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ASSESSMENT OF THE FUNCTIONAL PERFORMANCE OF PNEUMATIC GRAIN CONVEYORS

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ABSTRACT The functional performance of pneumatic grain conveyors was assessed, based on tests performed on five conveyors by the Praire Agricultural Machinery Institute. Pneumatic conveyors using positive displacement and centrifugal blowers were evaluated. Positive displacement blower equipped conveyors conveyed more grain but required more power, resulting in similar efficiencies to centrifugal blower equipped conveyors. Pipe diameter, pipe length, the type of pipe used and the air tightness of pipe joints, all had an effect on conveying rate. Grain damage due to conveying was minimal. The dust free environment and freedom of operator exposure to moving parts were positive safety aspects of pneumatic conveyor operation. Ear protection should be worn due to high noise levels. Comparisons to grain auger performance are made where applicable.

INTRODUCTION

Although pneumatic conveyors have been used commercially for many years to convey different types of materials, the use of air for on-farm conveying of grain has only become popular in the last six years. There are presently at least five different manufacturers marketing farm size pneumatic grain conveyors in western Canada.

Since 1976, the Prairie Agricultural Machinery Institute has evaluated five different pneumatic grain conveyors. Based on these evaluations, this paper discusses various operational aspects including the effect of various adjustments and component characteristics on rate of work, power requirements, efficiency, quality of work and safety. Typical performance curves are presented for the two types of blowers used on the various machines. Results are compared to pneumatic conveying theory and grain flow patterns are investigated. Comparisons, where applicable are made to grain augers.

GENERAL DESCRIPTION OF PNEUMATIC CONVEYORS

All pneumatic conveyors evaluated were mounted on two wheel trailers and were power take-off driven (FIGURE 1). A blower provided both suction and discharge air to convey grain without passing it through the blower. Grain entered the air stream through the intake nozzle. At the intake nozzle, there was an adjustable secondary air port which controlled the amount of air required to provide for a continuous flow of grain. Grain and air were separated at the separator cyc lone. The air was screened or filtered before entering the blower. The grain dropped into the rotary air lock where it was raetered into the discharge air stream which conveyed it to the discharge cyclone. Intake and discharge locations could be varied by adding additional sections of pipe.

Although the basic principle of operation was similar for all pneumatic conveyors evaluated, the following differences existed.

1. Three of the machines used centrifugal blowers while two used positive displacement blowers.

2. Various sizes and types of pipe or tubing materials were used on the various machines. Pipe sizes varied from 102 to 203 mm in diameter. Pipe materials used included galvanized metal tubing, aluminum tubing, flexible rubber tubing and flexible vinyl tubing. Some of the pipe had smooth inside walls and some had corrugated inside walls.

3. The pneumatic conveyors using centrifugal blowers were equipped with automatic air regulator valves located between the blower and separator cyclone. The valve controlled static suction on the blower and balanced the air flow to the amount of grain being conveyed. This maintained the blower in its most efficient operating range. Conveyors equipped with positive displacement blowers did not require air regulator valves since power requirements and total head were directly proportional to throughput.

4. The conveyors equipped with centrifugal blowers used constant speed air locks while the conveyors equipped with positive displacement blowers provided adjustable speed air locks.

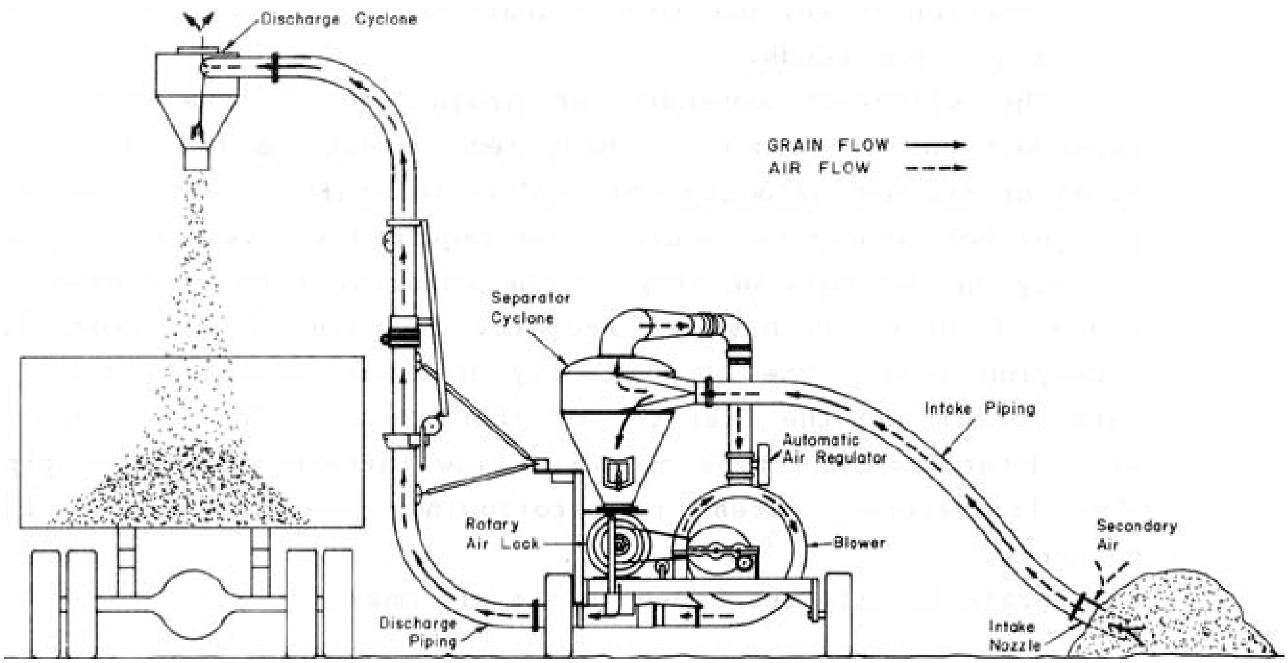

FIGURE 1. Schematic View of Pneumatic Conveyor Showing Air and Grain Flow.

THEORY OF OPERATION AND LITERATURE REVIEW

Some of the variables involved in pneumatic conveying of grain include the air intake vacuum or suction, discharge air pressure, air velocity and bulk density of the material being conveyed.

The capacity of a pneumatic conveyor depends on the ability of the blower to provide adequate suction and discharge pressures to overcome the following losses (1, 5)*:

1. Air friction losses at the entrance to the intake nozzle.

2. Air friction losses in the pipe. These losses depend on pipe length, diameter, type and bends in the pipe network.

3. Air friction losses in the cyclones. The cyclones dissipate the energy of the air/grain mass which causes the grain to separate from the air.

4. Losses to support a vertical column of air as created by elevation differences in the system.

5. Losses due to acceleration of the grain.

6. Losses to lift the grain due to elevation differences in the system.

7. Friction losses due to the grain moving in horizontal pipes and around bends.

The efficient movement of grain through the system is dependent on air velocity. Many recommendations have been made (1, 4) on the air velocity required to maintain an efficient flow and yet not damage the grain. The required air velocity depends largely on the bulk density of the material being conveyed. A range of 20 to 30 m/s is generally recommended for most farm conveying jobs. The air velocity in turn determines the flow rate (m^3/s) and the diameter of the piping. The air velocity also determines the type of grain flow pattern within the pipe.

The literatures cites the following possible grain flow patterns:

1. Grain totally suspended in the air mass.

2. Grain settling out, forming dunes and then moving along the bottom of the pipe.

3. Grain settling out, forming blockages and moving out in slugs when the pressure builds up.

RESULTS AND DISCUSSION

The results given compare the average performance of three pneumatic conveyors using centrifugal blowers to two pneumatic conveyors using positive displacement blowers (7). Where applicable, comparisons are made to grain auger (6) performance.

RATE OF WORK

The rate of work for pneumatic conveyors depended on the type of blower, type of grain being conveyed, the secondary air opening, speed of the air lock, length of intake piping, length of discharge piping, pipe diameter, the use of flexible or rigid piping, and air tightness of piping joints.

Maximum Conveying Rates and Types of Grain: The maximum conveying rate was very dependent upon maintaining a steady flow rate. Best conveying rates were obtained with the intake nozzle completely submerged in grain and with the shortest intake and discharge piping assemblies.

FIGURE 2 gives the maximum conveying rates in four different grains. The maximum conveying rates for the pneumatic conveyors using positive displacement blowers is nearly double that for the centrifugal blower equipped conveyors. Conveying rates for each pneumatic conveyor type remained similar, regardless of the type of grain being conveyed, indicating the air stream is capable of conveying a certain mass of grain, regardless of its density. For example, maximum conveying rates for centrifugal blowers was about 27 t/h and for positive displacement blowers it was around 52 t/h, regardless of grain type.

* Numbers in parenthesis refer to appended references

In comparison, the average maximum conveying rate for 178 mm diameter grain augers was somewhere between that of a centrifugal blower and a positive displacement blower equipped pneumatic conveyor. Grain auger conveying rates were more dependent on grain bulk density, indicating augers are capable of conveying a certain volume of grain rather than a certain mass of grain per unit time. Maximum auger conveying rates varied from 28.2 t/h for oats to 41.0 t/h for wheat.

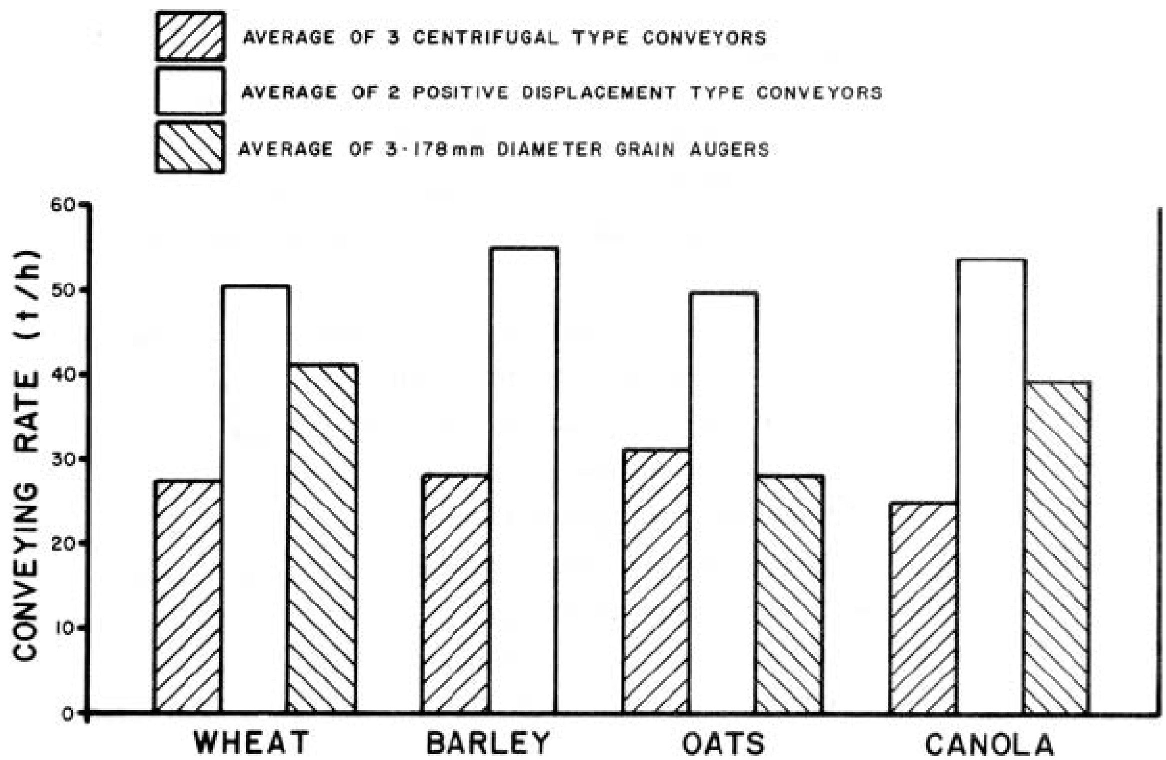

FIGURE 2. Maximum Conveying Rates in Various Grains.

<u>Effect of Secondary Air Open:</u> The amount of secondary air introduced at the intake nozzle was very important in obtaining maximum conveying rates. FIGURE 3 illustrates the effect on the conveying rates in wheat for a positive displacement type conveyor when the area for the entrance of secondary air was varied. The optimum area for the entry of secondary air was 320 mm^2 for a maximum conveying rate of 57 t/h. Similar relationships occurred for centrifugal type conveyors and for other grains. The amount of secondary air required, depended on grain properties such as bulk density, particle size, partical shape and grain flow characteristics. The trend was for material such as wheat and canola to require larger secondary air openings than oats and barley. Reducing the secondary air opening, resulted in increased vacuum at the intake nozzle and increased grain entering the line. Closing the air intake too much resulted in line plugging due to insufficient air. Plugging also occurred in the discharge line if not enough air was allowed to enter the secondary air opening. This was especially noticeable as the length of the discharge piping was increased.

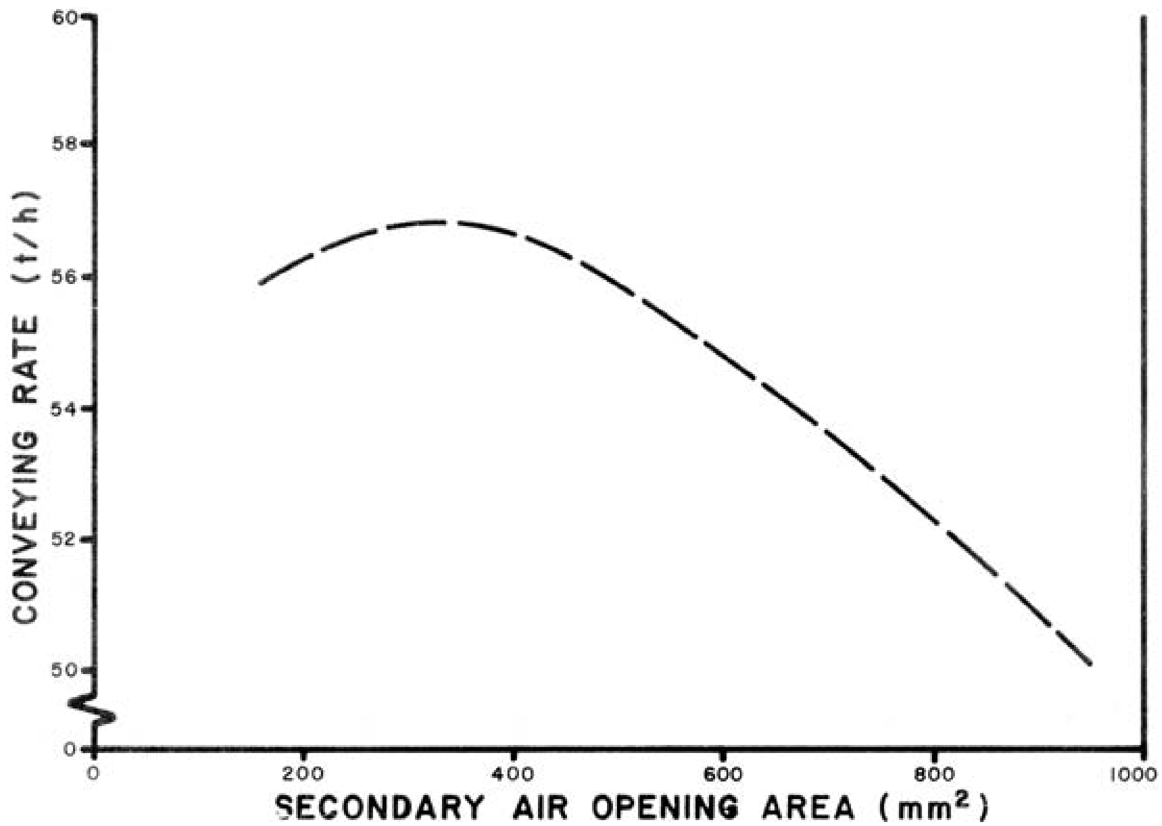

FIGURE 3. Conveying Rates in Wheat for Various Secondary Air Openings.

Effect of Air Lock Speed: Only the positive displacement type conveyors were equipped with variable speed air locks. Low air lock speeds resulted in grain build-up and eventual plugging of the separator cyclone. Fast air lock speeds resulted in improper feeding of the air lock. The optimum air lock speed had to be obtained by trial and error for each grain. The effect of air lock speed on conveying rate in wheat for a positive displacement pneumatic conveyor using 102 mm diameter line is shown in FIGURE 4. The optimum air lock speed range was between 45 to 55 rpm, resulting in a conveying rate of 34 t/h.

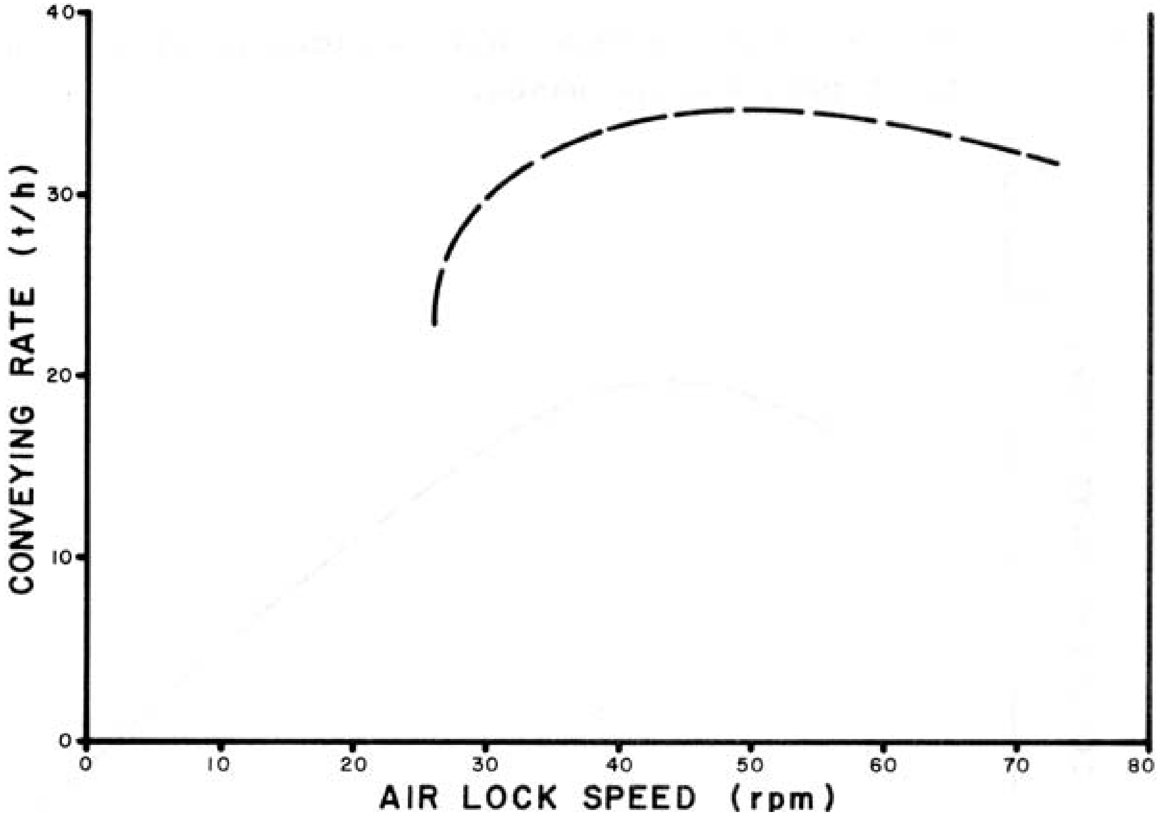

FIGURE 4. Effect of Air Lock Speed on Conveying Rate in Wheat.

Effect of Pipe Diameter: According to the literature (2, 3), grain flow occurs at the periphery of the inlet. Therefore, theoretically a large diameter pipe would result in the intake of more grain than a smaller diameter pipe. However, there must also be sufficient air velocity to ensure steady flow of the grain taken in. Therefore, pipe diameters must be sized to the blower, based on air velocity. FIGURE 5 compares the conveying rates in four grains when using 102 and 127 mm diameter intake lines on a positive displacement type conveyor. Using the smaller diameter intake line resulted in a 27%, 41%, 43% and 24% reduction in conveying rates in wheat, barley, oats and canola, respectively.

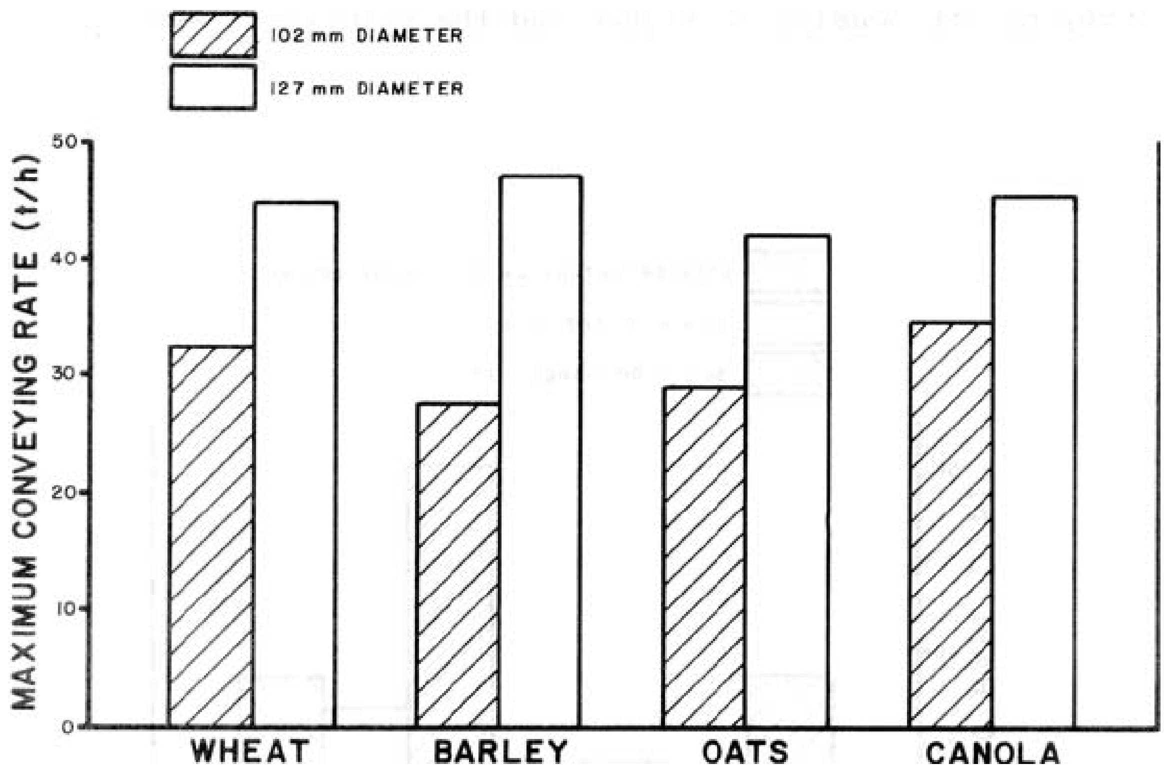

FIGURE 5. Effect of Pipe Diameter for a Positive Displacement Blower Equipped Pneumatic Conveyor.

Effect of Pipe Length: Air flow and grain flow losses increased as intake and discharge pipe lengths were increased. FIGURE 6 shows the effect on conveying rates in wheat for the two types of conveyors tested, when the lengths of intake and discharge pipe were separately increased to 30.5 m. Conveying rates were reduced significantly. It was observed that with longer lengths of pipe, grain flow was not as smooth and there was a greater tendency for plugging. This indicated there was insufficient air velocity to maintain a steady flow of grain. To avoid plugging the secondary air opening had to be increased or more air had to be introduced by not fully submerging the intake nozzle. This resulted in higher air velocities but reduced conveying rates due to a reduced grain to air ratio.

Increasing the length of discharge pipe had less effect on conveying rate than increasing the length of intake pipe. This agrees with Henderson and Perry (4), that a pressure system is more efficient than a suction system because the discharge conveying air density is higher and the velocity lower.

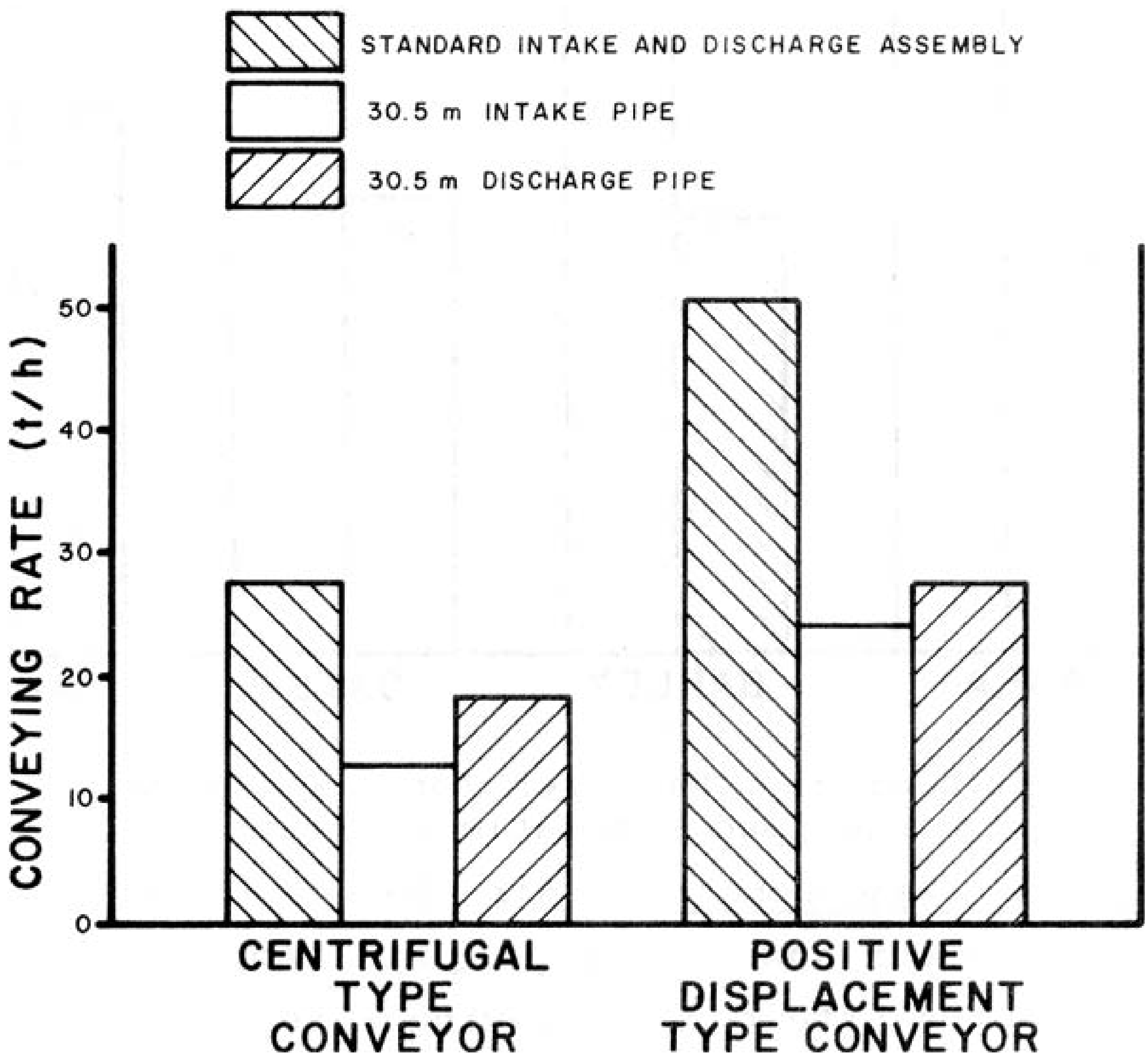

FIGURE 6. Effect of Pipe Length on Conveying Rates.

Effect of Rigid Versus Flexible Pipe: Pneumatic conveyors could be used with either rigid or flexible pipe. FIGURE 7 indicates the effect on the conveying rate of using rigid pipe and elbows for the 3 m intake or using flexible pipe. Using the rigid pipe intake assembly resulted in a 52% greater conveying rate. The smooth interior of the rigid pipe resulted in much less air and grain flow loss than the corrugated interior of the flexible pipe. However, using the rigid pipe was more inconvenient due to the need for perfect pipe and elbow alignment. The preference was to use the flexible intake pipe due to its ease of handling and superior maneuverability.

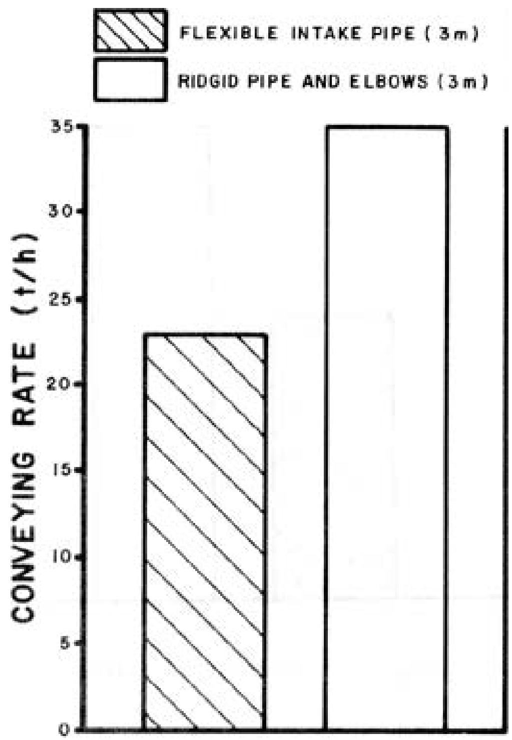

FIGURE 7. Effect of Rigid Versus Flexible Pipe on Conveying Rates.

<u>Effect of Properly Sealed Joints:</u> Observations indicated that snap-on ring connectors between adjacent lengths of pipe were not air-tight. More effective seals, using rubber inner tube bands under the connector, were fabricated and the effect on conveying rate was determined. Using properly sealed connectors on a 30.5 m intake line resulted in a 66% increase in conveying rate (FIGURE 8). Properly sealed connectors on a 30.5 m discharge line had little effect on conveying rate. This illustrates the requirement for properly sealed pipe connections on the vacuum side for pneumatic conveying systems.

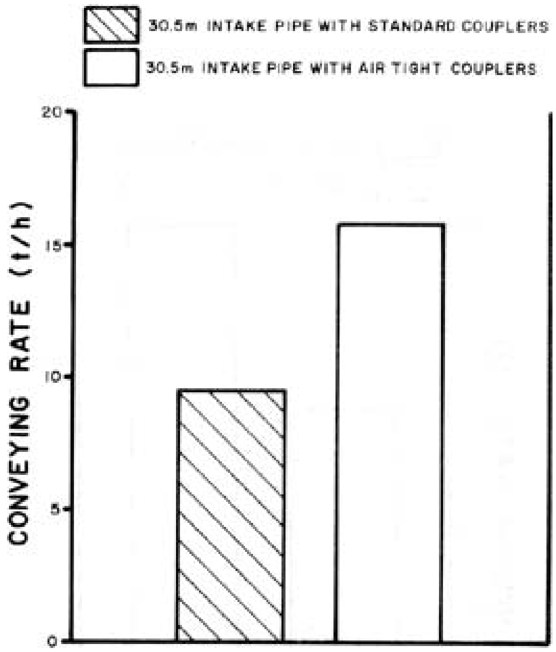

FIGURE 8. Effect of Properly Sealed Joints on Conveying Rates.

POWER REQUIREMENTS

FIGURE 9 shows the maximum power take-off requireraents for the two types of conveyors while running empty and in four different grains.

For positive displacement blowers the trend was for the power requireraents to increase as the bulk density of the material increased. For example, the maximum power requirement for conveying wheat was 60.8 kW while for oats it was only 49.9 kW.

The maximum power requirement when using centrifugal blowers occurred under no load, when conveying air only and was 40.6 kW. This is due to the effect of the automatic air regulator (FIGURE 1) which is completely closed under no load conditions. Measurements under no load conditions on one centrifugal blower type conveyor indicated that the static vacuum on the blower side of the valve was 24.4 kPa while the static vacuum on the intake line side of the valve was 2.8 kPa. As grain entered the system, the vacuum on the intake line increased and the air regulator valve gradually opened, reducing the overall vacuum the blower must overcome. Under full load the valve opened completely and the static vacuum on the blower side of the valve was 19.4 kPa while the vacuum on the intake side of the valve was 18.8 kPa. Also, as more grain entered the system, less air was being pumped, reducing the blower power requirements.

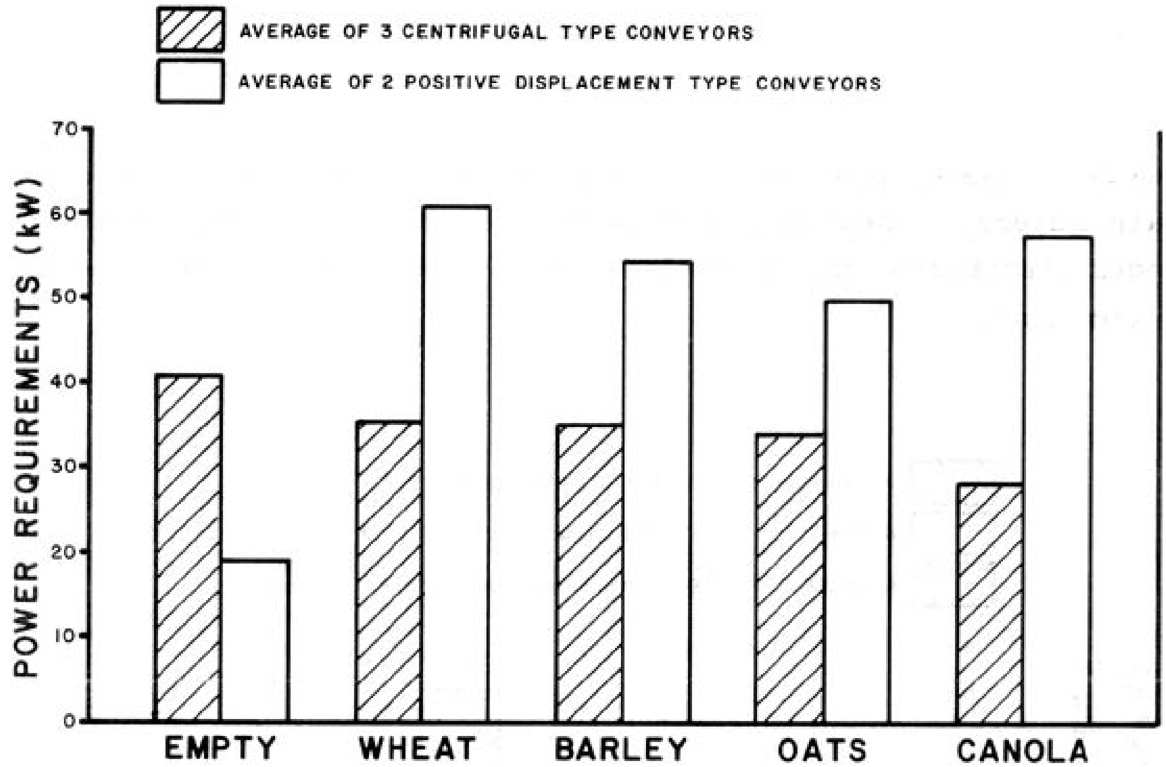

FIGURE 9. Pneumatic Conveyor Power Requirements.

EFFICIENCY

Specific capacity can be used to compare the conveying efficiency of pneumatic conveyors and grain augers. A high specific capacity indicates efficient energy use while a low specific capacity indicates inefficient conveying. FIGURE i0 shows specific capacity per metre of vertical lift for the two types of pneumatic conveyors and 178 mm diameter grain augers in wheat, oats and canola.

Specific capacities for the two types of conveyors are similar. This illustrates that although the positive displacement blower equipped conveyors have higher conveying rates, this requires more power, resulting in them being no more efficient than centrifugal blower equipped conveyors.

The specific capacity per metre of vertical lift for grain augers was 5 times greater than for pneumatic conveyors in wheat and oats and 4 times greater in rapeseed. Therefore, considering only specific capacity, grain augers are considerably more efficient than pneumatic conveyors. This inefficiency is one of the biggest disadvantages of pneumatic conveying. However, grain handling does not usually conflict with other farm operations and therefore the required power is usually available on most farmsteads. Also, pneumatic conveyors have other advantages over grain augers. Pneumatic conveyors are able to convey grain over longer distances and provide a relatively dust free operating environment.

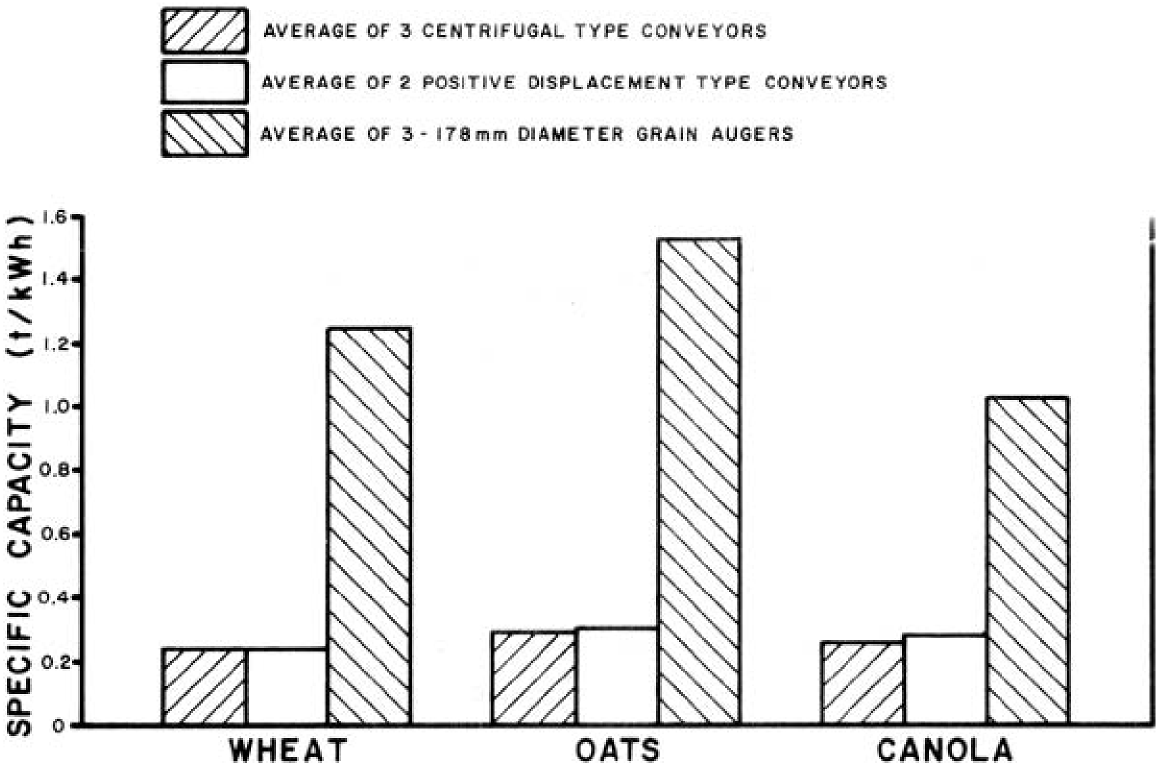

FIGURE 10. Conveyor Efficiency Comparisons for Various Grains.

QUALITY OF WORK

Grain Damage: Tests were performed to determine the amount of grain crackage each time a sample of dry wheat was passed through the conveyors. The increase in crackage for each pass ranged from 0.15 to 0.5%. This indicates that if the number of passes through the conveyor are kept to a minimum, grain damage should not be a problem. No differences in the amount of cracking was noted between the two types of pneumatic conveyors. Factors affecting the amount of cracking were the type of pipe, number of bends, type of air lock and type of couplers.

Grain auger results in dry wheat (6) have shown that each pass through an auger causes less than 0.2% crackage.

Filters and Screens: Conveying air, after it has been separated from the grain in the separator cyclone, is filtered or passed through a screen before entering the blower (FIGURE 1). Centrifugal blower equipped conveyors are equipped with screens to prevent grain or large fines from entering the blower. Because of close tolerances, positive displacement blowers require a more complete filtering of the fines. The fine mesh filters used with the positive displacement blowers had a tendency to get clogged and reduce conveying rates. Tests with one positive displacement conveyor indicated that the conveying rate was reduced up to 14% when using dirty filters. The pressure differential measured across clean filters was 0.8 kPa. After filters became clogged, the pressure differential increased to 3.2 kPa.

OPERATOR SAFETY

The main feature and advantage of pneumatic conveyors was that they were much safer to operate than a grain auger. The operator was not exposed to flighting or rotating parts and working near the intake nozzle in a confined area was virtually dust-free. Working near the discharge was, however, extremely dusty.

Noise levels, when powered with an 80 kW tractor, varied from 85 to 98 dBA for centrifugal type conveyors and from 94 to 109 dBA for positive displacement type conveyors. Noise levels were very loud and irritating when operating near metal bins or enclosed areas and ear protection is definitely recommended. Air exiting the discharge is described as supersonic and when mixed with stationary air, turbulences and shock waves form (9). In order to reduce the noise, the discharge cyclone has to be properly designed to eliminate shock wave formation and reduce exit velocity. All types of pneumatic conveyors have potential to be much quieter with the use of properly designed discharge cyclones and mufflers.

BLOWER PERFORMANCE CURVES

To gain some insight into why the two types of pneumatic conveyors tested had different conveying rates, tests were conducted to determine blower performance curves. Usually, fan performance curves provide flow rates over a range of static pressures or static suction. The performance curves for pneumatic conveyors were expressed in terms of flow rates over a range of total head (i.e. the sum of static suction and static pressure) with the blowers operating at standard power take-off speeds. Velocity pressure measure-rments were made by simulating fuli load conditions for conveying wheat, using throttling devices on the intake and discharge lines. Performance tests also included power measurements and differential air temperature measurement.

FIGURES 11 and 12 illustrate typical performance curves for a centrifugal blower and a positive displacement blower, respectively. For both types of blowers, flow rate and air velocity decreased as total head was increased. For the positive displacement blower, the power input increased as the blower delivered larger total head (i.e. moved more grain). For the centrifugal blower, the power input decreased as total head was increased, due to the balancing effect of the automatic air regulator valve.

The performance curves clearly illustrate the characteristics of the two types of blowers. The centrifugal blower has high volume, low pressure characteristics while the positive displacement blower has low volume, high pressure characteristics. As described earlier, the positive displacement blower had approximately double the conveying capacity. However, as shown, power requirements were also higher, resulting in the two types of conveyors being approximately equally efficient for moving grain.

As total head increased, the temperature differential between ambient and discharge air increased. For the positive displacement blower at the highest total head (64.4 kPa), air temperature differential was 120°C. The highest total head for the centrifugal blower was 29.0 kPa which resulted in a temperature differential of only 58°C. Preliminary tests were conducted to determine the effect the air temperature would have on the temperature of the grain after one pass through the conveyor. In dry wheat, a 3.5°C increase in grain temperature was measured with the positive displacement conveyor, while no grain temperature increase was experienced with the centrifugal blower. Further work needs to be done in this area to determine the effect of increased air temperature on grain quality.

GRAIN FLOW PATTERN

Observations were made, with the use of a 1.2 m section of clear polyethylene tube, to determine the type of grain flow pattern. Basically, all three types of grain flow patterns cited in the literature were observed. Although the grain to a large extent remained suspended in the air mass, it moved along the bottom part of the pipe in waves or slugs, indicating the grain mass slowed down until pressure build-up caused it to move along the line. This also accounts for the pulsating action of the intake nozzle experienced by the operator. If the conveyor was overloaded, the frequency of the waves slowed down and the density of the waves or slugs increased.

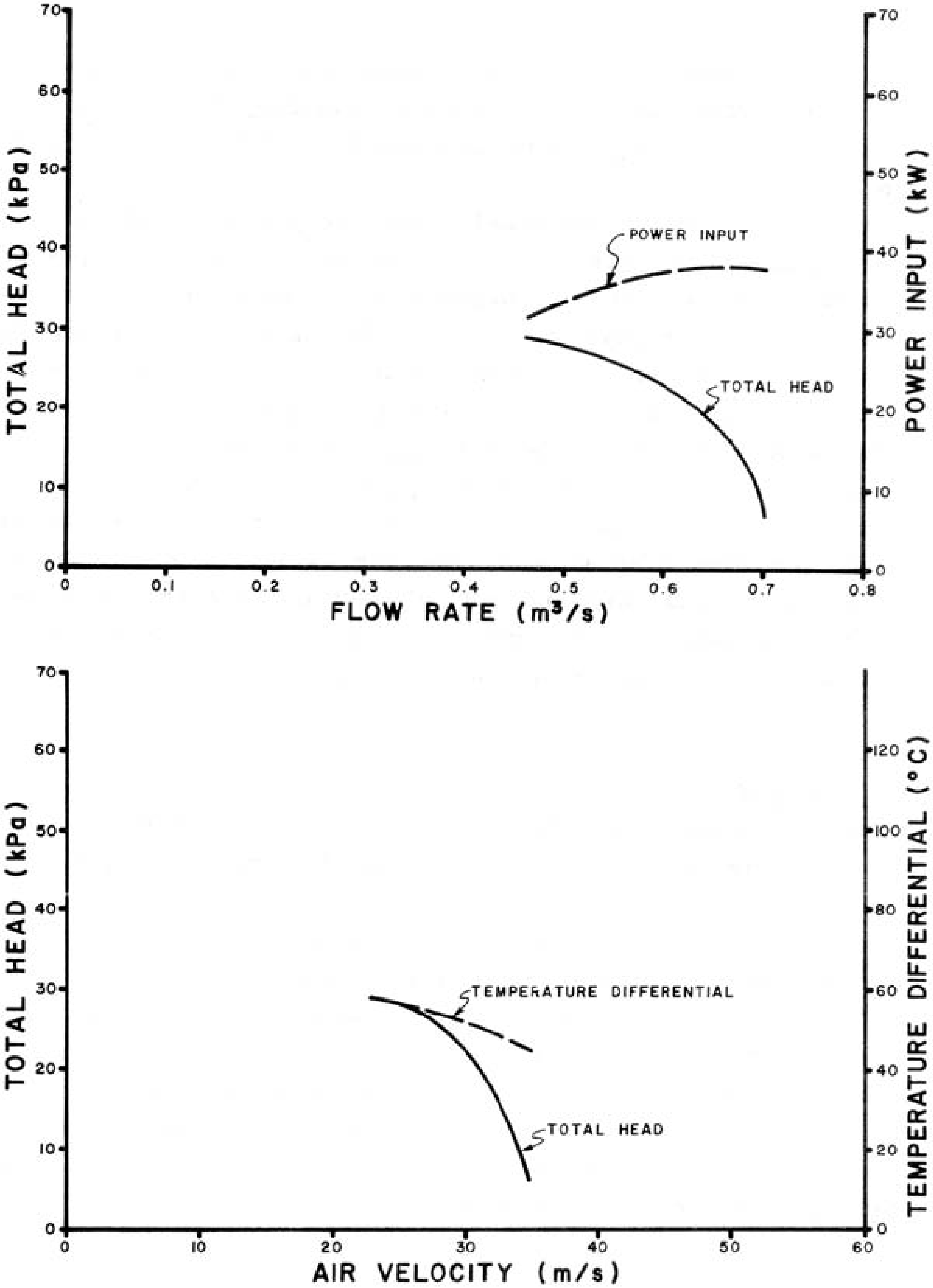

FIGURE 11. Typical Performance Curves for Centrifugal Blowers.

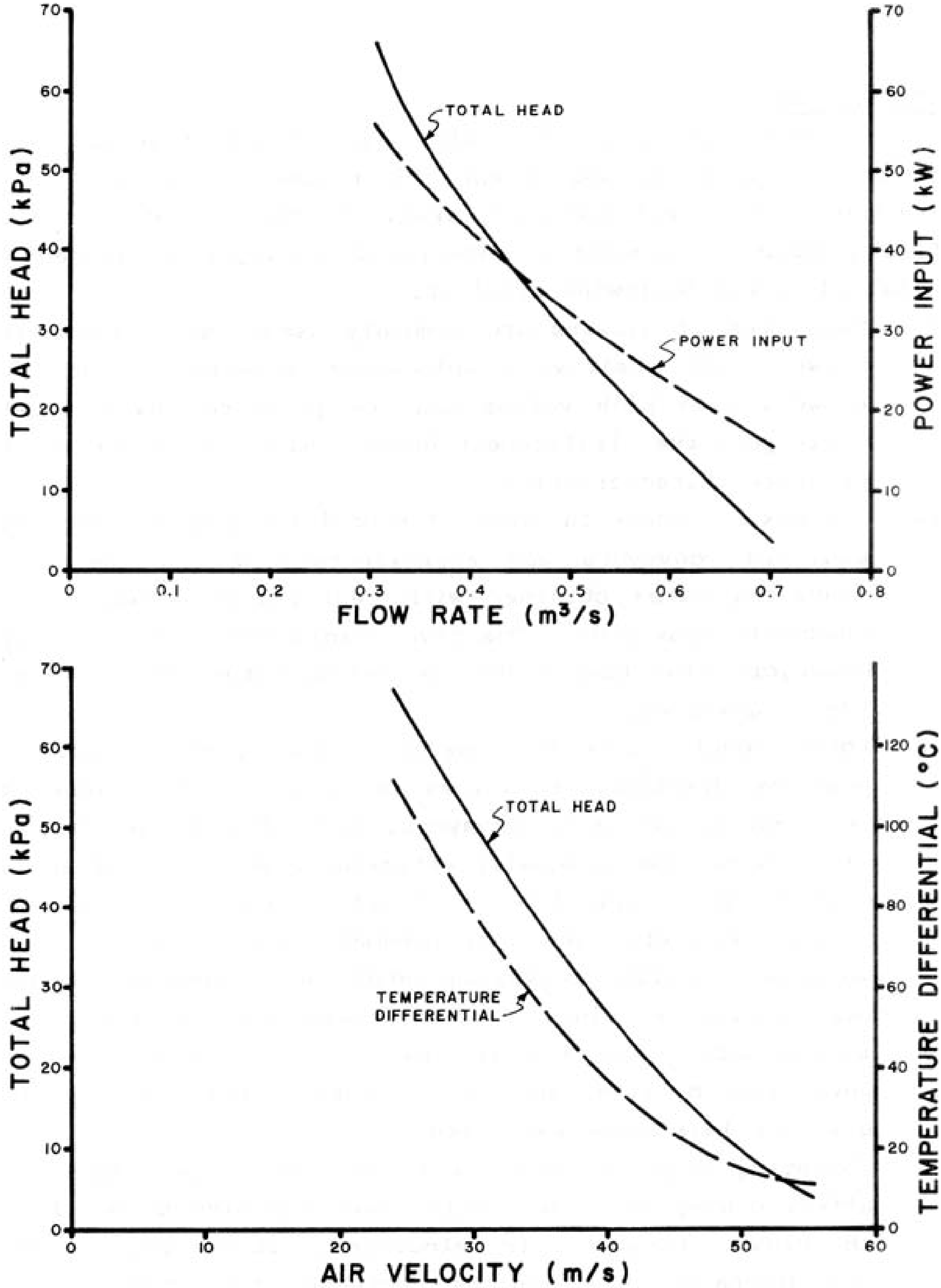

FIGURE 12. Typical Performance Curves for Positive Displacement Blowers.

CONCLUSIONS

On-farm conveying of grain using power take-off driven pneumatic conveyors, has recently increased in popularity. The Prairie Agricultural Machinery Institute has to date, evaluated five pneumatic conveyors. Pneumatic conveyor assessment has resulted in the following findings:

1. Two types of blowers are commonly used; namely centrifugal blowers and positive displacement blowers. Centrifugal blowers have high volume and low pressure characteristics while positive displacement blowers have low volume and high pressure characteristics.
2. The maximum conveying rates for positive displacement blower equipped conveyors was approximately double the maximum conveying rates obtained with centrifugal blower equipped pneumatic conveyors. Positive displacement blower equipped conveyors also have higher conveying rates than an 178 mm grain auger.
3. Power requirements for pneumatic conveyors equipped with positive displacement blowers was significantly higher than for centrifugal type conveyors, resulting in the two types of conveyors being equally efficient based on their specific capacity per vertical meter of lift. Grain augers are up to 5 times more efficient than pneumatic conveyors.
4. To obtain maximum conveying rates, each pneumatic conveyor has optimum settings for secondary air opening s at the intake nozzle and for air lock speed. Both have to be determined by trial and error. With centrifugal type blowers, air lock speed was fixed.
5. Conveying pipe diameter and conveying pipe leng th both affect conveying rates. Pipe diameters have to be sized to the blower, based on air velocities. Increasing the intake and discharge pipe lengths decreased the conveying rate. Pressure systems are more efficient than vacuum systems at increased pipe lengths.
6. The use of rigid pipes with a smooth interior resulted in 52% greater conveying rates than flexible pipes with corrugated interiors. However, the flexible pipe was more convenient to use.
7. Properly sealed joints, particularly on the suction side, were necessary for most efficient grain conveying.
8. Grain cracking is not a problem if the number of times the grain is conveyed is kept to a minimum.
9. Proper air filtering is required for positive displacement blowers due to the very close tolerances associated with these blowers.
10. Pneumatic conveyors are safe to operate due to the operator not being exposed to any moving parts and due to the relatively dust-free environment. However, the use of ear protection is strongly recommended due to the excessive noise at the discharge.
11. The grain flow pattern was observed to be in waves along the lower portion of the conveying pipe.

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