1.37	1.36
GRAIN MOISTURE %	11.10	11.50	16.60	16.70	16.49	16.50	17.55	17.21
GRAIN TEMPERATURE	79.00	77.00	77.00	77.00	79.00	79.00	79.00	79.00
ANGLE OF REPOSE (deg.)	22.00	20.00	27.20	26.60	30.66	25.40	28.10	26.24
1000 KERNEL WT. gms.	24.00	23.80	26.20	25.30	26.66	26.30	26.02	25.25
SIEVE ANALYSIS (gms)								
sieve 7 overs		45.50	59.75	60.33	60.63	59.88	60.60	59.79
sieve 9 overs		51.75	39.13	38.71	38.04	38.71	38.40	39.83
pan		2.75	1.08	0.92	1.83	1.00	1.00	1.00

	YELLOW DENT CORN					
	Experiment 1		Experiment 2		Experiment 3	
	Before	After	Before	After	Before	After
TEST WEIGHT lb/bu	57.40	59.5	57.40	57.9	57.9	58.60
PEARLING VALUE %	----	----	----	----	----	----
GRAIN DENSITY gm./cc	1.35	1.36	1.36	1.35	1.33	1.34
GRAIN MOISTURE %	13.10	11.60	13.10	12.10	12.10	11.70
GRAIN TEMPERATURE	77.00	77.00	77.00	77.00	79.00	79.00
ANGLE OF REPOSE (deg.)	26.50	20.60	26.60	21.50	25.00	21.30
1000 KERNEL WT. gms.	---	---	---	---	---	---
SIEVE ANALYSIS (gms)						
sieve 7 overs	---	---	---	---	---	---
sieve 9 overs	---	---	---	---	---	---
pan	---	---	---	---	---	---

	SORGHUM					
	Experiment 1		Experiment 2		Experiment 3	
	Before	After	Before	After	Before	After
TEST WEIGHT lb/bu	59.11	59.8	59.8	59.85	59.75	59.58
PEARLING VALUE %	---	---	----	----	----	----
GRAIN DENSITY gm./cc	1.40	1.34	1.38	1.37	1.37	1.37
GRAIN MOISTURE %	14.30	13.64	13.64	13.80	13.6	14.00
GRAIN TEMPERATURE	78.00	79.00	79.00	79.00	79.00	74.00
ANGLE OF REPOSE (deg.)	28.50	24.90	28.00	25.30	28.50	27.30
1000 KERNEL WT. gms.	----	----	----	----	----	----
SIEVE ANALYSIS (gms)						
sieve 7 overs		89.33	89.30	85.00	85.00	86.30
sieve 9 overs		7.66	7.60	10.00	10.00	9.40
pan		2.88	2.80	5.00	4.50	4.50

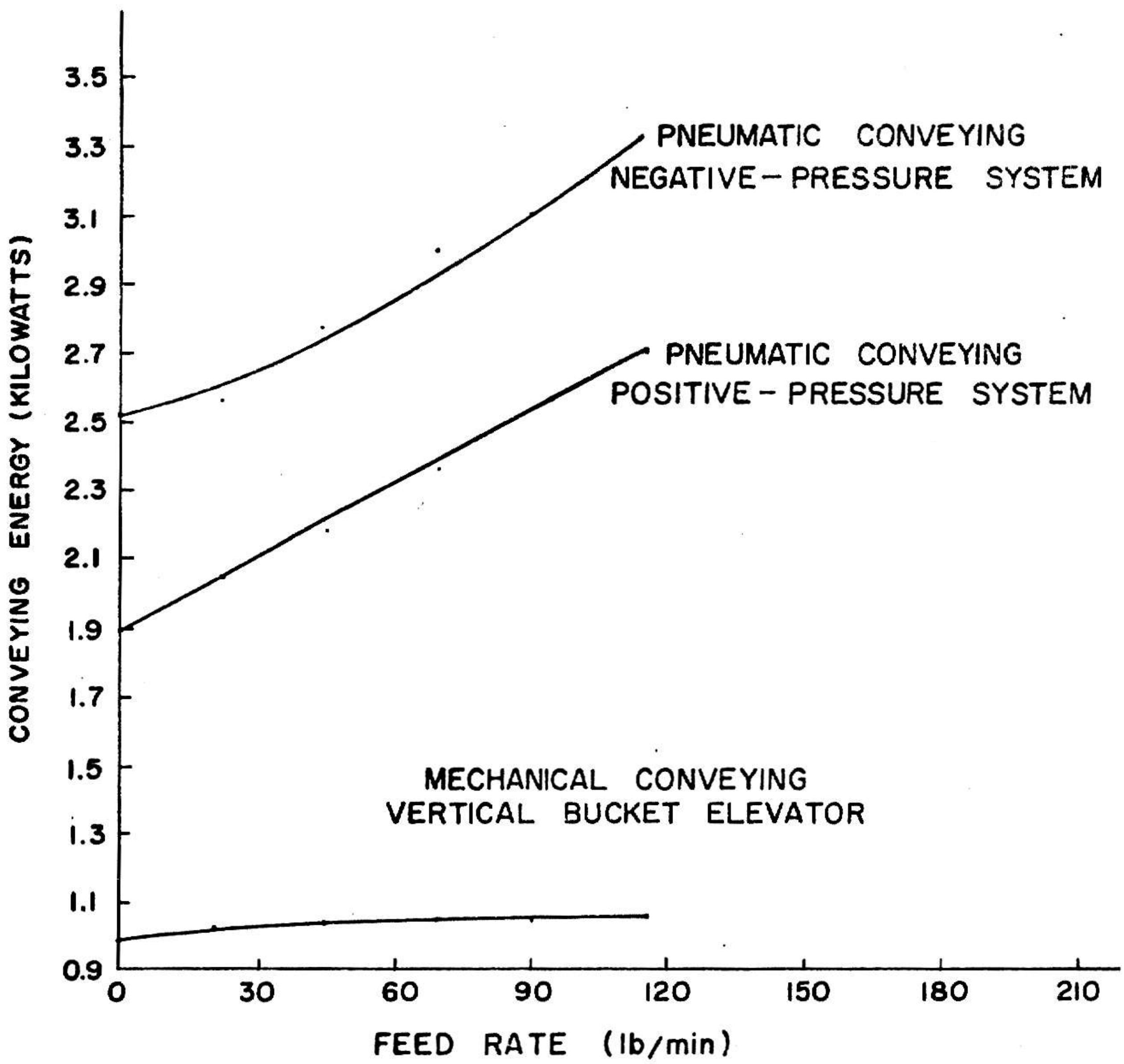
TABLE NO . 13

COMPARISON BETWEEN PNEUMATIC CONVEYING SYSTEMS AND MECHANICAL HANDLING SYSTEM.
HARD RED WINTER WHEAT, 60.1 TEST WEIGHT, 11.0% MOISTURE CONTENT.
KANSAS STATE UNIVERSITY

FEED RATE (lb/min)	POSITIVE-PRESSURE ENERGY INPUT KILOWATTS	NEGATIVE-PRESSURE ENERGY OUTPUT KILOWATTS	VERTICAL BUCKET ELVVATOR ENERGY INPUT KILOWATTS	POSITIVE VS BUCKET KILOWATTS	NEGATIVE VS BUCKET KILOWATTS
000.0	1.89	2.53	0.998	0.892	1.532
22.0	2.05	2.63	1.027	1.023	1.603
45.0	2.18	2.78	1.032	1.148	1.748
70.0	2.36	3.00	1.029	1.333	1.973
91.0	2.57	3.11	1.038	1.532	2.072
115.0	2.70	3.33	1.054	1.646	2.276

COMPARISON OF POWER CONSUMPTION
K.S.U. CLEANING HOUSE
1-30-77

	T.W.	%M.
H.R.W. WHEAT	60.10	11.0



Graph 16

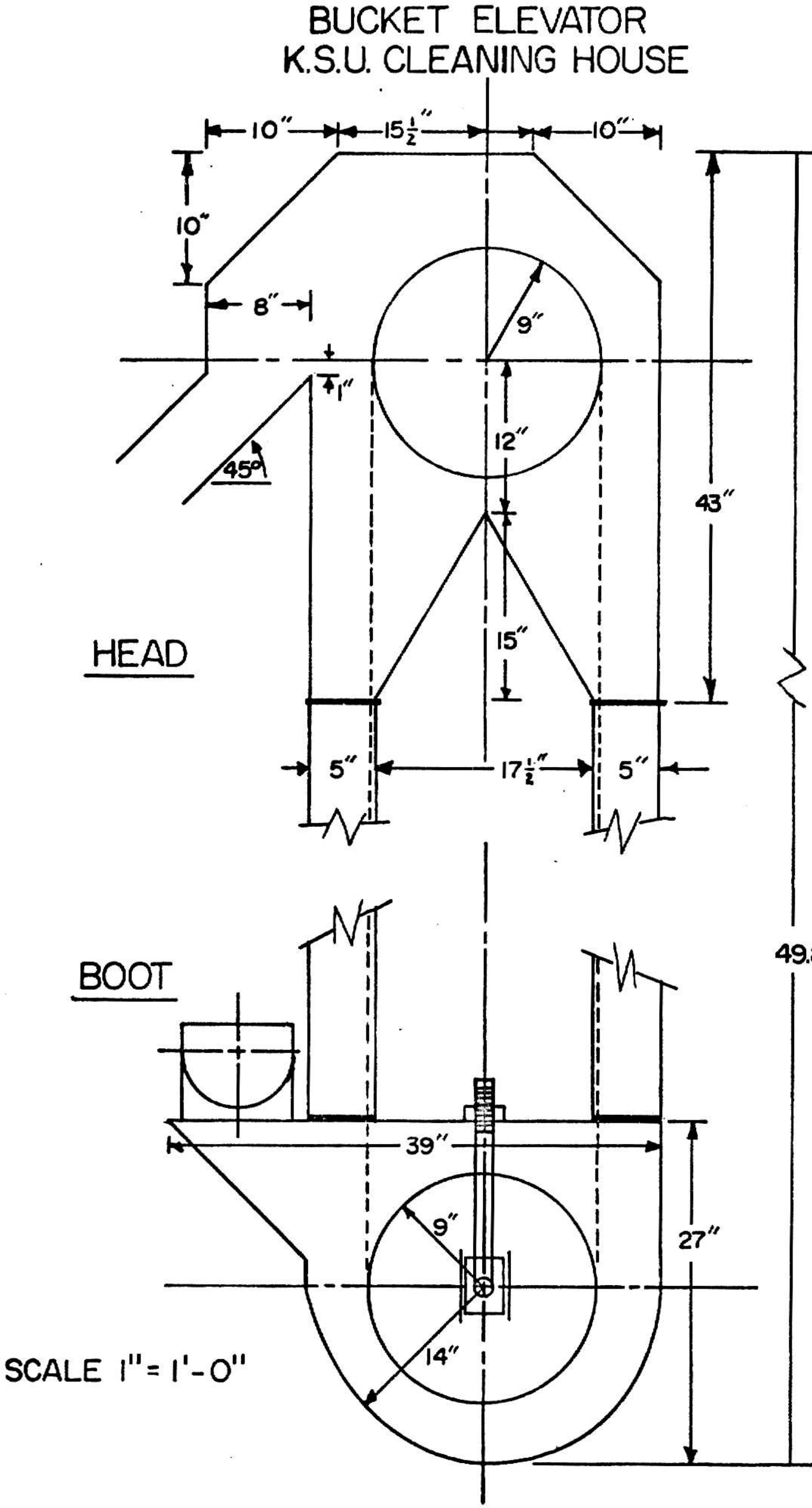

BUCKET ELEVATOR
K.S.U. CLEANING HOUSE
10"
15 1/2"
10"
10"
8"
9"
1"
12"
45°
43"
HEAD
15"
5"
17 1/2"
5"
BOOT
49.8'
39"
9"
27"
SCALE 1" = 1'-0"
14"

Fig. 27

TABLE NO. 14

Positive System Type of Grain	Actual Choking Limit of Air Conveying Velocity (fpm)	Practical and Safety Conveying Velocity (fpm)	Load (lb./min)	Max. Solid/Air Ratio	Max. SP_1	Min. Solid/Air Ratio	Min. SP_3 At Discharge Point
Dry HRWW	3057	3515	115	25.3:1	126"	3:1	11.4
Dry sorghum	3577	4113.5	129	23.5:1	117"	2.7:1	9.3
Temp. HRWW	3264	3753	110	22.1:1	136"	2.8:1	11.1
Dry yel. corn	3270	3760	74	15:1	84"	2:1	5.25
Negative System Type of Grain							SP_2
Dry HRWW	3543	4074	170	8.1:1	36"	.35:1	3.2
Tempered HRWW	3509	3967.8	159	7.2:1	38"	.8:1	4.36"
Corn	3089	3567	176	9.1:1	34"	.63:1	3.78"
Sorghum	2931	3370.6	177	9.5:1	48"	.57:1	3.32"

TABLE NO. 15

EFFECTS OF GRAIN SIZE

Variables (Dep - Indep)	Smallest (Milo)	HRWW Dry	HRWW Temper.	Largest Yellow Corn	System
VP2 - FR	-.010	-.014	-.013	-.017	+
VP2 - SP1	-.014	-.014	-.012	-.019	+
VP2 - SP2	-.015	-.015	-.013	-.020	+
VP2 - SP3	-.16	-.15	-.15	-.13	+
VP1 - FR	-.0054	-.0048	-.0052	-.0056	-
VP1 - SP1	-.040	-.041	-.039	-.060	-
VP1 - SP2	-.024	-.027	-.024	-.035	-
FR - AVG. AMPS	65.6	88.1	58.5	30.9	+
FR - AVG. AMPS	59.1	74.0	81.8	93.7	-
SP1 - FR	0.76	0.94	1.08	0.88	+
SP2 - FR	0.69	0.89	1.00	0.82	+
SP3 - FR	0.066	0.087	0.087	0.084	+
SP1 - FR	0.13	.12	.13	0.09	-
SP2 - FR	0.22	.18	.21	0.16	-

POSITIVE CONVEYING SYSTEM - K.S.U. CLEANING HOUSE

TABLE 16 - AIR FLOW CHARACTERISTICS ONLY

TYPE OF CONVEYING	HORIZONTAL	HORIZONTAL	VERTICAL	VERTICAL	VERTICAL
LOCATION	POINT - I (1)	POINT - II (1-2)	POINT - III (2-3)	POINT - IV (3-4)	POINT - V 4-5
DISTANCE FROM POINT I.	0.0"	24"	388"	164"	100"
CONVEYING PIPE I.D.	2.87"	1.888"	1.888"	1.888"	1.888"
MATERIAL CONVEYED	AIR	AIR	AIR	AIR	AIR
SIZE OF MEAS. HOLE	1/8	1/8"	1/8"	1/8"	1/8"
STATIC PRESSURE (INCH-H_2O)	18.5	15.0	8.4	6.13	1.38
VELOCITY PRESSURE (INCH-H_2O)	0.45	2.15	2.38	2.4	2.35
TOTAL GAUGE PRESSURE (INCH-H_2O)	18.68	17.15	10.78	8.53	3.73
HEAD LOSS BETWEEN POINTS (INCH-H_2O)	0	(1-2) 1.575	(2-3) 5.98	(3-4) 1.99	(4-5) 4.55
REYNOLDS NUMBER	28.32 $\times 10^5$	30.33 $\times 10^5$	32.49787 $\times 10^5$	32.49208 $\times 10^5$	31.413 $\times 10^5$
TYPE OF FLOW	TURB.	TURB.	TURB.	TURB.	TURB.

NEGATIVE CONVEYING SYSTEM — K.S.U. CLEANING HOUSE

TABLE 17 — AIR FLOW CHARACTERISTICS ONLY

TYPE OF CONVEYING	LOCATION	DISTANCE FROM POINT	CONVEYING PIPE I.D.	MATERIAL CONVEYED	SIZE OF MEAS. HOLE	STATIC PRESS INCH H_2O	VELOCITY PRESS. INCH H_2O	TOTAL GAGE PRESS. INCH H_2O	HEAD LOSS (ft.)	REYNOLD'S NO.	TYPE OF FLOW
VERTICAL	POINT I (1-2)	109" FROM INLET	3.907"	AIR	1/8"	1.51	-2.383	-0.873	55.311	155033	TURBULENT
VERTICAL	POINT II (2-3)	373" FROM INLET	3.907"	AIR	1/8"	2.0	-6.0	-4.0	213.229	186061	"
HORIZONTAL	POINT III (3-4)	FROM PNEU. LIFT 264" TO AIR PUMP	5.8299	AIR	1/8"	0.5	-9.5	-9.0	268.56	447082	"

RESULTS AND DISCUSSIONS

Data of these studies were analyzed statistically to determine the most important factors (the dependable ones) which are directly related to conveying, and the interaction among factors which significantly affect conveying the three tested grains.

Regarding the positive-pressure system, grain treatments of milo, and dry and tempered HRWW are leading others in all measurements recorded and data calculated in this study. For instance, the maximum conveying capacity of milo, dry and tempered HRWW and corn were 123.3, 115.8, 110.3 and 84.5 lb./min. respectively. With leaks direct after blower air output, these figures were reduced to 48.2 lb./min. for corn and 46.6 lb./min. for dry HRWW only. There were four variables--SP_3, average amperes used, electrical energy input kilowatts and motor horsepower--which exhibit significant heterogeneity of variance from experiment to another.

Table 15 shows that each unit increase in feed rate (FR) lb./min. will increase SP_1 by about 0.94, 0.88 to 0.89, 1.08 and 0.76 of a unit with dry and tempered HRWW, corn and milo respectively. The increase in SP_2 per unit increase in FR is less than the change in SP_1 when the same grains are conveyed. But the effect of increase in FR to SP_3 is far less than on SP_1 and SP_2, because it measured at the grain discharge point. This reduction is in effect more than ten times. The VP_2 value is reduced by an increase in FR, depending on the size and shape of the grain conveyed. The smaller the grain, the less is the reduction.

While in negative-pressure system, each unit increase in FR increased the SP_1 by 0.12-0.13 of a unit with dry, tempered HRWW and milo, but only about 0.09 with corn. The SP_2 is increased at least 50 percent more per unit increase in feed rate than is SP_1. The change in SP_2 per unit addition in FR is substantially greater with milo and tempered HRWW than with dry HRWW or corn.

In comparing the measurements of the two systems illustrated in Table 15, it showed the effect on FR of a unit increase in average amperes used is greater with the positive-pressure system than with the negative-pressure system with dry HRWW, but the reverse is true with tempered HRWW. Apparently, the moisture has a considerable effect.

To provide information on the level of the test variables at which the greater change in conveying occurred by the effect of grain size and shape, Table 15 presents the reductions in VP_2 per unit increase in FR is greater for the larger and rougher grain, such as corn, than for the smaller and smoother grain, such as milo, when the positive system is used.

The same holds for SP_1 and SP_2 as the independent variables, but the reverse holds true for SP_3 in relation to VP_2. The same is true when the negative system is used. With corn, the effect on FR of a unit increase in average amperes used is decidedly greater with the negative-pressure system, and with milo, the reverse is true. The difference is not great with corn. In other words, with the negative-pressure system, the increase in FR per unit increase in average amperes is much greater than with milo.

With the positive system, the increase in SP_1, SP_2 or SP_3 per unit increase in feed rate is always greater for corn than for milo. It is the reverse with the suction system. The effect of FR per unit increase in average amperes is lessened by tempering HRWW if positive system is used. The reverse holds true, but much less if the suction system is used. Tempered HRWW tends to increase the effects of SP_1, SP_2 per unit increase in FR with either conveying system. The change in SP_3 per unit increase in FR is unaffected by tempering.

In operating with pneumatic conveying systems and under the conditions sampled by this study (Tables 11, 12), the test weight of dry HRWW after conveying is larger under a positive system than that of a negative system, but the reverse is true with corn. The test weight of milo is unaffected by either air conveying system. The percent of moisture after conveying in tempered HRWW and milo is higher under the negative system than that under the positive system, but the moisture content of dry HRWW is unaffected by both systems. The percent of moisture of corn is increased after conveying under the suction system. For the negative pressure system, there are no differences among the grain treatments; but under the positive pressure system, tempered HRWW has a temperature a bit higher than milo or dry HRWW. Tempered HRWW definitely increases the true mean angle of repose especially under the suction system. Milo has the largest true angle of repose of all the grains studied under a positive system, but only tied for the largest such angle with the negative pressure. Corn is intermediate between dry and tempered HRWW with regard to the angle of repose. The amounts of overs with sieves 7 and 9 are as follows: HRWW is less than tempered HRWW and milo mostly regardless of system investigated. However, these grain differences are somewhat accentuated under the negative system. The overs of sieve No. 9 are far less for milo than with dry and tempered HRWW. The pan contents are affected by the system with milo but not with either dry or tempered HRWW. When milo is conveyed, the overs of sieves 7 and 9 have larger percent under a negative system. The pearling value of dry HRWW is lower under the negative system, but tempering leads to the reverse effect.

An attempt was made to predict the difference between the mechanical and pneumatic conveying of whole grains from the standpoint of kilowatts consumed on such specific conveying. The data illustrated in Table 13 contains a comparison of vertical leg bucket levator (Fig. 27) and a pneumatic conveying positive-pressure system (Fig. 4) and negative-pressure system (Fig. 19) to convey dry HRWW. Six loads (lb./min.) were studied with paired comparison of the mechanical and both positive and negative pressure systems. It is concluded that the pneumatic system, positive-pressure and negative-pressure, definitely takes higher average kilowatts than the bucket elevator (Table 13 and Graph 16).

Graph 16 clearly suggests that the difference in kilowatts used by positive-pressure system and the vertical bucket elevator increased in proportion to an increase in load input to the system. The data used along with the appropriate statistical calculations concludes that the difference in kilowatts used increase in proportion to the increase in difference for each unit increase in load, on the average.

Tables 9 and 10 indicate how much of an air leakage in a positive-pressure system do affect the performance of the conveying system. It has been found that air leakage, particularly in a positive-pressure system, reduces the measurements under study. Leakage has a drastic effect on the increase in

SP_3 per unit in FR if dry hard HRWW or corn. There is about a 2/3 reduction in corn, with sometimes a bit less than 50 percent. The effect of leakage in a positive system on the relationship between VP_2 and SP_1 is very much the same when FR is the independent variable. Leakage greatly increases the change in flow rate per unit increase in average amperes, especially with corn. The increases were observed to be 15 percent and 233 percent respectively for dry HRWW and corn.

We worked on the ratio of lb. of solids to lb. of air, based on the logical sense of sequences in designing a system. This relationship is commonly expressed in terms of volume of air associated with unit of weight of solids. This ratio of both systems increases as load input increases, but is not a determinant. Because pressure developed by both systems is a major factor, the reverse is true. There is a border line between the two ratios of the systems for distinguishment. Regarding the positive pr ssure (high pressure), the maximum and minimum of solids to air ratio with increasing loads and pressures are achieved as shown in Table 14.

Therefore, the ratio between the two phases - solids vs. air - vary over wide limits, because of the different types of systems designed, and shape, particle size and density of conveyed grains. The degree of loading may be used as a distinguishing characteristic in discussing a variety of systems where air and solid particles are in current movement. Corn has the lowest solid-to-air ratio both for maximum and minimum load conveyed. Dry HRWW, sorghum and tempered HRWW have the greatest solids-to-air ratios respectively, for both minimum and maximum loads conveyed by the same positive system. Thus, particle size, load carried and pressures developed by blower are all determinants for better solids-to-air ratios; in fact, they are proportional with them. The smaller the particle size, the higher the solids-to-air ratio, and the reverse is true.

With the negative system (Table 14) the solids-to-air ratio of sorghum and corn are higher than dry and tempered HRWW, although the same load is carried by the same negative system. Load and particle size play the major role in determining the solids-to-air ratio, but they are not actually directly proportional.

In comparing the two systems regarding solids-to-air ratio, the positive pressure system has larger solids-to-air ratio for both maximum and minimum loads. In fact, this ratio never was below 2. The negative system has lower solid-to-air ratio for both maximum and minimum loads.

There is no standard ratio of solid-to-air on the inverse for differentiation between these two systems, because of the variety of system designs and types of material conveyed. The general rule is that the high-pressure conveys more material with less air.

An air-conveying velocity of the positive-pressure system, no load conveyed, is 6000 FPM. With an average load of whole grains (lb./min.), Tables 1-4 dry sorghum choked earlier than corn, tempered and dry HRWW, respectively. Although density of whole kernels is considered important, particle size, shape of kernel, and conveyed load of grain are the determinants of the actual choking limit of air-conveying velocities. All conveyed grains conveyed at a common feed rate except corn, which choked at 50 percent less than did the other grains. These real choking velocities do not allow any increase of load conveyed; with even minimum addition of load, choking definitely occurs.

Practical and safety margins for air-conveying velocities of whole grain are shown in Table 14. These are economical conveying velocities from the standpoint of saving in power consumption and personnel requirements.

The negative-pressure system produces a suction of an air velocity 5,000 FPM at no load. The system chokes with a feed rate of loads shown in Tables 5-8. Dry and tempered HRWW, corn and sorghum choked respectively.

The difference between the actual choking limit and the safe and practical air-conveying velocities for both systems are due to the type of conveying system, load capacity, shape, and particle size of grains. It is clear from Tables 5-8 that sorghum chokes at a higher air velocity with positive systems than at negative systems. The same is true with corn, but the reverse is true with dry and tempered HRWW. The reason for this difference is not known.

It should be indicated that it is not possible to compare power consumption of these positive and negative pressure systems. Conveying pipelines' diameters and system lengths are different.

Six energy consumptions were paired by feed rates to find the significance of the measured input kilowatts differences between the two systems. The differences were taken in order of negative-positive system, Table 13. It is concluded that the negative system definitely uses more energy than the positive system. The positive system vs. the bucket elevator (mechanical handling) proved that the positive-pressure consumes more energy than the bucket elevator. The higher energy consumption of the negative-pressure system, as compared to bucket elevator, is even more certain and striking than when positive-pressure is used.

The air pressure at the pickup point is always greater than the discharge point for positive system. The air is compressed due to the high pressure developed into the conveying pipeline, particularly when pipe diameter gets smaller as in the positive pressure system. The ambient air temperature and density are usually 90°F and 0.0695 lb./ft.^{3}, respectively. The air density is reduced again near the discharge point due to the reduction in air pressure in the pipe as it approaches its discharge point.

The sealed receiving separators in the negative system make the pressure and temperature higher than any point in the pipeline. Therefore, the conveyance air density increases at its discharge point compared to that at its input point. The increase in air temperature and density in the positive system is always more than the negative system.

CONCLUSION

In regard to the positive pressure system, Graph 1 shows the air velocity at various loads, just before or at the choking point, with the same positive displacement blower for dry, tempered hard red winter wheat, sorghum and corn. The minimum conveying velocity of the above grains was approximately 3400 ft./min. at a maximum conveying capacity (lb./min.) (Tables 1-4). Practical and safe operating velocities would be at least 15 percent greater than the actual minimum conveying velocities (Table 14). Corn conveying capacity was low, due to the constant blower speed, larger particle size, and unit weight of kernel. When corn is conveyed pneumatically, additional air conveying velocity and power is needed for efficient conveying.

The total pressure drop (inch H_2O) for the actual conveying of the grains tested is proportionally increased as feed rate (lb./min.) is increased (Graph 4). This proportionality concludes that the increase in weight of conveyed grain adds more resistance and causes high conveying pressure drop.

Pressure loss through the feeding mechanism device and stock acceleration requirement are sharply increased with load (Graph 3), but decrease little with heavy loads.

Although corn conveyed 30 percent less than other grains (Graph 5), it consumed the highest power (kilowatts). Tempered wheat has a better conveying efficiency than dry wheat. When moisture is added to the kernels, swelling decreases the kernel's density. This yields more surface area per unit weight.

Conveying velocities for maximum conveying loads by the negative pressure system for sorghum, corn, tempered and dry hard red winter wheat (Tables 5-8) are lower than positive pressure system (Graph 8). This negative system can convey large kernels (corn) in amounts equal to that for the smaller wheat and sorghum grains. The two systems are different in principle and layout. The larger pipe diameter and the great air volume might be the reason.

Maximum solids to air ratio for the above grains at the choke-up points are only 10:1 compared to 25:1 for the positive system (Graphs 7 and 13). Sorghum has the highest conveying pressure drop of the grains conveyed in this study (Graph 10). Dry and tempered hard red winter wheat and corn have the same pressure drop, although the load carried by the latter is less than the former.

Negative pressure system consumed more power (kilowatts) for conveying sorghum and dry wheat than corn and tempered wheat at equal loads (Graph 11).

OBSERVATIONS DURING RESEARCH

When the load (lb./min.) carried by the positive-pressure system increases above 60 lb./min., the blower begins to pulsate, and this greatly increases as load increases, which has a great effect on measurements taken because liquids at manometers bounce continuously upward and downward. This presents a problem in annotating accurate reading, particularly with the inclined tube.

At maximum capacity of conveying, the blower develops a 10 PSIG. The colored distilled water will splash from the U-tube if it is not large enough. This eliminates taking readings of static pressures at higher loads. This caused a difficult problem at the choke-up point, because the water blew from the U-tube. Therefore, I used carbon tetrachloride (density 1.583 gm/mil at 25°C). (Mercury could not be used because of the sanitation reason in the cleaning house.)

The same problem existed for static pressure at point II. Because of the high pressure produced by the blower, the grain conveyed tends to slide from the measuring hole made on the conveying pipe into the U-tube. This grain plugs the U-tube and causes false readings of the static pressure. A screen placed over the hold helps a great deal to stop the grain.

Every time an experiment is run, it is preferable to check all the liquid in the manometers for foreign materials.

Usually the last reading recorded in each table indicates the system's maximum conveying capacity before choking occurs. It is very difficult to take measurements at the moment of choking, as velocity and static pressures tend to bounce around erratically. Also, the electric energy decreases, due to the plugging of the grain-choked conveying pipes. As mentioned before, velocity pressure is difficult to measure, especially when using a pitot tube. Centering the front head of the pitot tube into the center line of the conveying pipe is difficult, particularly when a great load is being conveyed by the system. The moving grain hits the pitot tube head and moves it off the pipe's center line. Accurate measurement of velocity pressure could be achieved if the velocity pressure were measured at different points from the center line of the conveying pipe cross section. The average measured pressures is the velocity pressure.

A problem encountered in the conveying of corn is that the pricarp of the corn suffers a high percentage of breakage, blocking the inner tube of the pitot tube and causing wrong measurements of the velocity pressure. Therefore, it is essential to examine the pitot tube and use air to knock any dust or small piece inserted into the inner pipe of the pitot tube. The non-uniform flow rate causes a number of early choke-ups in a positive conveying system. The choke-ups happen when air pressure develops into the feeding spout, as a result of the air released from the air lock wheels while it is revolving. Therefore, due to the air pressure into the pipeline, the stock holds the flow of grain back, and when the air pressure is released, the grain flow starts to fall at a rate faster than the air lock can take. Thus, the amount of grain exceeds its limit compared to the air velocity developed by the blower, and the system chokes up.

SUGGESTIONS FOR FUTURE WORK

During the experiments, I have become aware of several points or outside factors that may have affected the results of the experiments. The equipment needed was being used for other purposes in the Department of Grain Science, which caused the introduction of uncontrolled variables in the settings to the system. For example, both positive and negative systems are used continuously for conveying tempered wheat to the flour mill and dirty wheat to the dry cleaning machines, respectively. I feel my research suggests several directions for enhancing future investigations in this area. It would be much easier to conduct such studies if it were possible to build a new pneumatic conveying system, based on the most recent knowledge published about pneumatic conveying systems, specifically for experimental uses, to include:

- provision for different blower speeds
- provision for varying diameters and lengths of pipes
- interchangeable components to accommodate different kinds of grain
- variable number of bends in the pipes
- totally sealed sophisticated manometers

An additional suggestion would be that the physical and mechanical tests on the conveyed grains should be done directly after the experiment is completed. This would help a great deal in determining the effects of air on grain. Time delays negatively influence the accuracy of the results.

There is a need for larger bins, to avoid the system's running out of grain before reaching the maximum capacity of the system. A researcher needs a few minutes from time of changing input load to recording the results.

It should not be necessary to use the conveyed grain more than twice. Further conveying tends to break the kernels and the system is not then conveying totally "whole grains."

It would also maximize the efficiency of experiments if all experiments could be checked immediately, and compared with other experiments of the same run, to find out differences which might be due to unseen leaks or malfunctions.

A further suggestion would be for research of this kind to be done either as a joint project of several graduate students, or with undergraduate students working under a graduate student in charge of the project. This work involves a system extending from first floor to the fifth floor. It is, therefore, obviously impossible to simultaneously check the pick-up point, flow rate, manometers in different points of the system, and other aspects of the work that should be monitored for maximum reliability of the results.

GLOSSARY OF TERMS

FR = (Feed) Flow Rate (lb.min.)

SP_1 = Static Pressure Inch H_2O at Point I

SP_2 = Static Pressure Inch H_2O at Point II

SP_3 = Static Pressure Inch H_2O at Point III

VP_2 = Velocity Pressure Inch H_2O at Point II

Q = Volume of Air Conveying (cu.ft./min)

G = Mass of Air Conveying (lb./min.)

V_2 = Velocity of Air Conveying (ft./min.) at Point II

D_0 = Air Density at Room (lb./ft.^{3})

D_1 = Air Density (lb./ft.^{3}) at Point I

D_2 = Air Density (lb./ft.^{3}) at Point II

D_3 = Air Density (lb./ft.^{3}) at Point III

HRWW = Hard Red Winter Wheat

P = Ambient Atmospheric Pressure inch H_G

P_0 = Absolute Pressure (lb./ft.^{2})

P_1 = Absolute Pressure (lb./ft.^{2}) at Point I

P_2 = Absolute Pressure (lb./ft.^{2}) at Point II

P_3 = Absolute Pressure (lb./ft.^{2}) at Point III

T_0 = Temperature at (Room) System Inlet

T_1 = Absolute Temperature °R = (F + 459.97) at Point I

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PNEUMATIC CONVEYING TESTS WITH DIFFERENT DRY GRAINS

by

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AN ABSTRACT OF A MASTER'S THESIS

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MASTER OF SCIENCE

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ABSTRACT

Pneumatic conveying of whole grain is still considered an "art," not fully developed. Although much research in air conveying has been carried out by the milling industry since 1920, no universal system of air conveying has been developed by the milling engineers. The difficulties are due to the variety of physical characteristics of grains, which may be correlated to equally variable arrangements of conveying equipment.

Investigations of air conveying of whole grains are very limited and conservative. The objective of this investigation was to provide information for conveying whole grains through pneumatic systems. Both positive and negative pressure systems equipment at Kansas State University were used.

The following grains were conveyed pneumatically: semi-clean hard red winter wheat at 11.0 percent moisture; clean tempered hard red winter wheat at 16.6 percent moisture; semi-clean sorghum at 12.5 percent moisture, and clean yellow dent corn at 13.0 percent moisture.

Conveying measurements and calculated data were analyzed by the analysis method. Data indicated that air conveying velocity, air volume flow rate, air weight flow rate, electrical energy input, output and conveying efficiency varied from one

grain to another in both systems.

It was found that there is little difference in power consumption between the two air conveying systems. However, significant differences were observed between these two systems and the mechanical conveying system.

Many experts in grain handling believe that air conveying is not competitive with mechanical conveying in either original or operating costs. The high initial cost of pneumatic conveying equipment is balanced by its lower building costs. Power costs of pneumatic conveying is relatively high, but it has a low maintenance cost. However, pneumatic conveying systems have several advantages over mechanical systems regarding safety standards, sanitary requirements, ease of operation, saving in space and reduction of fire hazards.