THE STORAGE AND HANDLING OF
ONIONS IN BULK

Thesis for the Degree of M. S.

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Lester Frank Whitney

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This is to certify that the

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Walter M. Carleton
Major professor

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THE STORAGE AND HANDLING OF ONIONS IN BULK

By
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Through their cooperative efforts, their administration and organization, this thesis problem was made possible.

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INTRODUCTION

Sponsorship of Problem

This thesis problem was conducted under the joint sponsorship of the Agricultural Engineering and Soil Science Departments of Michigan State College, and the Aerovent Fan & Equipment Company of Lansing, Michigan.

All labor expense involved in engineering and construction was defrayed by the Agricultural Engineering Department, while all materials of construction for both the bins and the handling equipment were furnished by the Department of Soil Science. Ventilating fans and controls were supplied by the Aerovent Fan and Equipment Company.

The bulk storage system is installed in the storage building located on the Michigan State College muck farm in Laingsburg, Michigan. Fifteen hundred bushels of onions were available for the initial experiment. The experiment is scheduled for an overall length of five years.

Justification

Michigan muck farmers produce a large part of the national onion crop of 35,000,000 bushels. With these farmers, as with any businessmen, the unit cost of production is of major importance. From the time the soil is prepared to the ultimate sale of the product, efficiency of operation is often the deciding factor whether the farmer makes a profit or a loss.

A simple observation reveals that the harvesting and storage operation is the least efficient of the entire season. The bulk of the onions grown are hand topped into crates by migrant labor. These crates are stacked and allowed to cure for an average span of from four to six weeks. Then the crates are rehandled, hauled into the storage and stacked. Upon sale, the crates of onions are again manually handled, and dumped onto an onion screen where the onions are prepared and packed for market.

The research involved in this thesis is concerned with an investigation of the possibility for eliminating the bulk of the manual labor, thereby considerably increasing the efficiency of the harvesting operation.

Ideally, a complete mechanization of all phases is desired. That is: 1. mechanical topping into bulk transportation; 2. mechanical unloading of the wagons or trucks; 3. bulk storage immediately following the harvesting; and 4. mechanical removal of the onions from the storage onto the onion screen.

1. Mechanical topping into bulk transportation: Several mechanical toppers have been devised. However, with these machines the main complaint of the farmers is that too much bruising is incurred. It has been their belief that the storage quality of the onions is affected. Much more research is needed on this phase.

2. Mechanical unloading: Wagons are now being equipped with several different designs of unloading equipment. Bruising can be controlled during this phase quite effectively.
3. Bulk storage: The conveyance of the onions in bulk onto the pile is the first step in storing. This must be done with carefully controlled measures to prevent bruising. In addition, the storage must be equipped with crop drying facilities both for the initial curing and for drying during the storage season.
4. Mechanical removal: Some means is necessary for the initial removal of onions from the pile. Then the removal from under, and finally the elevation onto the onion screen must be accomplished with a minimum of bruising with a series of conveyors and elevators.

Further justification from the farmers' viewpoint, involves such things as reduced capital investment, and a much reduced depreciation cost on the bulk installation as compared with the crate system. With crates, over and above the cost of incessant handling comes the necessary expense of constant repair. An estimate of five cents per crate per annum amounts to a sizeable expense.

The elimination of the hazards of the elements during the curing season is an important factor. Heretofore, considerable loss has been suffered from improper field curing.

Fig. 1. An Example Showing Crates Stacked Seventeen High in Storage.

Fig. 2. Storage of Empty Crates Illustrating Some Disadvantages of This System.

Review of Literature

A study of the work previously done with the storage of onions was largely limited to non-literary sources. While considerable progress had been made, the only information published was of a non-technical nature.[3,7] The opinions and observations by C. L. Fitch in the Packer strongly reflected the need for research on the problem. The earliest record of any progress was as recent as 1946.

Some work in Colorado on the storage of Sweet Spanish Onions was in progress. However, no information was available at the time.

Conferences with different members of the faculty staff and with others provided the bulk of information. Tours of storages already in operation provided additional ideas. The errors made along with possible improvements were noted and applied to the research problem. Thus, an accumulation of practical information proved to be the basis for construction of the bins and the handling equipment.

Much of the original planning for the construction of the experimental bins was done by joint consultation between members of the cooperating agencies prior to the official start of the project. Sketches were submitted by Mr. Mitchell and approved by Professor Farrall.

OBJECTIVES

As a guide for the problem, the following list of objectives were chosen:

1. Investigate the practicability of using bulk storage for onions.
2. Design and build bins and equipment for bulk handling of onions with materials, labor, and equipment available to farmers.
3. Determine the amount of air and air temperature necessary to satisfactorily dry onions.
4. Determine the amount of shrinkage.
5. Determine the optimum depth of storage.
6. Determine conditions for safe keeping in bulk storage.

PROCEDURE

1. The practical aspects of bulk storage were to be determined by actual experiment. Onions were to be handled and stored in bulk with the resulting storage records to be the basis for practical comparisons with the field cured crate system.

2. As shown in the skeleton floor plan on page 7, there were to be seven experimental bins and a slatted floor area for crate storage. The air duct was to be located centrally with controlled inlets into each bin and under the crate storage area.

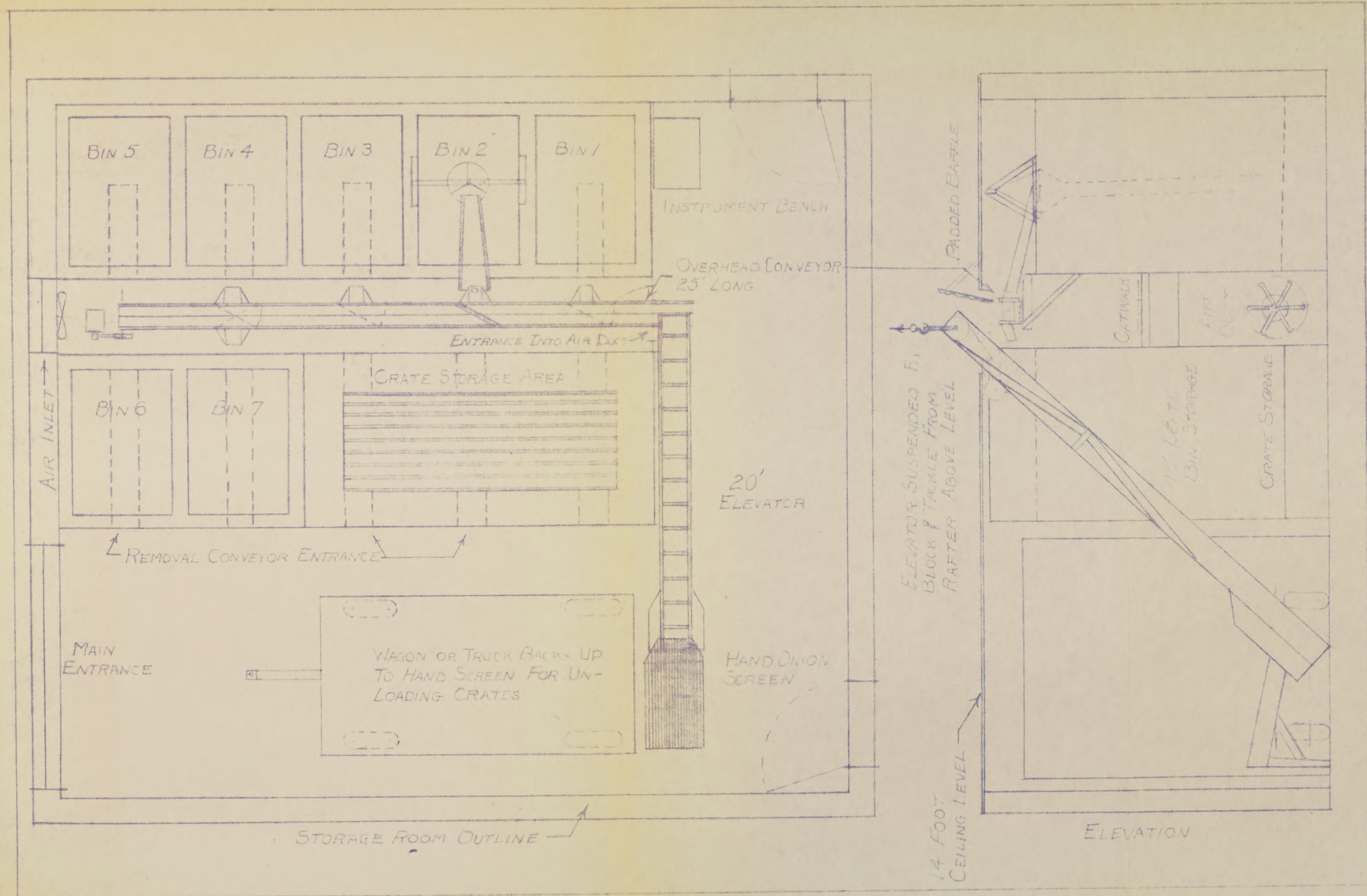


DIAGRAM OF FLOOR PLAN

Elevation of the onions was to be at the inside end and then emptied onto an overhead conveyor. For filling each bin, the onions were to be intercepted on the conveyor and hansoned[3] into the bin. Definite measures were to be taken to reduce bruising.

3. Air supply and air temperatures for the satisfactory curing of onions were to be determined by varing the supply of air into different bins by means of the controlled inlets. No heat was to be added the first year, nor were recirculation facilities to be incorporated at that time. Records of temperatures and air flow data were to be correlated with the corresponding storage results.

4. The amount of shrinkage was to be determined for both the field curing and the bin curing method. Samples were to be picked at random and weighed at the beginning of the storage season. At the end of the season, the samples were to be weighed again and the net loss was to be considered shrinkage. Percentages of sprout and rot were to be determined. The comparison of one method with the other was to be the basis for determining the relative merits of each.

5. The optimum depth of storage was to be determined by observing the resultant crushing effect on the bottom layers of onions. Depths of storage were to be varied from six feet to twelve feet. Higher depths were not possible because of the lack of head room in the building.

6. After the curing period, conditions for safe keeping were to be investigated. Minimum temperatures were to be maintained and the desired humidity was to be determined. Onions are safe from frost injury at 32°F. For the proper screening of onions, the outer shucks must be perfectly dry.

Construction of Apparatus

Air inlet: Alteration of the wall for installing the blower was made as the first step in construction. This consisted of knocking out the wall (two layers of building tile with a four inch layer of zonolite insulation) over an area four feet wide by four feet six inches high. By carefully chipping the mortar, the edges of the opening were sufficiently even to dispense with the reinforced concrete lintel. Instead, a substitute four inch thickness of oak was used as a header. The opening was finished with 1" x 4" yellow pine and weatherproofed with caulking compound and paint. An insulated door was fitted to the opening.

Framework: Layout of the bin framework began with the placement of the 6" x 12" girders on the concrete floor. Along the air duct, air openings into each bin were made by segmenting the girder. Floor joists of 2" x 8" maple were spiked to the studs to provide for a strong tie at the bottom of the bins. The joist and stud assembly were then spiked to the girder.

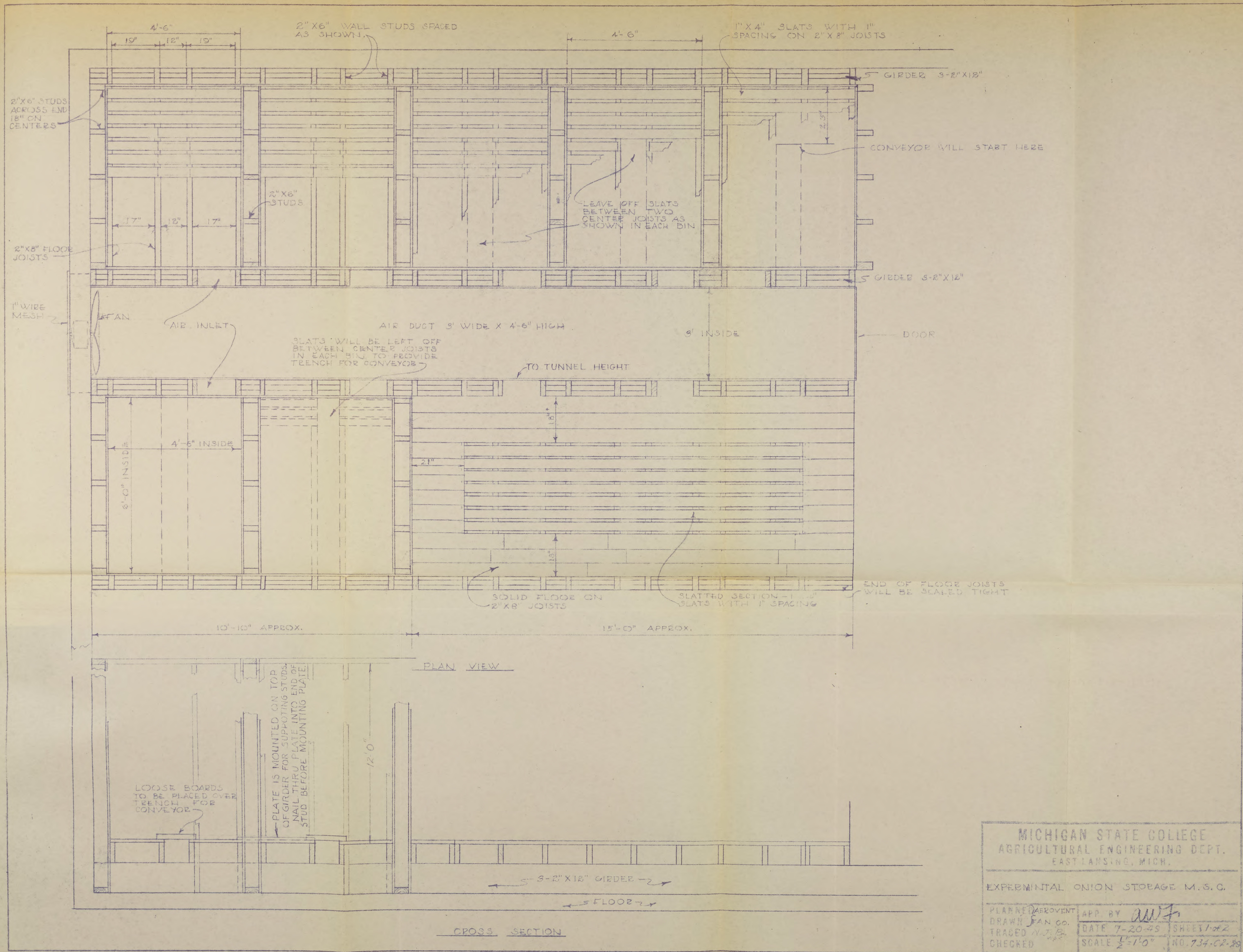
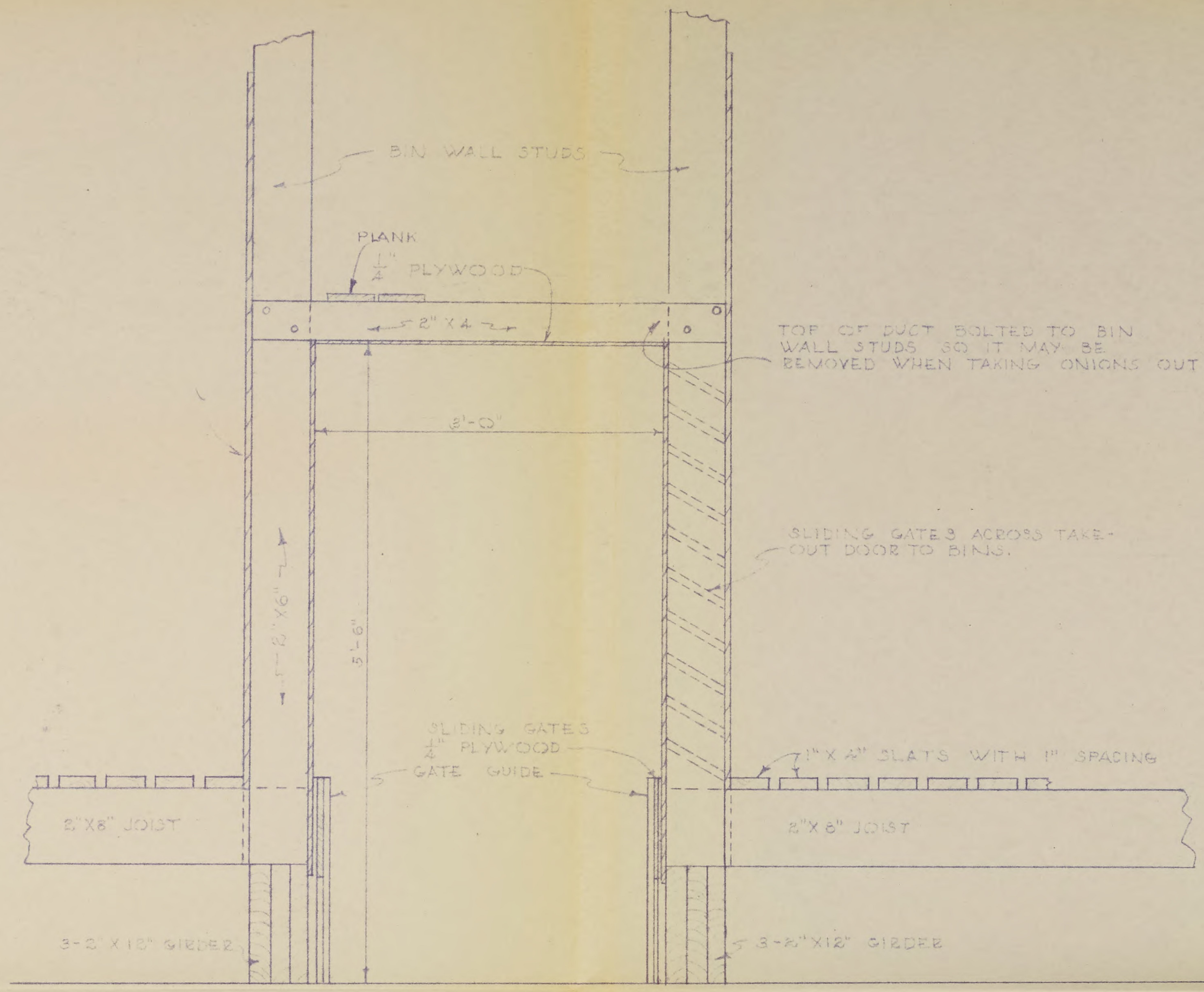
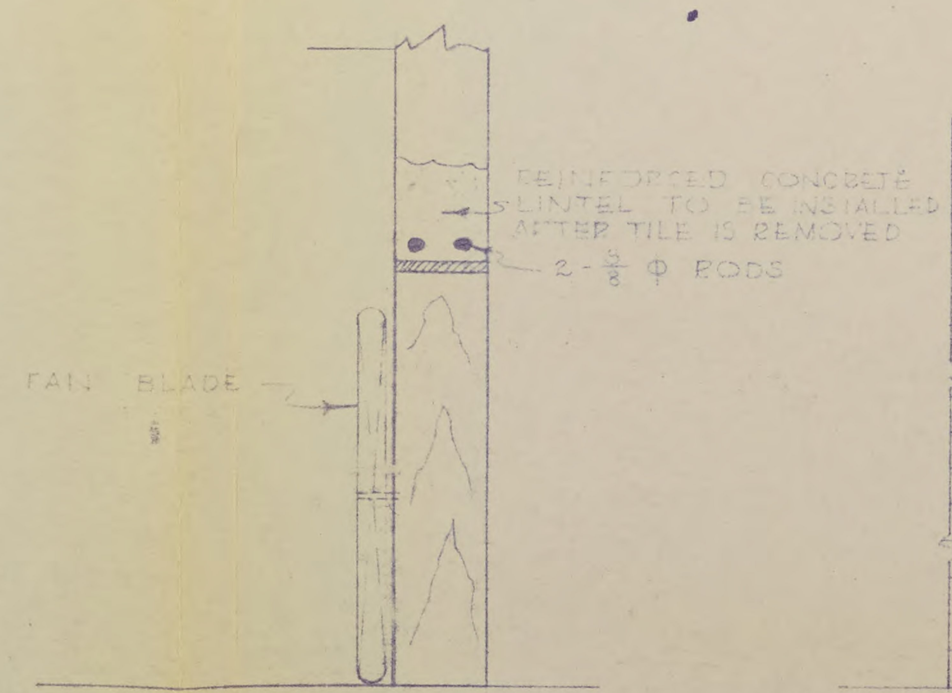

4'-6"
19"
12"
19"
2"X6" WALL STUDS SPACED AS SHOWN
4'-6"
1"X4" SLATS WITH 1" SPACING ON 2"X8" JOISTS
GIRDER 3-2"X12"
2"X6" STUDS ACROSS END 18" ON CENTERS
2'-3"
CONVEYOR WILL START HERE
2"X6" STUDS
17"
12"
17"
LEAVE OFF SLATS BETWEEN TWO CENTER JOISTS AS SHOWN IN EACH BIN
2"X8" FLOOR JOISTS
GIRDER 3-2"X12"
1" WIRE MESH
FAN
AIR INLET
AIR DUCT 3' WIDE X 4'-6" HIGH
3' INSIDE
DOOR
SLATS WILL BE LEFT OFF BETWEEN CENTER JOISTS IN EACH BIN TO PROVIDE TRENCH FOR CONVEYOR
TO TUNNEL HEIGHT
18"
4'-6" INSIDE
8'-0" INSIDE
21"
18"
SOLID FLOOR ON 2"X8" JOISTS
SLATTED SECTION
SLATS WITH 1" SPACING
END OF FLOOR JOISTS WILL BE SEALED TIGHT
10'-10" APPROX.
15'-0" APPROX.
PLAN VIEW
PLATE IS MOUNTED ON TOP OF GIRDER FOR SUPPORTING STUDS. NAIL THRU PLATE INTO END OF STUD BEFORE MOUNTING PLATE.
12'0"
LOOSE BOARDS TO BE PLACED OVER TRENCH FOR CONVEYOR
3-2"X12" GIRDER
FLOOR
CROSS SECTION
MICHIGAN STATE COLLEGE
AGRICULTURAL ENGINEERING DEPT.
EAST LANSING, MICH.
EXPERMINTAL ONION STORAGE M.S.C.
PLANNED AEROVENT
DRAWN FAN CO.
TRACED N.J.B.
CHECKED
APP BY AWF.
DATE 7-20-49
SHEET 1 of 2
SCALE 1/2"=1'-0"
NO. 734-C2-29

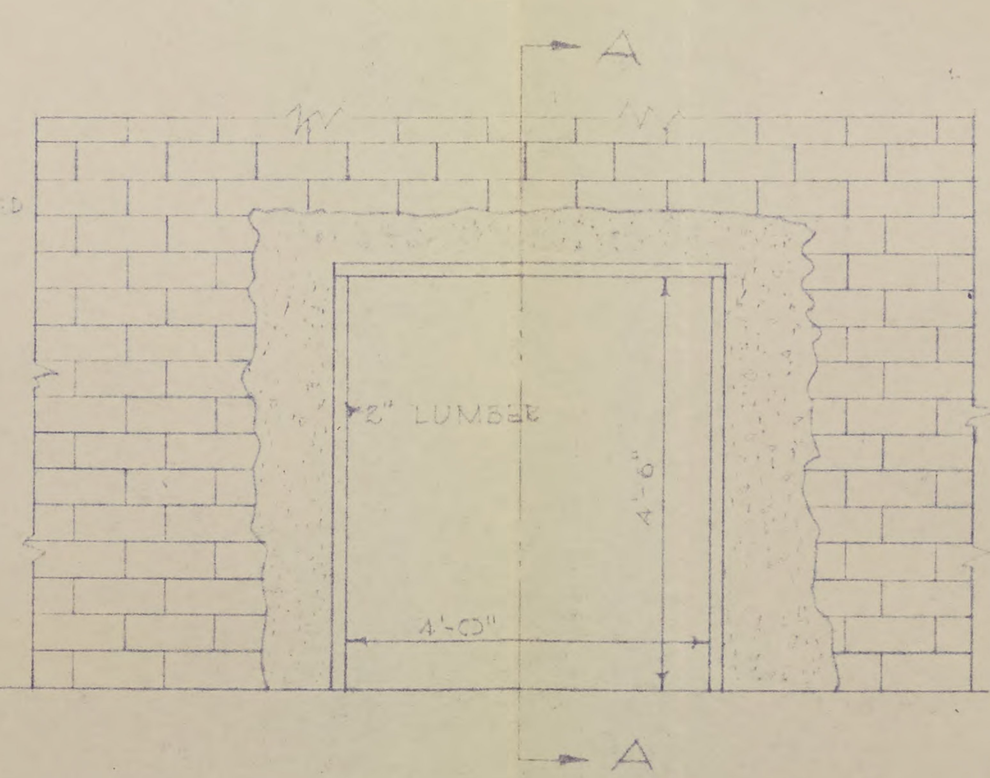
Fig. 4. Plans of Construction Detail (A).



AIR DUCT SECTION



WALL SECTION



ALTERATIONS TO WALL FOR INSTALLING BLOWER

MICHIGAN STATE COLLEGE AGRICULTURAL ENGINEERING DEPT. EAST LANSING, MICH.		
EXPERIMENTAL ONION STORAGE M. S. C.		
PLANNED AEROVENT DRAWN FAN CO. TRACED NJB-WR CHECKED	APP. BY	
	DATE 7-20-49	SHEET 2 of 2
	SCALE 1/2"=1'-0"	NO. 734-02-29

Fig. 5. Plans of Construction Detail (B).

It was thought that the twenty inch space under the bin floor, formed by the girder and joists, would provide as a plenum chamber. With such small bins, uniform flow of air over the area of the bin might be difficult to achieve without some means for reducing the effect of the entrance velocity.

In the center of each bin, the joist spacings were twelve inches to provide a trench for a conveyor to facilitate removal of the onions. Conveyor trenches for opposite bins were aligned to permit the use of but one conveyor to empty both bins.

The air duct framework was formed by nailing a header between the bin wall studs. Entrance into the air duct is through a doorway at the inside end.

Sheathing: Quarter inch plywood was chosen as the material for sheathing. Both the bin walls and the air duct were lined. Because of the experimental nature, a minimum of leakage was desired. Caulking compound and strips of wood ripped diagonally from two inch square stock were used as a sealer.

Flooring: Each bin floor was made from 1" x 4" native lumber with inch spacing between the boards. The flooring over the conveyor trench was made removable in order to facilitate use of the emptying conveyor.

Full inch rough lumber was found to be sufficient on joist spacings up to two feet and with a storage depth of twelve feet.

Over the crate storage floor space, 1" x 4" slatted floor was again used, but with the exception that the eighteen inch perimeter was boarded air tight with center match lumber. The purpose for an air tight perimeter was that air flow through the crates would disperse sufficiently to ventilate the outer shell of crates. Otherwise, the course of least resistance would be followed by the air in the case of a complete slatted floor and the inner crates might suffer from lack of ventilation.

Initial removal facilities: Corncrib type sliding slats were installed between the studs directly in line with the conveyor trench. Inch boards were fixed to slide at an incline of forty-five degrees between scabbing nailed to the studs (Fig. 6). Each bin is equipped with such a removable wall section.

Since these slatted sections would necessarily have to be exposed, air leakage at this point might affect the storage behavior. Thus, at all such places, including the conveyor trench openings between joists, plywood panels were fitted and held in place with window screen buttons.

Air flow control doors: As was pointed out earlier, each bin was independently supplied with air from the main duct. The amount of air flow into each bin is easily regulated with the aid of sliding doors.

Since as part of the experiment some of the bins were to be supplied air intermittently, the operating pressure within the air duct would vary with the fluctuations in

Fig. 6. View of Main Duct Showing Air Control Gates and Slatted Wall Section.

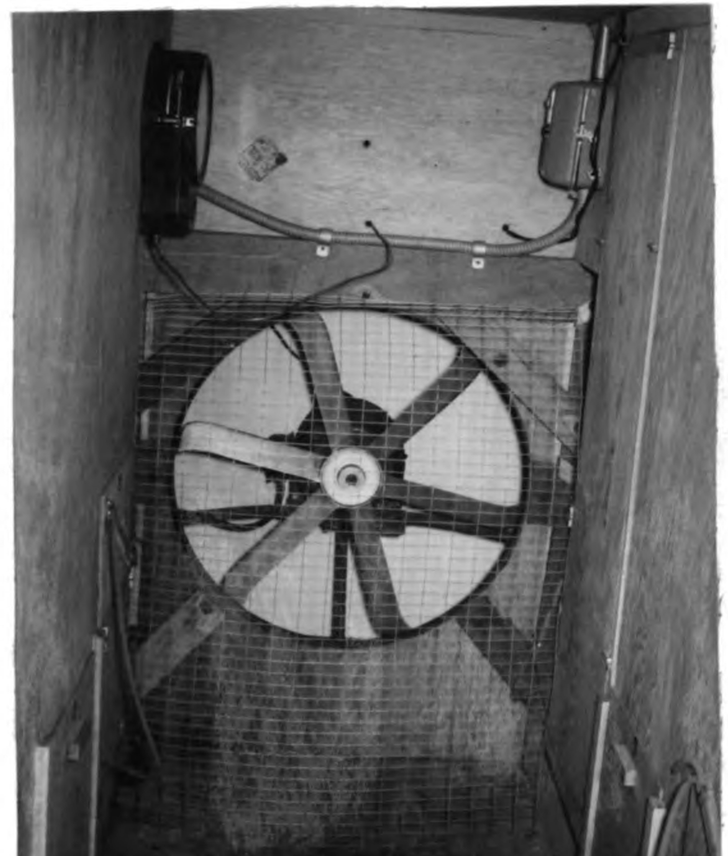


Fig. 7. Axially Mounted Fan, Magnetic Switch, and Time Recording Apparatus.

air demands. To compensate for this fluctuation and to insure constant operating pressure, sliding doors were made in the top of the duct itself. A maximum opening of three square feet is available for adjustment.

Selection of blower: A statement of specification is in order concerning the blower used for the experiment. One fan was to supply air for all bins. The fan chosen and supplied by the Aerovent Fan Company was a thirty-two inch Macheta blade Aerovent Fan axially mounted on a three horsepower 220 volt electric motor delivering 9900 cfm at 1" H_2O static pressure. This assembly was mounted within a cast iron orifice frame without wire guards. It was necessary to fasten this frame to the duct with bolts and short pieces of two inch stock.

For safety, wire guards were fitted over the air inlet and directly in front of the fan within the air duct.

The fan was operated with a magnetic starter which could be used manually or controlled thermostatically.

Design and construction of handling equipment: Control of bruising is perhaps the greatest single factor in the bulk storage of onions. A bruised onion is thought to be highly susceptible to rotting and sprouting. With this fact constantly in mind, the handling equipment was designed and constructed.

Trash removal: It was decided that as much muck and trash as possible be removed before the onions were placed in storage. This elimination was to reduce the number of

possible "wet spots" in the pile. Further, this operation was to be done in the storage and before elevation. A simple hand onion screen constructed of wood slats was used. Crates from the wagon were emptied onto this screen and pushed into the boot of the elevator.

Elevation: Removal of the onions from the wagon level to the ceiling was the next problem involved in the handling scheme. This problem was further complicated by the lack of floor space as well as head room. Also, it was desired that the elevator be removable after the harvesting period.

After considerable research and consultation, it was decided to use plans for a twenty foot elevator already designed.[5] However, with the existing design, there was considerable possibility for bruising and damage to the onions.

The simplest and most logical solution involved small pieces of canvass attached to the wooden flights as shown in Fig. 9. Sufficient slack in the canvass is required to compensate for the travel of the chain around the sprockets. These "hammocks" were easily attached and able to withstand hard usage. Very little bruising was incurred.

The onions were to drop from the head end of the elevator onto the conveyor. However, since the conveyor was necessarily suspended but eight inches from the ceiling, it was necessary to mount the elevator such that the head end protruded above the ceiling level.

Fig. 8. View Showing First Stage of Storage Process.

Fig. 9. Elevator in Position Showing Canvass Hammocks.

It was found that the speed of the elevator was somewhat fast for onions causing some bruising. At the head end of the elevator, the velocity of the onions was such that they were thrown rather than dropped. A well padded baffle board deflected the onions onto the conveyor with reduced bruising.

Conveying: Next in the chain of handling equipment was the twenty-five foot conveyor running along the ceiling and in the middle of the catwalk between the two rows of bins. Here again a very simple design was used as shown in Fig. 14. The framework was constructed of inch oak boards fastened together with screws. Under the conveyor belt deck, cross members made of 2" x $2\frac{1}{4}$" oak were placed three feet o.c. for rigidity. To further strengthen the frame, pieces of $\frac{1}{4}$" x 1" strap iron were morticed into the bottom edge of the sideboards. Hardwood runners of $\frac{1}{2}$" x 1" stock to support the return belt were fastened to these pieces with counter-sunk screws.

To keep within the space limitations it was necessary to use four inch diameter belt pulleys. Since the desired capacity required an eight inch conveyor belt, and since four inch diameter pulleys with eight inch face are not standard, it was necessary to use two pulleys of four inch diameter and $4\frac{1}{2}$ inch face.

The conveyor belting was equally unconventional. Complying with belting recommendations that one ply of belting material be used for each two inches of pulley

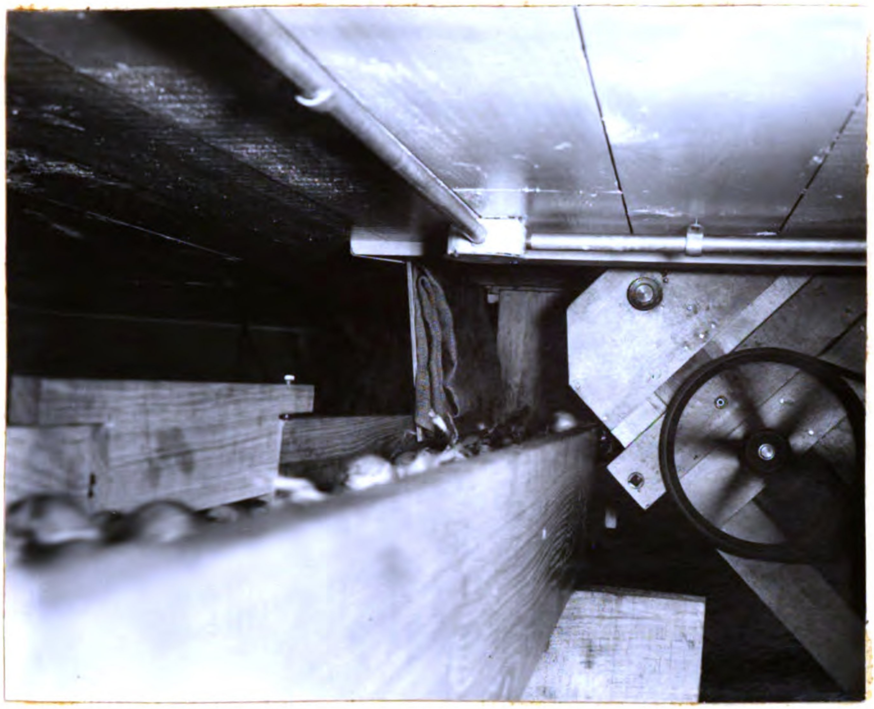


Fig. 10. Onions Are Transferred from Head End of Elevator to Overhead Conveyor.

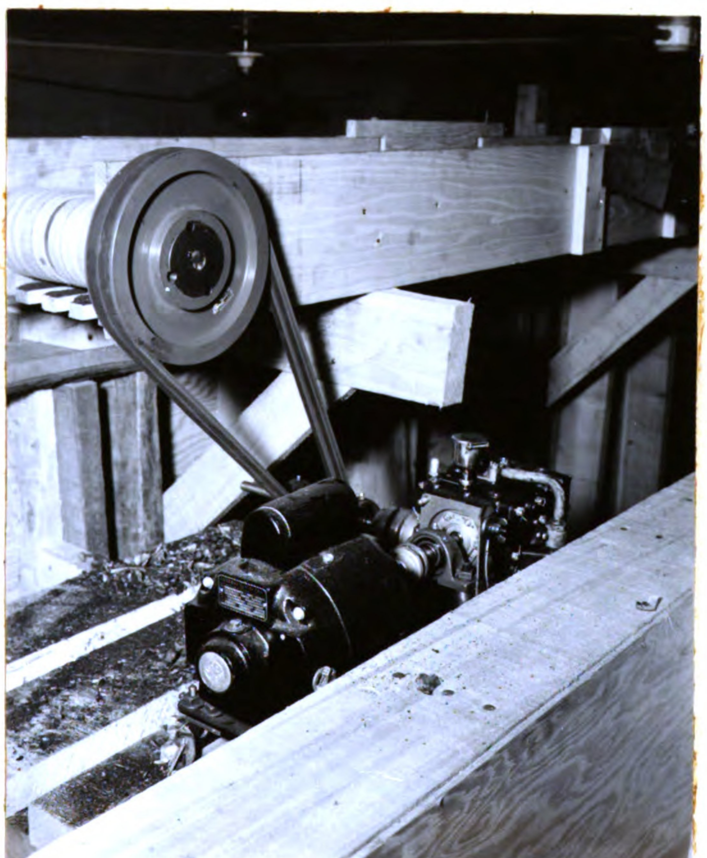


Fig. 11. Driven End of The Overhead Conveyor.

diameter, it was found that two ply belting eight inches wide was not available. Canvass duck-belting four inches wide was used in two widths running independently.

To increase the coefficient of friction between the canvass belting and the driving pulley facings, which were of shellacked wood, a piece of rubber belting was fitted to the face of the driving pulley and fastened with flat headed screws.

For this conveyor, a notch thirteen inches long was cut out of the side board at the center point of each bin for filling purposes. The onions were intercepted at this point by a baffle board. It served as a false side which was hinged and could be made to swing out and crowd off the onions through the notched opening. At each of the openings, a small metal chute was fastened permanantly to which a removable swinging chute could be attached.

This swinging chute had verticle as well as horizontal motion, and it reached to the top midpoint of the bin. About four feet in length, it too was made of sheet metal but with wooden sides for regidity. A 3/8" carriage bolt $1\frac{1}{2}$" long with a coil spring, washer, and winged nut was used as a connecting fastener for flexibility and easy removal.

The filling tube: At this point, the onions are at the top of the bin ready to be lowered. The problem of how to bring the onions down to the floor level without bruising proved to be interesting.

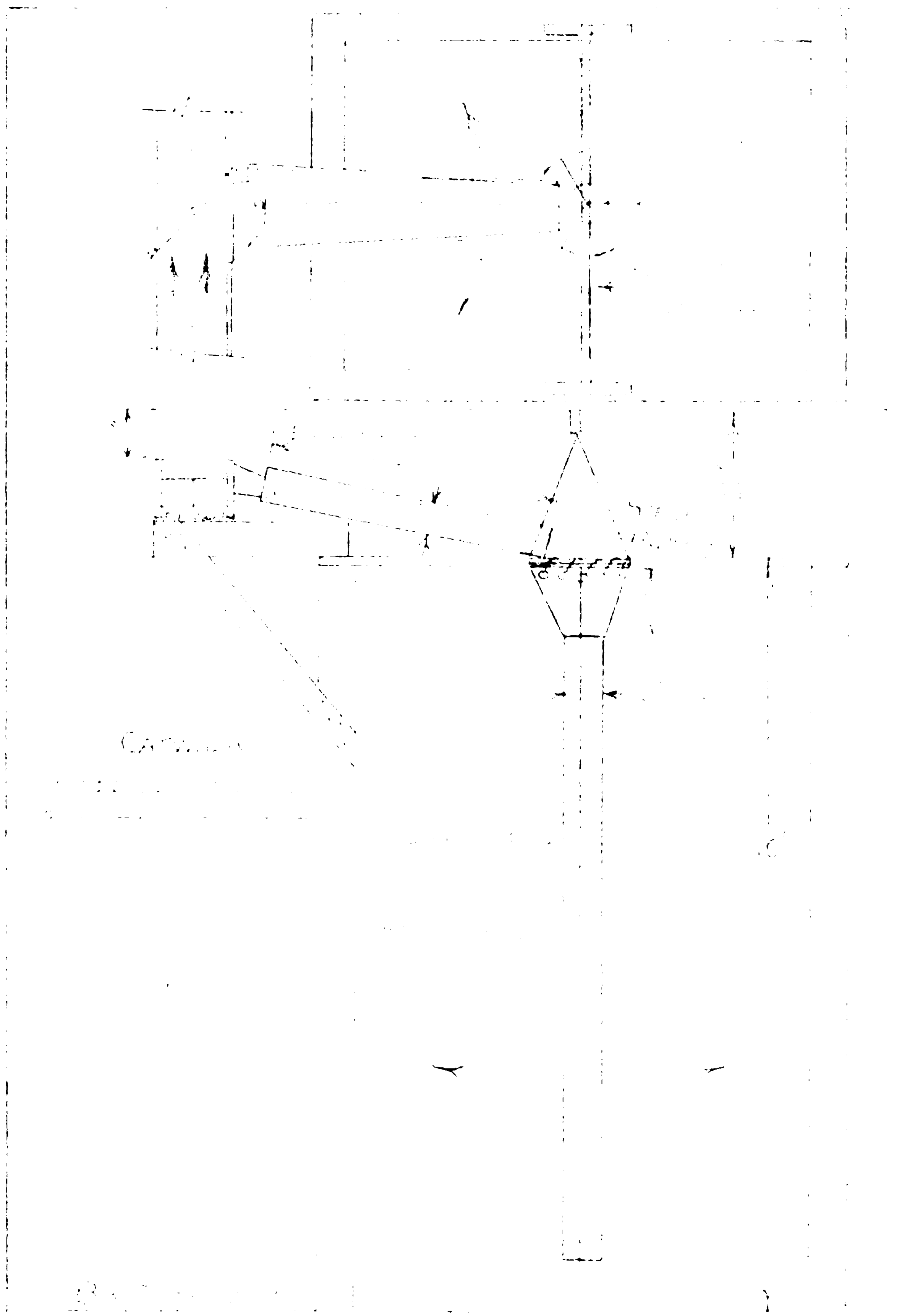


Fig. 12. [illegible]

Fig. 13. Showing Placement of Onions in Bin Using Canvass Filling Tube. Also, Note Position of Shrinkage Samples and Thermocouple Wires.

In the filling operation, it is necessary to distribute the onions evenly over the floor area so that all extraneous matter will be so placed. This makes for as uniform an air flow distribution as possible.

A canvass tube suspended so that the swinging chute emptied into it. From Fig. 12, the tube was six inches in diameter and ten feet in length. For the top twelve inches, the tube funnels out to a diameter of eighteen inches. It is held in circular shape at the top by lacing to a stiff metal ring. This ring was suspended with ties to a framework spanning the width of the bin.

Conveyor for emptying: A fourteen foot model of the conveyor already described was constructed to slip into the conveyor trench made by the joists. The notable changes to the original design were: 1. a continuous solid side board, and 2. a belt tightener flush with the frame.

Change one was natural since all onions were to be discharged at the driving end.

Change two was necessary upon consideration of the problems involved. The conveyor trench was constructed twelve inches wide, with the trench of opposite bins directly alligned. It is obvious that a conveyor with as near smooth sides as possible be used in order to avoid catching while inserting under the bins.

From Fig. 14, the hardwood bearings were fastened to a sheet metal plate. This plate was fastened to the wooden frame with stove bolts and winged nuts. The wooden frame

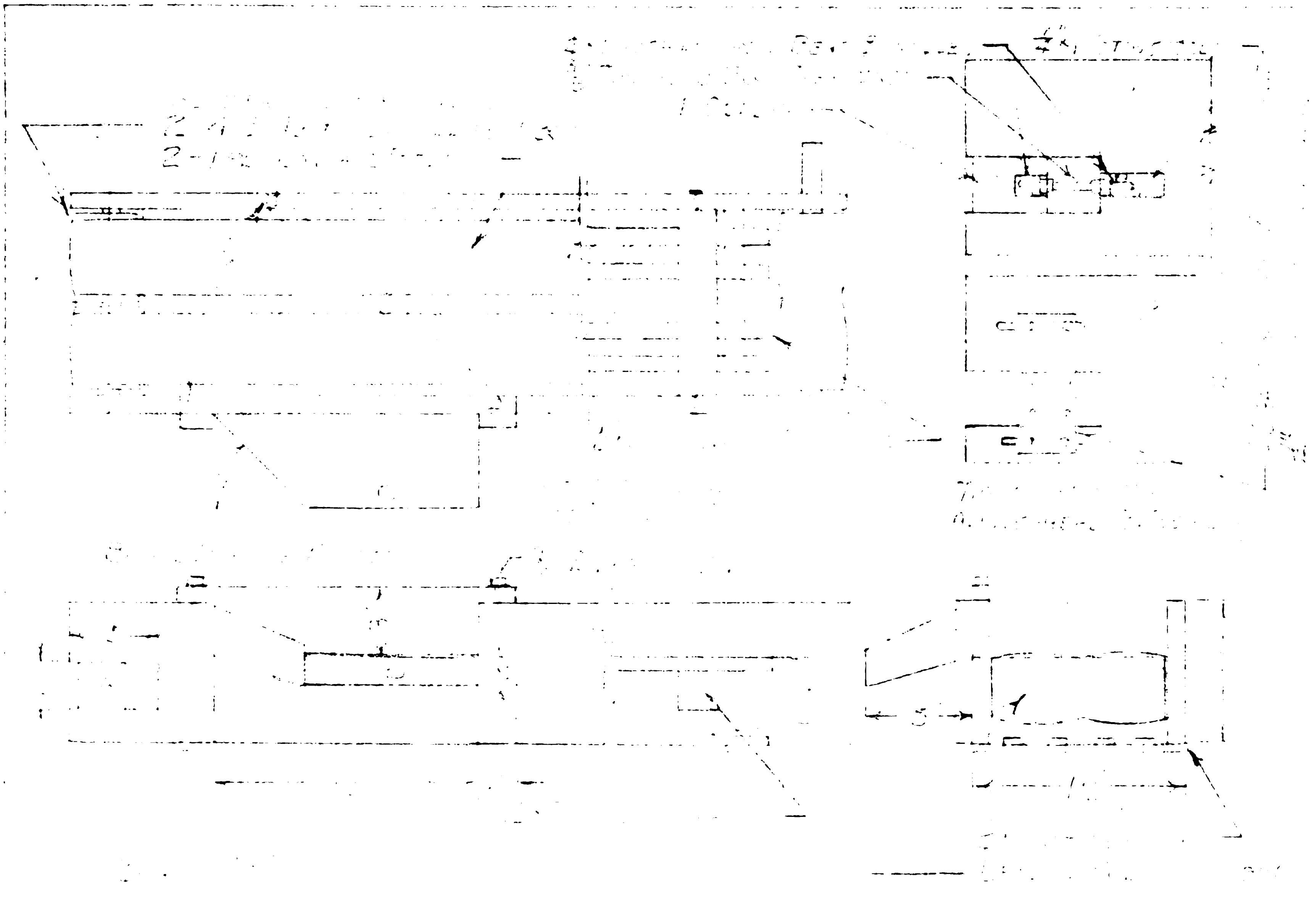


Fig. 34.

was slotted to allow for the necessary tightening action. Tightening is accomplished by inserting hardwood wedges.

Power unit: Both the overhead conveyor and the emptying conveyor were to be driven by an interchangeable power unit. Thus, it was necessary to make this unit portable. In addition, for experimental purposes, it was desirable to have variable driving speeds readily available in the determination of the optimum conveying speeds.

The first consideration was the motor. A $\frac{1}{2}$ hp. 110 v. G. E. motor equipped with thermal "cut-out" was used.

Secondly, the speed reducing unit chosen was a war surplus Vickers pump unit. The speed reduction ranged from one third the motor speed in one direction with gradual reduction to a complete stop and then a gradual increase to one third speed in the opposite direction. This unit was ideally suited to this experimental work.

The power from the motor was transmitted to the speed reducer shaft through a die cast flexible coupling to compensate for misalignment. Then the reduced speed shaft transmitted power through another flexible coupling to a shaft mounted with two ball bearings; a $2\frac{1}{2}$" double V-belt pulley was keyed on the shaft between the bearings. The entire assembly was bolted on a welded steel frame. Steel pipe spacers and shims provided solid mountings at the necessary levels.

Instrumentation

Thermocouples: It was desired to investigate the heating effect within the pile of onions. In addition, it was necessary to obtain the wet and dry bulb temperatures of the air before entering and after leaving the bin. To accurately accomplish this, constantin-copper wire thermocouples were to be deployed throughout the bin.

For each bin and for the crate storage, a complete set of thermocouples was made. Ten were deployed throughout the bin with a wet and dry bulb below and above the bin.

The constantin wire was common for the set in each bin. Individual copper wires for each thermocouple completed the circuit to give the desired local temperature reading on the Brown Recording Potentiometer.[1]

Thermocouples were made by baring a space on the common constantin wire and then winding a bare copper wire tightly around. Perfect electrical connections were insured by soldering the splices.

All thermocouple wires were cumulated at one point and connected by solder to multiple femate recepticles mounted on a panel. The corresponding male plug was attached by a cord to the twelve point recording potentiometer and was to complete the necessary circuit connections.

Instruments and records were centralized at a protected area with a well lighted work bench.

Manometers: Determination of the rates of air flow into each bin was to be made with the aid of inclined tube manometers. Pressure differentials between the air duct and the plenum chamber of each bin were to be measured in inches of water directly. The manometers were made from glass tubing with rubber tubing for the "U". At an incline of thirty degrees, the "U" tube was fastened to a small piece of plywood with small pieces of copper and screws. Rubber padding at the fastening points helped guard the glass from breakage. Graduated scales were inked on heavy paper and were adjustable to the water level. Scales were magnified to read directly in inches.

Upon mounting, a level was used to insure accurate angular position. A base line was scribed on each of the manometers, and the level was adjusted to this line. Screws at four corners were used.

The static pressure differential desired was obtained by extending the low side into the plenum chamber with a three foot piece of glass tubing. To minimize the effect of the velocity pressure at the high side, a piece of rubber tubing was used as a shield.

Thermostatic control of the fan: It was decided to experiment with automatic operation of the fan during the storage period. The fan was to be controlled thermostatically with two thermostats. The fan would operate only when the temperature outside was low enough and when the temperature inside was above that considered too high for proper storage.

If the temperature outside was above the desired, the fan could not operate to supply warm air; or if the temperature inside was sufficiently cold for storage, the fan could not operate. Thus, a definite range was established.

The only discrepancy in this operation was that the thermostats could not distinguish cold dry air from cold damp air. Wet bulb thermostats were not available for the experiment.

Record of fan operation: Time of fan operation was another factor to consider. It was desired to have a record of the number of hours that the fan operated. Several methods were considered of which two were selected as most practical.

A recording volt meter could be connected across the terminals of the fan motor; or the heat from the motor would cause an abnormal raise in the temperature record as scribed by the pen of a recording thermometer.

The latter solution was selected on the basis of practicability and availability of the instruments. A recording thermometer was mounted such that the bulb was in direct contact with the motor. However, insufficient heat was generated to substantially move the scribe.

Calculations

Coefficient of flow: In order to measure the amount of air flow through an orifice, it is necessary to determine its coefficient of flow. By definition the coefficient of flow is the ratio: actual delivery cfm/theoretical cfm.

For this calculation, the fan was to operate at $\frac{1}{2}$" H_2O static pressure. Catalogue rating of the fan at this pressure is 13,760 cfm.

To check this delivery, the air inlet was traversed with a velometer having direct readings in feet per minute. Using the mean velocity, the actual delivery was determined at 15,300 cfm.

Four of the openings were controlled to adjust the static pressure to the desired. The areas and mean velocities of each opening were determined. The resulting theoretical cfm was 23,800.

Coefficient of flow: 15,300/23800 = .64.

Assumptions for this result are:

a. Standard atmospheric conditions.

b. All air supplied by the fan passed through the four air openings.

c. Entrance conditions at all openings into the bins were the same.

d. The coefficient of flow for the air inlet was one.

Rate of air flow: By using the differential static pressure across an opening, the resulting velocity of the air can be obtained. The manometers used indicated the static pressure in inches H_2O. Velocity can be determined directly from Fig. 15 constructed from data given.[2]

Using the formula Q = C A V.

Q - quanity of air flow - cfm
C - coefficient of flow
A - area of opening - sq ft
V - velocity of air - fpm

By application of the above formula, rate of air flow through the opening was obtained. It was assumed that all of the air flow through the orifice passed through the onions.

Determination of moisture removal: Amount and rate of moisture removal is an important consideration. The calculation of this quanity is made possible by use of the psychrometric chart.[4]

The following example illustrates the use of the chart:

Air into bin = 42.7 cfm/sq ft bin floor area
Dry bulb temperature = 55° F.
Wet bulb temperature = 52° F.
Relative humidity = 80%
Specific volume = 13.12 cu ft/lb
Weight H_2O/lb dry air = <u>52</u> grains

Air leaving bin = 42.7 cfm*
Dry bulb temperature = 59° F.
Wet bulb temperature = 58° F.
Relative humidity = 95%
Specific volume = 13.28 cu ft/lb
Weight H_2O/lb dry air = <u>70</u> grains

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* The specific volume of the air leaving the bin will have increased slightly according to the increase in temperature and the decrease in pressure.

a. Determine grains removed/cfm

Air in: $\frac{\text{grains/lb}}{\text{cu ft/lb}} = \frac{52}{13.12} = 3.97$ grains/cu ft

Air out: $\frac{\text{grains/lb}}{\text{cu ft/lb}} = \frac{70}{13.28} = 5.27$ grains/cu ft

Net moisture removal: $5.27 - 3.97 = 1.30$ grains/cu ft

Time rate: grains/cu ft x cu ft/min/sq ft
$1.30 \times 42.7 = 55.5$ grains per min/sq ft

b. Determine time required to remove 1 lb H_2O per sq ft bin floor area.

$\frac{\text{Grains/lb}}{\text{Grains/min}} = \frac{7000}{55.5} = 126$ min/lb

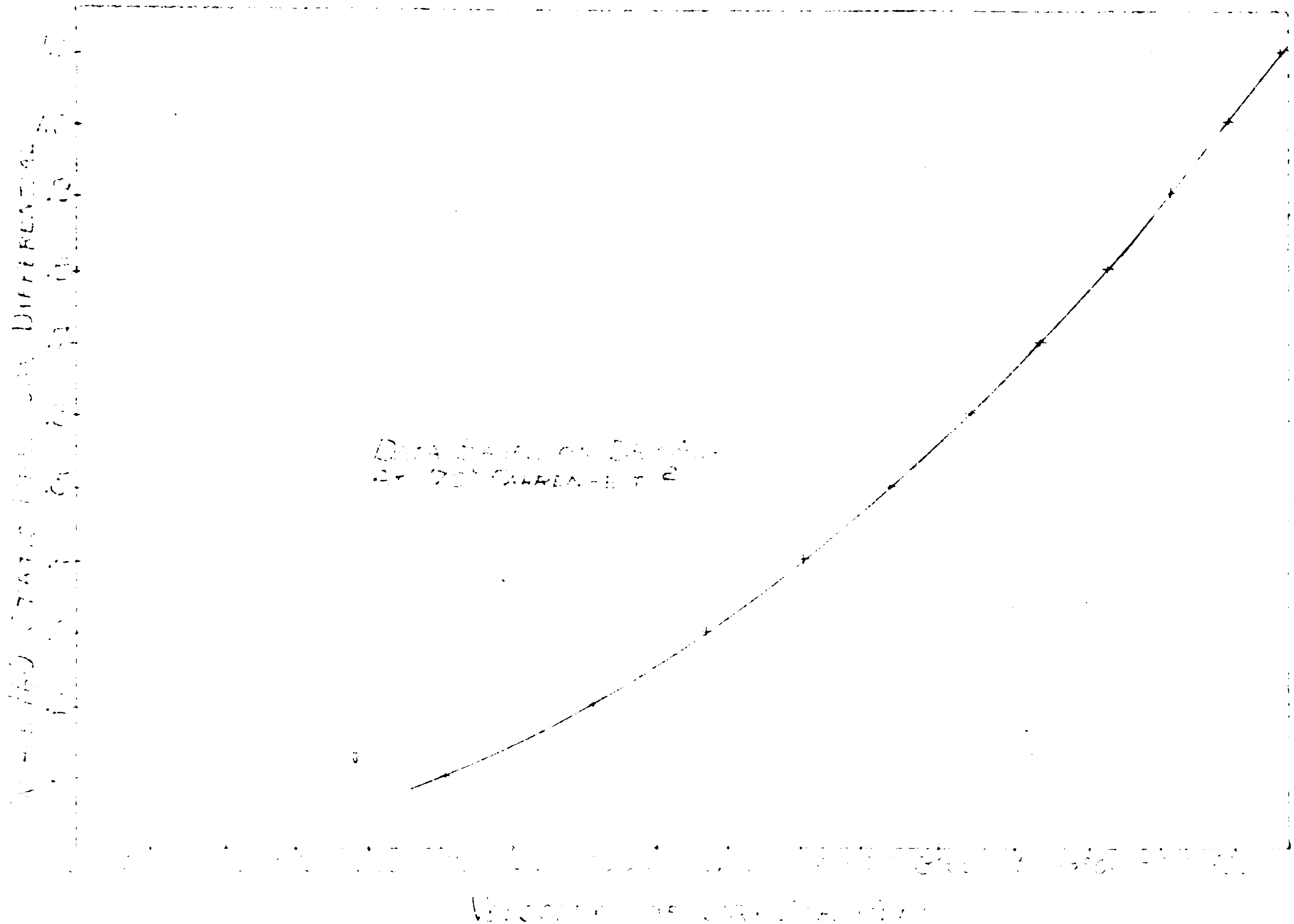

Fig. 15. Curve Showing Relationship Between Velocity and Static Pressure Differential.

Storage of Onions

Shrinkage samples: The harvesting and storing process began in the field where the onions were machine topped into crates. After the field plot weighing, the crates were loaded onto wagons and brought into the storage.

From the lot used to fill each bin, 550 pounds in crates were picked at random and field stacked. This sample was to be field cured and handled normally. Shrinkage at the end of the storage season was to be determined and then compared with shrinkage in the corresponding bin.

Shrinkage within the bin was to be determined similarly. Here again random samples were taken and bagged. Mesh onion bags with fifty pounds net weight were tightly sewed and tagged stating the location within the bin. A total of ten bags were to be placed within each bin.

Filling the bins: Screening, elevation, and conveying of the onions have already been discussed. Use of the filling tube and the actual filling of the bin is the final step in the storing process.

At first, it was thought necessary to eliminate any bruising that might be incurred by the weight of a man moving inside the bin. With this idea, a "boatswain's chair" was to be suspended from the ceiling. A block and tackle would raise the person filling the bin as the level of the onions raised.

Fig. 16. Field Stacked Shrinkage Sample Crates Showing Conventional Curing Method.

Fig. 17. View of Chickering Onion Topper Used in Harvesting.

However, further thought revealed a much simpler solution. The weight of a man moving slowly on top of the onions would create a pressure much less than the succeeding layers of onions. With well padded feet, skinning and gouging of the onions would be practically eliminated.

Thus, a man with well padded feet controlled the filling tube, placed the shrinkage samples, and placed the thermocouples throughout the bin. (Fig. 13.)

Initially, the onions were allowed to fill the canvass tube. By first twisting it from the bottom and then untwisting as the tube became filled with onions, a maximum drop of but one foot was maintained. With the tube continually filled, the onions were let out at the bottom only as fast as they dropped from the swinging chute into the funneled top section of the tube.

The open end of the tube was kept in motion thereby distributing both onions and extraneous mater evenly over the floor area.

After a depth of about one foot was reached, three sample bags were placed. Thermocouples were fixed in place and the filling process was continued.

As the level of the onions raised, the end of the canvass tube was progressively folded upward.

At the filling midpoint, the weight samples and thermocouples were again placed as well as about one foot from the top of the bin.

The original design of the canvass tube was of continuous seam. When the level of the bin approached the top, great difficulty was encountered in folding the tube. This often caused constriction of the opening and a need to halt the filling process.

Filling of the top two feet was best done using a piece of plywood to chute the onions, thereby eliminating the tube entirely. Thus the technique for filling the bin was established.

As an extension of the experiment, various depths, rates of air flow, and varieties of onions were to be used. The bins were numbered for reference from 1 to 7.

Bin No.1 was filled with machine topped Yellow Globe onions to a depth of ten feet. Bin storage of the onions was preceded by a three day field curing period. The bin was to be supplied with air day and night during the bin curing process.

The filling of this bin was an exception to the method described in a previous paragraph. Instead of the canvass filling tube, a telescoping sheet metal tube was used. However, excessive bruising led to discontinued use and to the development of the canvass tube used in all other bins.

Bin No.2 was filled similarly but with the canvass tube. Air was supplied only at night. Field curing for four days preceded storage.

Machine topped Yellow Globe onions from the fertilizer placement plots were stored in Bin No.3 to a depth of ten feet. Field curing for three days preceded storage. Air was supplied continuously but at a somewhat reduced rate.

With the tops on, Yellow Globe onions with no field curing were stored to a depth of eight feet in Bin No.4. Continuous air supply was maintained.

Bin No.5 was filled with Yellow Globe onions machine topped and brought directly in from the field. Depth of filling was nine feet. Air supply was continuous.

Sweet Spanish onions are considered to be more difficult to store than other varieties. On the average, they are larger with a greater tendency to bruise. Since only a limited supply was available, a depth of only six feet was reached in Bin No.6. Here again air was supplied continuously.

A twelve foot depth was attained in Bin No.7. Since the conveyor system was only able to fill the bin to the ten foot level, it was necessary to fill the remaining two feet with sacks of onions. Air supply was to be continuous.

The general condition of the onions at the time of storage was considered excellent. The onions were firm with tops well broken down. Very few large tops were evidenced. By and large, the bulk of the onions were two inch minimum. Some maggot rot was present, but the percentage at storage was not determined.

After seven bins were filled and the outside crate samples were stacked, insufficient onions were available for stacking in crates on the crate storage area.

Management of the storage: Curing in the bins was started immediately. The fan operation was controlled manually in order to supply air only when there was drying effect. Since no heat was added, favorable conditions for drying were obviously not continuous.

In direct conjunction with the fan operation, all temperatures were observed and recorded regularly. The Brown twelve point potentiometer was operated only at the time when readings were desired. For the first two weeks readings were recorded every four hours. For the remainder of the curing process readings were recorded every six hours.

The determination of whether the onions were cured or not was simply one of observation. The top layer was examined for dried tops and dry outer shucks. When this condition was reached, it was surmised that all onions below were cured. All the moisture removed from the onions below must pass through the top layer; and the top layer will not dry until all excess moisture was removed. Thus the foregoing conclusion was logical.

Management during the curing process involved considerable attention. During this period, it seems that the higher temperatures have little effect on the onions insofar as possible spoilage is concerned. Consider that the field curing process is a series of exposures to sunlight and then cold fall nights.

However, after curing, it is desirable to bring the temperature of the onions down to as near $32^{\circ}F$ as possible and hold it constant at that point.

After freezing weather began, it was no longer possible to leave the air inlet open because of the danger of freezing the onions. Automatic fan operation was impractical and manual operation was again resorted to. The fan was operated only when the weather permitted with temperatures above $32^{\circ}F$. It usually amounted to no more than two or three hours weekly.

Removal of onions: The removal of the onions was a progressive process beginning in the late fall and continuing until early spring. A schedule was determined to meet the sales demand.

It was decided to leave one bin intact until spring. The bin chosen for this was the twelve foot depth storage, Bin No. 7.

Since the sales demand was weekly at about fifty bushels, each of the remaining bins was to contribute approximately eight bushels. This meant continually disturbing the pile of onions, but it was thought that the storage results would not be affected significantly.

Weight data was recorded. Total weight, number of pounds sprouted, and number of pounds rotted were itemized. Possible value from this data might link the length of storage with the progressive amount of deterioration.

Checking shrinkage samples: As the shrinkage samples appeared from within the pile, total weights, pounds of rot, and pounds of sprouts were to be recorded along with the position of each within the bins.

The same data was to be obtained from the field cured samples and compared with the bin samples at the end of the storage season. However, there was premature sale of the field cured samples for six of the bins. Thus, a true comparison at the end of the season was not possible. The samples for bin No. 7 were kept until the end of the season before sale.

The data for each of the bins is summarized on the following pages.

Removal from the bins was not done entirely with the aid of the removing conveyor. Construction of the conveyor was completed later in the season. Much of the bin could be emptied through the slatted wall sections - although at some inconvenience. Crates were filled one at a time by placing on the storage floor and allowing the onions to drop from the slatted floor level. Onions from the bins with openings into the air duct were unhandy to remove. With the aid of the conveyor as shown in Fig. 18 and 19, the onions were easily handled.

Fig. 18. Removal of Onions with Conveyor in Place.

Fig. 19. Driven End of Conveyor with Hydraulic Reduction Unit.

RESULTS FROM THE INITIAL EXPERIMENT

Since the initial experiment was of an exploratory nature, the results have been largely from analysis based on observation rather than statistics. There was no guide available other than the practical recommendations of others. Then too, so many variables were necessarily entered into the problem that the storage results may or may not be due to the various storage treatments.

The construction of both bins and handling equipment were considered highly satisfactory from the functional view point. Also, the technique for filling and emptying the bins was established and found to be practical, at least on the experimental scale. Thus, the major portion of the problem was considered successful.

As for the practicability of the bulk storage method for curing and storing onions, it remains to be judged from the forthcoming results and analysis.

In all cases, it is now believed that too much air was forced through the bins during the curing process. Secondly, fan operation during the storage season after curing was insufficient. Because of these two factors, the bin samples may have undergone abnormal shrink.

In addition, the premature sale of the field cured weight samples on November 5, 1949, does not permit a true comparison on the storage methods. Thus, the results unjustly favor the field cured storage method.

Bin Number	1		2		3		4		5		6		7	
1 Variety of Onions	Yellow Globe		Yellow Globe		Yellow Globe		Yellow Globe		Yellow Globe		Sweet Spanish		Yellow Globe	
2 Pre-storage Treatment	3 day F.C. Mach. Top		4 day F.C. Mach. Top		3 day F.C. Hand Top		No F.C. With Tops		No F.C. Mach. Top		1 day F.C. Mach. Top		2 day F.C. Mach. Top	
3 Air Flow Rate $\frac{cfm}{sq ft}$	42.7		42.7		41.3		42.7		40.[illegible]		33.1		41.8	
4 Depth of Storage	10'		[illegible]		10'		8'		9'		[illegible]		12'	
5 Hrs. Fan Operation	567		377	Cure night only	494		494		490		456		456	
6 Shrinkage Sample	Bin	Out	Bin	Out	Bin	Out	Bin	Out	Bin	Out	Bin	Out	Bin	Out
7 Weight at Storage	200	550	400	550	400	550	350	550	400	550	[illegible]	550	[illegible]	550
8 Weight of Removal	184.3	509.7	377.6	504.7	[illegible]	[illegible]	[illegible]	507.4	361.6	[illegible]	[illegible]	[illegible]	471.1	[illegible]
9 % Weight Shrinkage	7.9	7.3	5.6	8.[illegible]	7.3	12.1	6.[illegible]	7.7	6.6	[illegible]	[illegible]	9.4	5.8	[illegible]
10 % Sprout and Rot	4.5	1.	3.4	1.8	5.4	2.0	1.5	2.4	11.8	1.6	14.6	3.6	5.7	[illegible]
11 % Total Loss	13.4	8.3	[illegible]	[illegible]	12.7	13.1	7.5	10.1	21.4	[illegible]	22.5	13.0	11.5	14.[illegible]
12 Date Sample Graded	[illegible]/50	11/4[illegible]	[illegible]/50	11/4[illegible]	3/50	11/49	2/50	11/49	1/5[illegible]	11/4[illegible]	3/50	11/4[illegible]	3/50	3/50

Table 1. Storage Results Based On Shrinkage Samples Recovered.

Analysis of Individual Bins

Bin No. 1 shows a slight increase in weight shrinkage (line 9) with a considerable increase from rot and sprout. Excessive bruising at the time of storage from the sheet metal tube may have caused these results. Also, the weight of sample recovered may not have been sufficient to base a true comparison.

Bin No. 2 shows a slight advantage for the bin cured samples. If the two samples were checked at the same time, the results may have shown a greater advantage. The onions were much smaller on the average and were handled using the canvass filling tube. As compared with Bin No. 1, the fan was operated only at night so that less total air was used. This could mean less weight shrinkage.

Bin No. 3 indicates some advantage for the bin cured samples. Since the air supply was continuous, a comparison of results with Bin No. 2 is interesting. Results indicate that too much air may be wasteful, as it causes excess shrinkage.

The onions in this bin were supplied from plots with different cultural practices. It has been observed that the keeping quality of onions may be affected by the type of cultural practices; i.e. fertilizer placement, amount of fertilizer, moisture conditions, etc. Thus, more variables will tend to alter the results.

Results for Bin No. 4 were highly significant in that the onions were stored with the tops on. Observation by the screening crew made special note of the consistant better keeping quality of this bin. The results show a definite advantage of the bin cured over the field cured. While the shrinkage of the outside samples for this bin compares with the other samples, the bin curing is by far superior considering the time basis for comparison.

It might be explained that the disadvantage of the onions with tops on is one of removal of these tops at the time of screening. No method is available at this time for removing other than by manual means. If successful research was conducted on this particular phase, this new method for handling onions might come into prominence.

Bin No. 5 shows drastic shrinkage. Consider that the onions from this bin were stored directly from the field. In addition, the weather at the time was rainy.

The results tabulated do not account for the dates of the progressive removal of the bin samples. Closer investigation reveals that while considerably more shrinkage occured in this bin than in the others, a rapid decline in the condition of the onions occurred at the time when the fan was not operated for a period of nearly a month.

So, while the storage results for this bin of onions are definitely inferior, it seems that the contributing factors have magnified this inferiorty.

Storage directly from the field is one of the many advantages of the bulk handling method. Therefore, it is necessary that there be much more investigation of this type of storage treatment.

Bin No. 6 of Sweet Spanish onions at a depth of six feet is another example of drastic shrinkage. According to information available, the storage of this variety is extremely difficult. The results bear this out.

The size of these onions was $2\frac{1}{2}$" - 3" minimum and may have been badly bruised in the handling, more so than the other bins.

The only samples recovered were two fifty pound bags. With only two samples as a basis, a logical comparison is hardly possible.

Reference is made to the note on page 5 that work is being done on this particular phase in Colorado.

Bin No. 7 is the only one available for a true comparison with the field cured method. The results show a marked advantage for the bin storage.

The onions in this bin were stored at a depth of ten feet with two additional feet in sacks to give the effect of twelve foot storage depth. Observation from the screening crew indicate that much of the sprouting may have been due to these sacks on top.

The onions from the bottom layers were observed to be sound with slight deformation due to the weights above. However, it was pointed out that the deformation was not sufficient to affect the quality for sale. Onions from this bin were slightly more deformed than onions in the other bins.

The condition of the onions at storage was very good. Size was 60 - 70% 2" minimum.

Note from the results that the percentage of weight shrinkage for this bin is much less for bin storage than for crate storage. This is significant from the economic viewpoint of the grower. A certain amount of weight loss is expected, but if this weight loss can be reduced by bulk storage, certainly this further justifies the means.

Rates of Air Flow

From recommendations made by the available sources, the rates of air flow chosen were as shown in Table 1, line 3. While these rates seem considerably in excess of what might be used in practice, it was felt that an excess of air would be better than an insufficient amount of air for this initial work.

Since then, practical applications and economic consideration have indicated successful results with flow rates as low as 10 - 12 cfm for each square foot of floor area.

Specifically, these rates have been associated with storage depths of ten and twelve feet.

Thermal Effects Within The Bin

As was mentioned, thermocouples were distributed throughout the bin for the purpose of investigating the thermal effects within the pile. It is known that certain respiration processes in onions do give off heat.

However, since the rate of air flow was so much in excess, the thermocouple data merely indicated a time lag in atmospheric temperatures. This of course reduced the value of the data taken insofar as this investigation was concerned.

Fan Operation

Management of the storage and the fan operation are very important. On a large scale, excessive operation will mean expensive losses in operating costs and weight shrinkage. On the other hand, inadequate operation will result in serious losses from rotting and sprouting. Management during the storage season is especially difficult in view of subfreezing weather and controlled recirculation of air seems necessary. Constant inspection of the onions is absolutely essential. With crate storage, it is not as necessary for this continual attention.

At this time, satisfactory instruments have yet to be devised for the complete automatic control of the blower fan. The Minneapolis-Hunnewell Company of Detroit is currently investigating the needs of crop drying installations.

SUMMARY

The results from this initial experiment indicate strongly that bulk storage is a practical method for curing and keeping onions. Results from work done on a much larger commercial scale further indicate the merits of the system.

While the optimum depth is not determined by the experiment, the twelve foot depth has proven to be practical from the economic standpoint. Deformation of the bottom layers of onions has not been sufficient to seriously affect the quality for sale. Along this same thought, the size of the onions is directly associated with the depth that they can be stored. The larger onions suffer much more than the smaller size.

A rate of air flow has been determined to give satisfactory results; specifically, the rate in use is twelve cfm/sq ft area at the ten or twelve foot depth. This is important in the selection of fans for large installations. Oversize fans mean greater capital investment. Also, if electricity is to be the source of power, definite limitations are placed on the horsepower available - especially in the rural districts.

Air temperatures for the curing process were atmospheric for the initial work. Further investigation of the Psychrometric Chart shows that the efficiency of the air in drying would be increased when operating at the higher temperatures.

Thus, the addition of heat seems a logical improvement. Whether the increased cost of adding heat would justify the use is a problem in economics.

Supplying heated air during the day and then cooling the onions down at night with cool air has been suggested. Fluctuation of temperatures during the curing process does not seem to have too much effect on the storage qualities.

The onion enters a period of dormancy after curing, and it is necessary to keep conditions favorable for this phenomena. Dry storage at 32° F. is considered ideal.

In evaluating the work done, it must be considered that this is the initial experiment of a project which should be continued for several seasons. In view of the fact that statistically, the results had little meaning, the objectives of the research were quite successfully investigated.

SUGGESTIONS FOR FURTHER STUDY

A. While the handling system was found to be very satisfactory, several changes are recommended.

1. Reduce the speed of the main elevator and double the number of flights, thereby keeping the capacity constant.
2. Remodel the baffle boards at the interception points to crowd the onions off the conveyor more easily and with less clogging.
3. Section the canvass tube so that as the bin is filled, these sections may be removed progressively, thus eliminating the constriction difficulties. Perhaps a zipper may be used.
4. Have control of all conveyors and elevators at the point where the person filling the bin is located. Switches to the motors hanging from a spring packed coiled leader cord may be a solution.

B. Bin samples were placed with difficulty since the floor area was so limited. These fifty pound samples might by substituted by smaller samples with more accurate weight determination.

C. Thermocouples used were directly exposed to the flow of air through the onions. An increase in effectiveness may result from one of the following:

1. Shielding the thermocouple in some manner.
2. Insert and seal the thermocouple in an onion.

D. In the operation of the fan, several possibilities should be considered.

1. Investigate the use of heat especially in the curing process. Temperatures up to 140° F. have been suggested.
2. Redesign the air inlet to provide some measure for recirculation and its control, possibly by automatic means. Recirculation is especially necessary during the sub freezing weather often experienced in the storage season.
3. Investigate some means for de-humidifying the air chemically. Some work has been done with Calcium Chloride and perhaps may be applied to onion storages.
4. Automatic controls to include humidity considerations. Also a fan operation record using the recording thermometer idea, but with a different source of heat. A heating coil in parallel with the motor circuit is suggested.

E. Pressures against the sidewall as exerted by the onions is a variable depending on the condition of the onions. The natural angle of incline is a contributing factor as well as the conditions of moisture on the surface of the onion. Further investigations suggested:

1. Observe behavior of onions in pile at different heights.

2. Investigate effect of moisture conditions and what happens as onions dry out.
3. Measure the sidewall pressure perhaps using the deflection of the sidewall stud. For accuracy in this phase, perhaps use a steel beam of uniform specifications.
4. Correlate this actual pressure with a theoretical analysis. Investigate pressures at different heights and conditions and tabulate as reference data.

F. For the onion storage project as a whole, store onions of the same variety, with as near identical cultural practices and handling procedure as possible. This will permit the use of statistical analysis to validate the merits of different storage treatments.

G. Investigate the effect on the storage quality of onions from bruising. Correlate the effect of size and height of fall as well as general condition of the onion with the susceptibility to rotting and sprouting.

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