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EC735 Hay Curing with Forced Air

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CURING HAY with Forced Air

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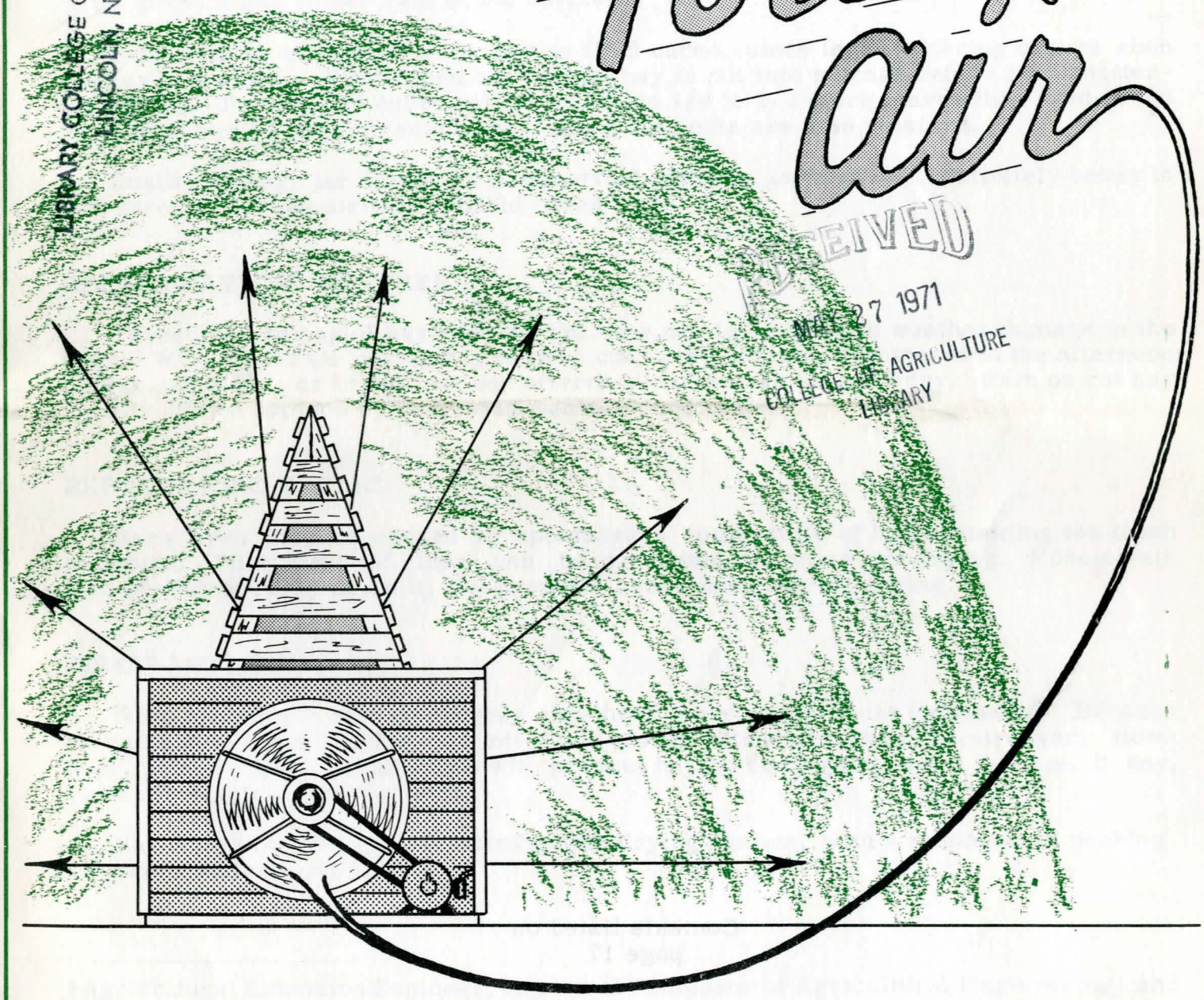

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Hay Curing With Forced Air

by
E. A. Olson, G. M. Petersen and F. D. Yung*

Forced air curing is a proven method of reducing haying losses. Early removal of hay from the field a high moisture content reduces leaf loss and possible weather damage. Curing is finished by forcing air through the hay.

MORE LEAVES - BETTER HAY

The saving of leaves is of major importance with legume hays. In alfalfa, leaves average less than 50 per cent of the total weight but contain approximately 70 per cent of the protein and 90 per cent of the carotene.

Leaf loss is extensive when hay is field cured, since leaf shattering occurs when dry hay is handled. With forced air curing, hay is put into storage before leaf shattering begins. Forced-air cured hay may contain 1/4 to 1/3 more leaves than field cured hay, as shown by experimental data. More nutrients are also retained.

Quality of hay, as shown by commercial grading, is in general definitely better in hay cured by forced air than in field cured hay.

HELPS BEAT THE WEATHER

Forced-air curing of hay reduces the time hay is exposed to weather damage in the field. With forced air curing hay may be cut in the morning and stored in the afternoon of the same day, or to cut late one afternoon and stored the next day. Rain on cut hay usually can be avoided by observing weather conditions.

REDUCES FIRE HAZARD

Barn fires may be caused by spontaneous combustion of hay containing too much moisture. This type of loss can be prevented by forced-air drying. Forcing air through hay not only dries it, but prevents overheating during drying.

DISADVANTAGES

With forced-air drying roughly one-third more weight must be handled. Because of this added weight haying equipment and storage structures must be stronger. However, research data indicate that with present haying equipment, there is little, if any, increase in labor requirements.

Hay must be carefully distributed on the drying system, with a minimum of packing, to permit uniform air flow.

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*Agricultural Extension Engineer, Assistant Professor in Agricultural Engineering, and Research Engineer in Rural Electrification, respectively.

COSTS

The cost of a hay drying installation, including blower and motor, usually ranges from $500 upward, exclusive of labor, depending on current prices and conditions under which the installation is made.

The use of the fan or blower required for forced-air curing of hay need not be confined to the hay crop. It can also be used for grain and seed drying, if it will give sufficient air delivery at static pressures up to 3 inches water column.

Power costs for drying hay will depend on the moisture content of the hay when it is placed on the drier, on weather conditions during the drying period, and on the quantity of hay involved. Under average conditions, with an electric motor, about 50 kilowatt-hours per ton will be used. At existing electric power rates this would be $0.75 to $1.50 per ton.

Overall annual costs, including operating costs plus usual fixed charges (depreciation, interest, repairs and insurance), may range from $1.60 to $3.00 per ton for hay cured in quantities of 50 tons or more. The average may be expected to be $2.00 to $2.25 per ton.

Requirements For Forced Air Drying

Three main items of equipment are necessary for drying hay with forced air. These are: (1) a power unit, preferably an electric motor; (2) a blower or fan, the size and type to be determined by specific needs; and (3) an air distribution system adapted to the storage.

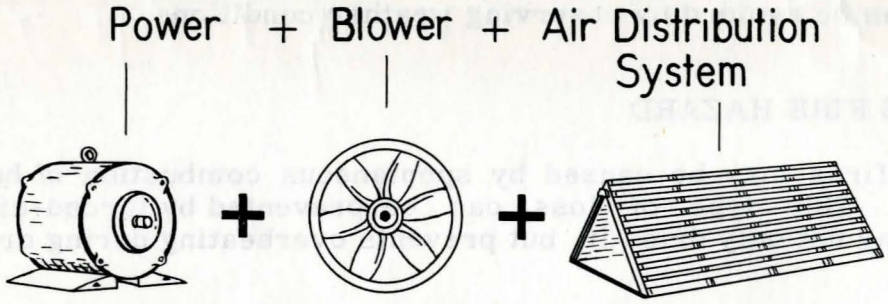


Fig. I—Requirements For Forced Air Drying.

POWER UNIT AND CONTROLS

The power unit used for operating the blower may be either an electric motor or an internal combustion engine. An electric motor is most commonly used because it is quiet, simple to operate, requires little attention, is adaptable to automatic controls, and presents little fire hazard. The electric motors on most single phase rural lines are limited to 7 1/2 horsepower or less. The local power supplier should be consulted before a motor is purchased.

Electric Motor Controls - When an electric motor is used, a starting switch with built-in overload and under-voltage protection is recommended. Starting switches may be of either manual or magnetic type. If automatic control of the power unit is desired, a magnetic type switch must be used.

Magnetic starter switches are of two general types. With the usual push button control, one type will re-close whenever the power comes back on after interruption, unless the "stop" button has been pushed. The other type magnetic switch will remain off after a power failure until the "start" button is pushed.

When a magnetic type starter switch is used with automatic controls, some form of manually controlled switch should also be installed. The manual switch should be opened for positive protection against the motor starting during inspection, service, or repair.

BLOWER UNIT

Common ventilating fans, ensilage blowers, threshing machine blowers, and similar units are not designed to move air against any appreciable static pressure, and are therefore not suitable for hay drying. Blowers to be used for hay drying must be capable of moving relatively large volumes of air against static pressure of at least 1 inch water column. For grain drying static pressures may be as high as 3 inches.

Four general types of blowers suitable for forced-air drying are available - the propeller fan, the forward-curved blade centrifugal blower, the backward-curved blade centrifugal blower, and the vaneaxial fan. Characteristics of these four types of blowers are shown in the following table:

BLOWER CHARACTERISTICS

Blower	Price	Efficiency	Noise	Operating Characteristics
Forward-curved Centrifugal	Medium-Low	Fair	Low	Blower speed must be changed with variation in static pressure to maintain uniform power demand. Suitable for use at static pressures of 3 to 4 inches water column.
Backward-curved Centrifugal	Medium-High	High	Low	Moderately uniform power demand without speed change through usual operating pressure range. Suitable for use at static pressures of 3 to 4 inches water column.
Propeller	Low	Good	High	Fairly uniform power demand without speed change. Suitable for use at static pressures less than 2 inches water column.
Vaneaxial	High	High	Medium	Fairly uniform power demand without speed change through usual operating pressure range. Suitable for use at static pressures up to 2 1/2-3 inches water column.

In selecting the blower for a particular installation, three factors must be considered - power, air flow and static pressure. It is necessary to obtain manufacturer's data showing air volumes to be expected when the blower is operating at different speeds against different static pressures. These data should show the power necessary to drive the blower under each condition. With such data, a suitable blower may be selected in accordance with the following discussion:

Power - Power requirements of the blower selected must not exceed the available power. The power unit may either be belted or direct-connected to the blower. A belt drive is generally preferred, since the blower speed may then be readily adjusted to suit different operating conditions. Furthermore, with a belt drive, the power unit may be removed for use on other jobs.

Air Flow and Static Pressure - The time required to dry hay is determined largely by the rate of air flow. High air flow produces fast drying. However, power requirements and operating costs increase rapidly as air flow is increased. The following rates of air flow have given good drying results with reasonable power requirements and drying costs:

1. For long hay, 18 cfm (cubic feet per minute) per square foot of floor, 1 1/2 cfm per cubic foot of storage volume, or 600 cfm per ton of dried hay. With this air flow, static pressures range from 3/4 to 1 inch water column.

2. For chopped hay, 20 cfm per square foot of floor, 2 1/2 cfm per cubic foot of storage volume, or 600 cfm per ton of dried hay. Static pressures may range up to 1 1/4 inches water column.

3. For baled hay, 30 cfm per square foot of floor, or 800 to 1000 cfm per ton of dried hay. Static pressures will range between 3/4 and 1 1/4 inches water column.

Selecting the Blower - To select the blower for a particular installation, the following steps must be followed:

Step 1. Determine floor area in square feet, storage volume in cubic feet, or tons of dried hay per filling.

Step 2. From air flow rates recommended above, determine the necessary flow and the probable static pressure for the intended hay conditions.

Step 3. Multiply value determined in Step 1 by air flow rate of Step 2 to find required cfm capacity of blower.

Step 4. From manufacturer's data for the type of blower desired, select the size of blower which will give the required air flow, as determined in Step 3, at the static pressure determined in Step 2.

At the same time the blower size is determined in Step 4, the power required to operate the blower should be noted. Different sizes and types of blowers may not require the same amount of power to deliver the same air flow at a given static pressure. Careful blower selection is important in making efficient use of power.

If a blower cannot be obtained which will deliver the required air flow with the available power, a lower air flow rate may be used, but drying will be slower. Power requirements can also be lowered by decreasing the quantity of hay dried at one time. This can be done by reducing the size of the installation, or by limiting air flow to part of the system. The divided main duct system shown on page 10 is commonly used to dry hay in half the mow at one time.

Air Distribution Systems

There are two general types of air distribution systems that may be used in a hay drying installation: (1) the central main duct or A-frame system, which distributes air through the center of the hay storage, and (2) the slatted floor or lateral duct system, which distributes air over the floor of the hay storage.

In selecting the distribution system, the tightness of the side walls and the width of the storage area must be considered. Storage structures may be classed as either tight-wall or open-wall. A tight wall has well fitted tongue and groove boards or comparable construction. A wall having visible cracks between siding boards should be classed as an open wall.

For storage spaces up to 18 feet wide with tight walls, or up to 22 feet wide with open walls, a central main duct or A-frame air distribution system is usually advisable. For tight-wall storages 20 feet or more wide, or open-wall storages 24 feet or more wide, a slatted floor or lateral duct system will probably give better results. Outdoor stacks are best dried with central main duct or A-frame air distribution systems.

A-FRAME SYSTEM

The A-frame, as shown in Fig. 2, is simple to construct and low in cost. The frame members are generally made of 2 x 4's; but for frames more than 6 feet wide, 2 x 6 members may be required. Framing members are generally spaced 2 feet apart and covered with 1-inch boards spaced 2 inches apart, or with cribbing. The inside cross-sectional area of the frame must allow 1 square foot of area for each 1000 cfm air flow.

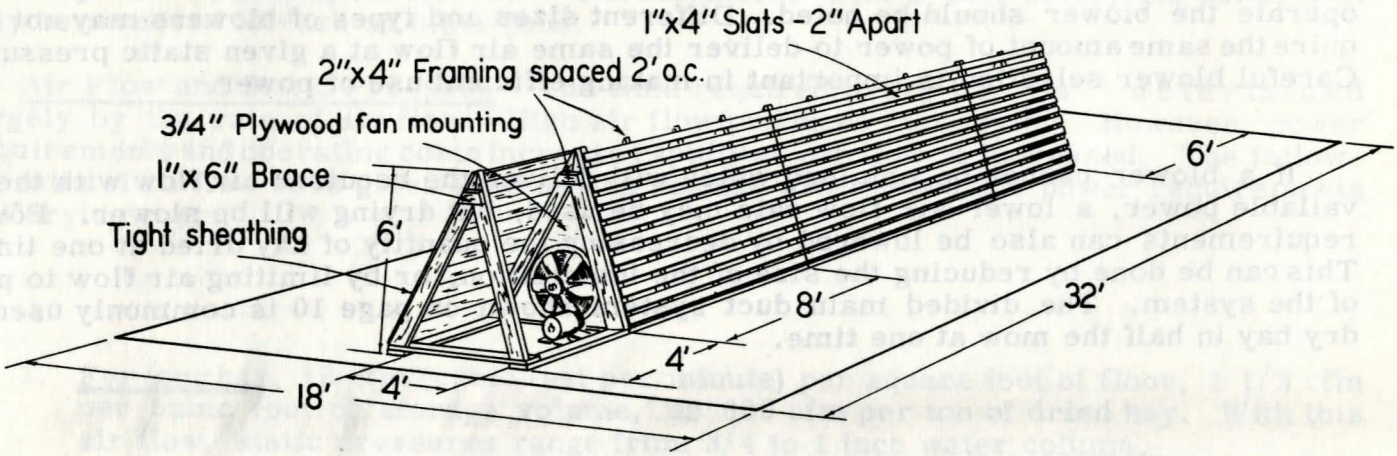


Fig. 2 - A-Frame Air Distribution System.

The shape will need to conform in general to the shape of the hay storage area. For a narrow high mow the A-frame should be narrow and high. If the mow is wide and low the frame should be wide and low. The object, in all cases, is to build the duct so that the covering of hay will be of uniform thickness on sides and top for satisfactory drying.

For example, assume a hay mow 20 feet wide and 36 feet long, with a possible hay depth of 14 feet. The floor area will be 20 x 36 or 720 square feet. As discussed under blower selection, page 4, for chopped hay the rate of air flow should be 20 cfm per square foot of floor, at 1 1/4 inches static pressure. Therefore, the fan should deliver 720 x 20, or 14,400 cfm. For this purpose, a fan delivering approximately 15,000 cfm at 1 1/4 inches static pressure should be selected.

Allowing 1 square foot per 1000 cfm, the area of the A-frame should be at least 15 square feet. A duct 6 feet wide at the bottom and 6 feet high would have an area of 18 square feet (6 x 6 divided by 2), adequate for the air flow. With the duct 6 feet wide at the bottom the distance to the wall on each side will be 7 feet. If the duct is 6 feet high, hay may be piled to a depth of 12 to 14 feet without making too long a path for the air. Therefore, this size and shape duct is satisfactory for the hay now.

When the A-frame is used in a mow with tight side walls, wire cribbing or slats should be nailed to the inside of the wall studs to allow air to escape.

Hay placed on the A-frame must be distributed to uniform thickness on sides and top. This will prevent excessive loss of air through thin layers of hay. Later cuttings of hay may be satisfactorily dried by placing a uniform layer of wet hay on top of the previously dried cutting, as shown in Fig. 3. Another method is to move the dry hay away from the frame so that wet hay can be placed directly on the frame.

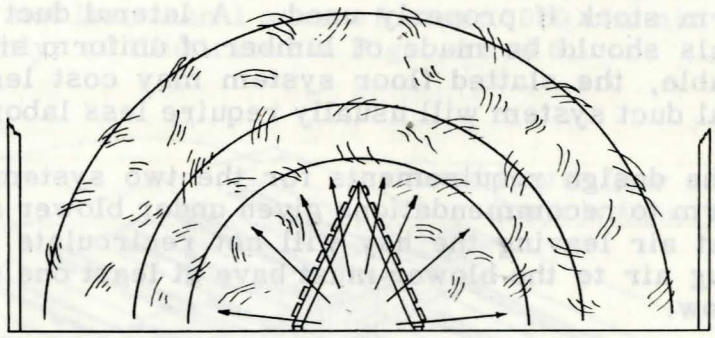


Fig. 3–Successive Fillings Placed In Uniform Layers.

SLATTED FLOOR AND LATERAL DUCT SYSTEMS

The slatted floor system and the lateral duct system are similar in requirements and operation. Both require an air tight floor. Both have a main duct through which air is brought into the storage space. Both distribute the drying air over the floor so that air moves upward through the hay. The slatted floor system will usually give slightly better air distribution than the lateral duct system, particularly with chopped hay. However, this difference is too small to warrant any appreciable increase in construction cost. The lateral duct system is more easily moved than is the slatted floor system, and cleaning the storage area is simpler.

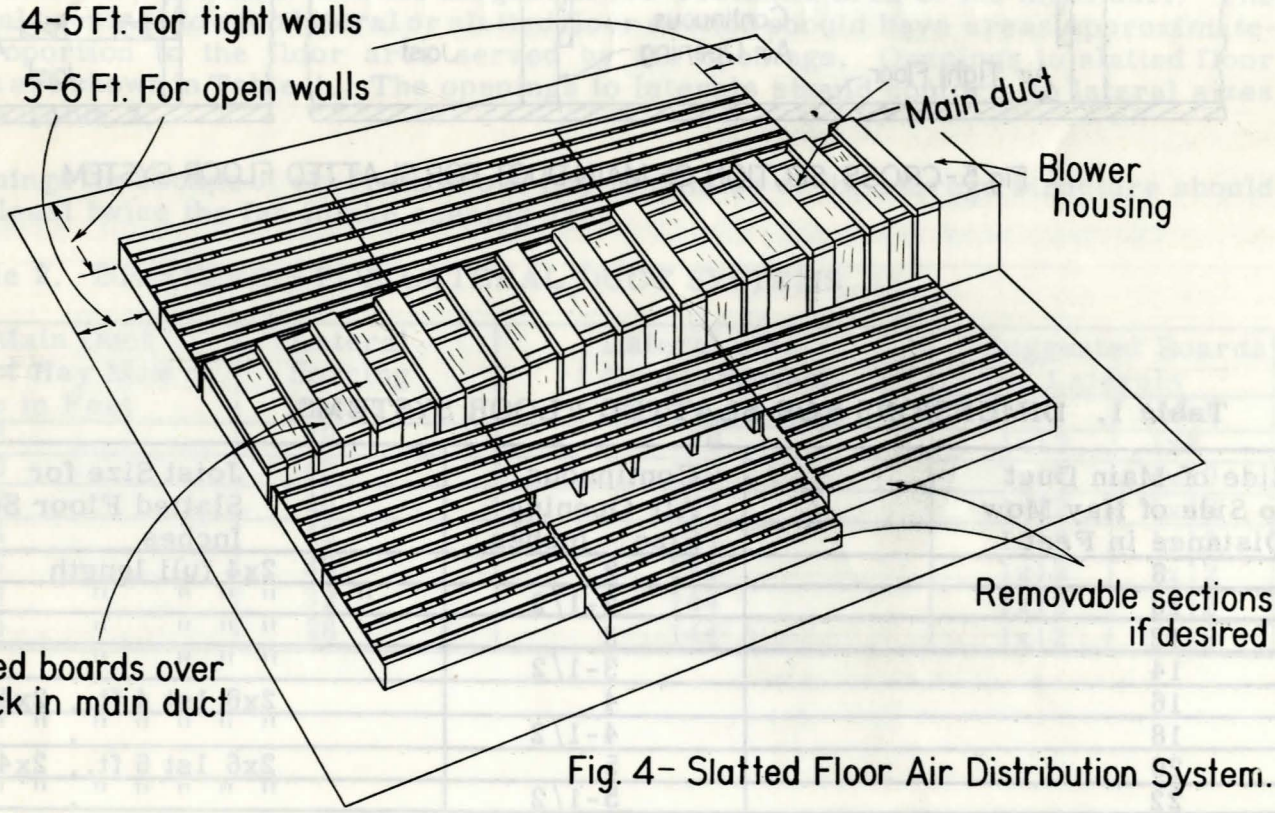


Fig. 4– Slatted Floor Air Distribution System.

A slatted floor system is shown in Fig. 4. While this drawing indicates uniform size slats on the slatted floor section, the slats might well be of irregular or non-uniform stock if properly used. A lateral duct system is illustrated in Fig. 6. The laterals should be made of lumber of uniform size. If reclaimed or native lumber is available, the slatted floor system may cost less. If new lumber is to be used, the lateral duct system will usually require less labor and may require less material.

The design requirements for the two systems are the same. The blower should conform to recommendations given under blower selection, page 3. It must be located so that air leaving the hay will not recirculate through the blower. The opening admitting air to the blower must have at least one square foot of area for each 1000 cfm air flow.

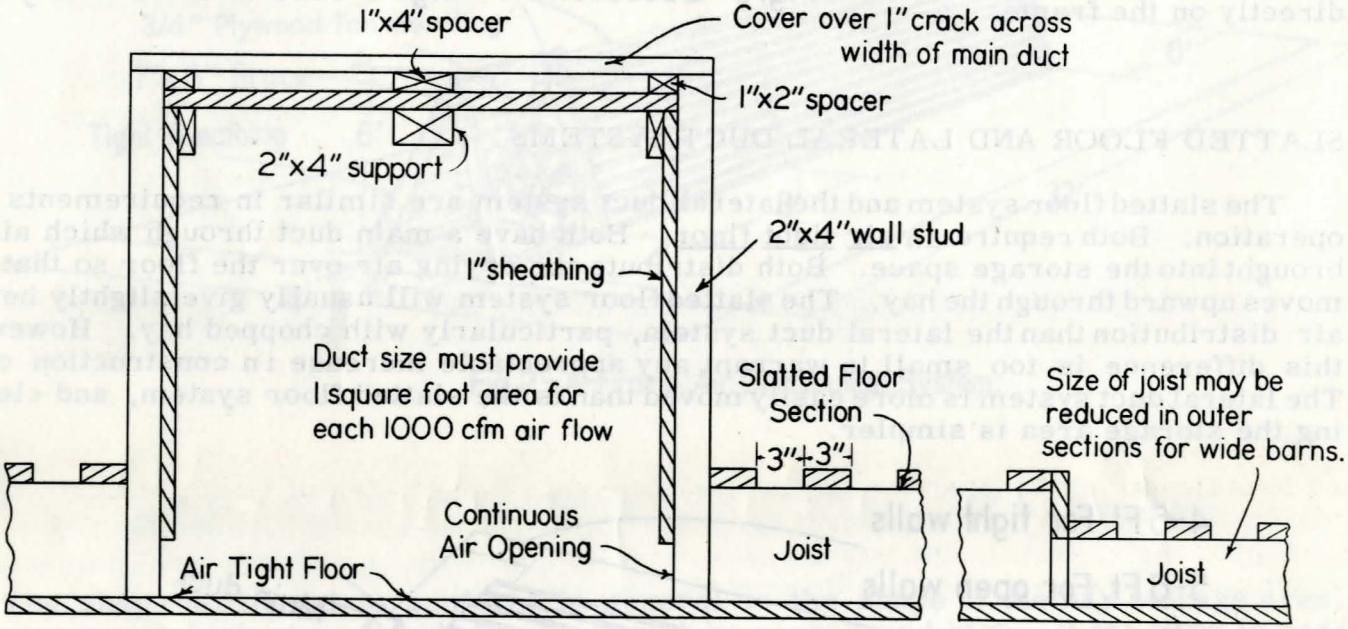


Fig. 5 - CROSS SECTION OF MAIN DUCT FOR SLATTED FLOOR SYSTEM

Table 1. DIMENSIONS FOR SLATTED FLOOR SYSTEMS.

Side of Main Duct to Side of Hay Mow Distance in Feet	Continuous Air Opening Size - Inches	Joist Size for Slatted Floor Sections Inches
8	2	2x4 full length
10	2-1/2	" " " " "
12	3	" " " "
14	3-1/2	" " " "
16	4	2x6 1st 4 ft., 2x4 beyond
18	4-1/2	" " " " " " " "
20	5	2x6 1st 6 ft., 2x4 beyond
22	5-1/2	" " " " " " " "

The main duct must be shaped to permit connection of the blower for unobstructed delivery of air from the blower discharge into the duct. At the blower end, the main duct cross-sectional area should be not less than 1 square foot per 1000 cfm air flow. The main duct may be tapered uniformly, as illustrated in Figs. 4 and 6.

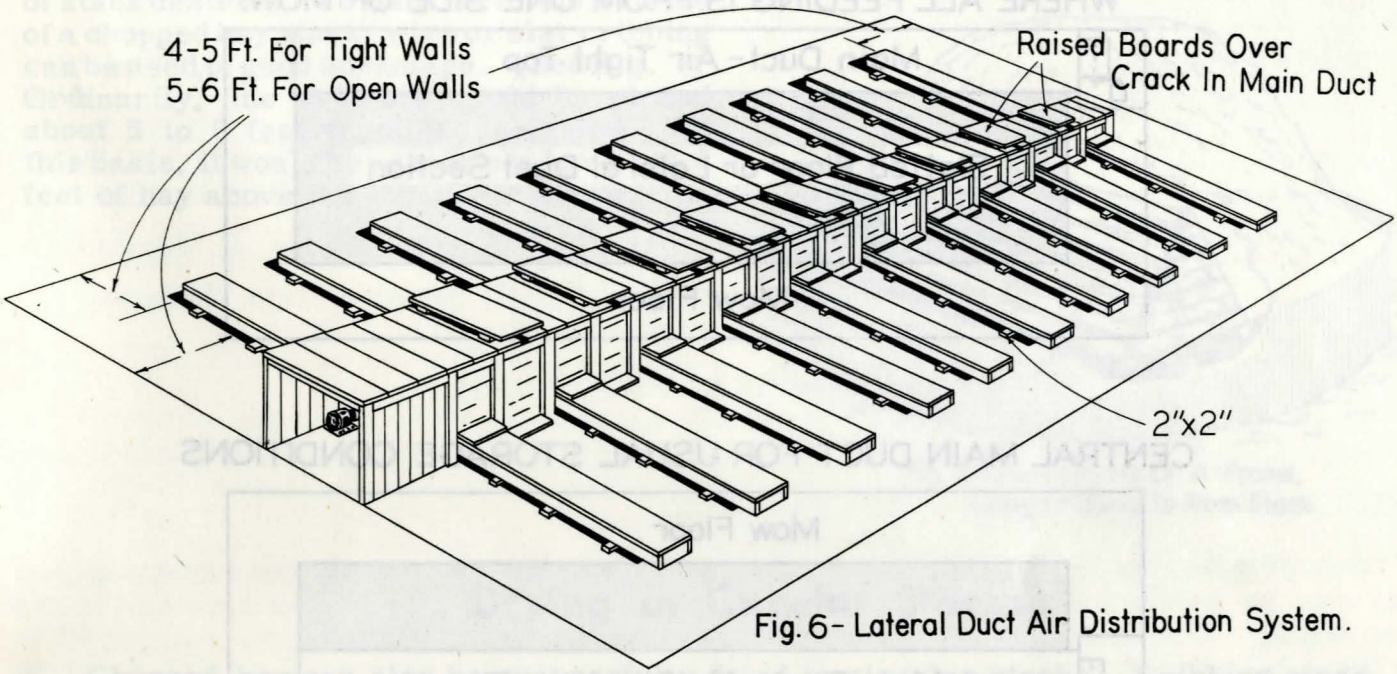


Fig. 6- Lateral Duct Air Distribution System.

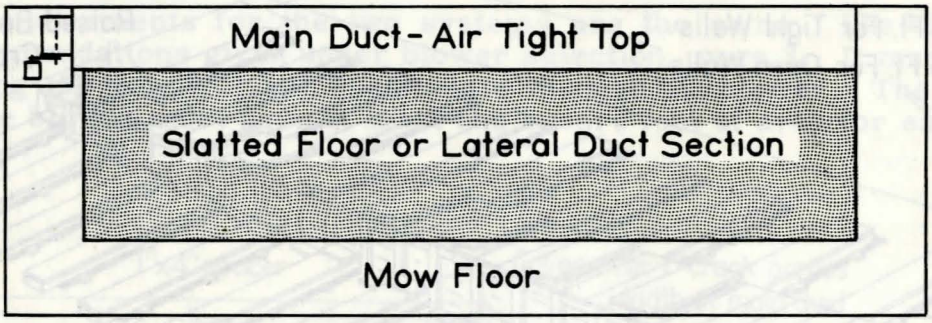
The total area of openings from the main duct to laterals or to the slatted floor sections should be not less than the largest cross-sectional area of the main duct. The individual openings to each lateral or slatted floor section should have areas approximately in proportion to the floor area served by the openings. Openings to slatted floor sections are shown in Table 1. The openings to laterals should conform to lateral sizes shown in Table 2.

Openings for escape of air from above hay to outside of the storage structure should total at least twice the fan intake opening area.

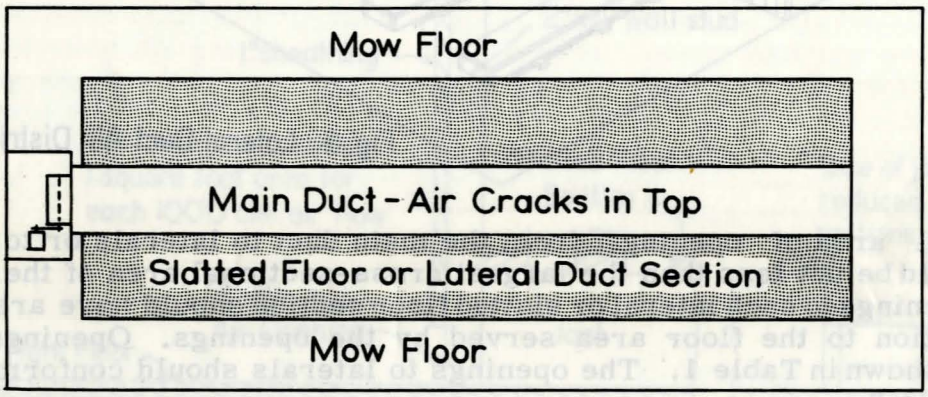
Table 2. DIMENSIONS FOR LATERAL DUCT SYSTEMS

Side of Main Duct to Side of Hay Mow Distance in Feet	Lateral Spacing Inches	Lateral Size Cross-Section Square Inches	Suggested Boards for Laterals	
			Top	Sides
8	48	96	1x12	1x8
10	48	120	1x12	1x10
12	48	144	1x12	1x12
14	42	144	1x12	1x12
16	36	144	1x12	1x12
18	32	144	1x12	1x12
20	28	144	1x12	1x12

SIDE MAIN DUCT FOR USE IN NARROW STORAGES OR WHERE ALL FEEDING IS FROM ONE SIDE OF MOW.



CENTRAL MAIN DUCT FOR USUAL STORAGE CONDITIONS



DIVIDED MAIN DUCT FOR LONG STORAGE STRUCTURES. DRYING MAY BE DONE ON ONE-HALF OF SYSTEM AT ONE TIME.

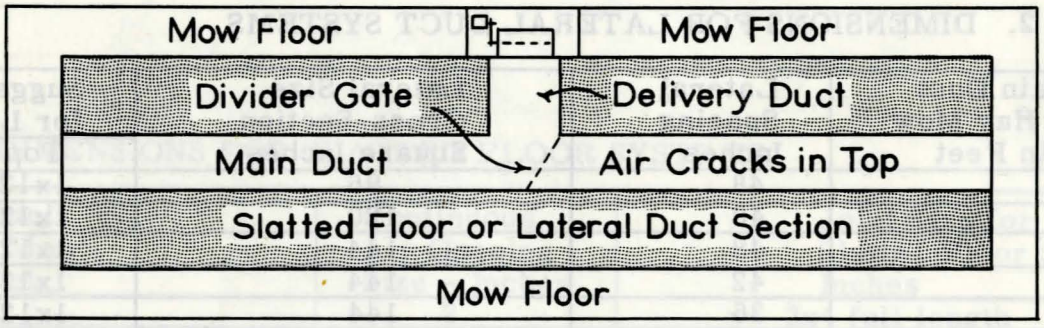


Fig. 7- MAIN DUCT ARRANGEMENTS FOR DIFFERENT STORAGE CONDITIONS

Stack Drying With A-Frame

The A-frame is readily adapted to drying hay in stacks. A separate frame will be required for each cutting of hay. The size and length of the duct should be determined by the amount of hay per cutting and shape of stack desired. To help form the outside of a chopped hay stack, wire or slat cribbing can be used to good advantage. (See Fig. 8) Ordinarily, the cribbing would be placed about 5 to 6 feet from the A-frame. On this basis, it would be possible to have 7 to 8 feet of hay above the top of the frame.

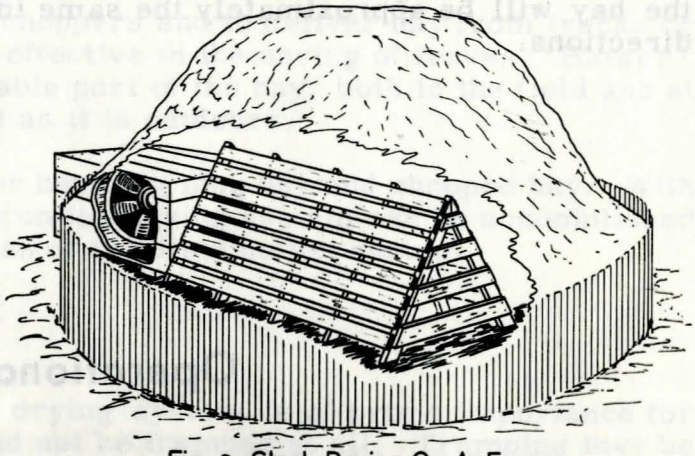


Fig. 8–Stack Drying On A-Frame, Using Cribbing To Form Stack.

Drying in Circular Stacks

Chopped hay can also be successfully dried in circular stacks. Cribbing rings, 16 feet in diameter, are commonly used to form the stack. In this system a vertical duct is built in the center of the ring, as illustrated in Fig. 9. In this size ring a center duct 4 feet square, made of reinforced wire cribbing or a wood frame covered with slats, will give good results. The height of the duct will be governed by the number of rings used in forming the stack. Duct height should be such that hay thickness is 1 to 2 feet greater on top than on the sides, as shown in Fig. 10. For a ring 16 feet in diameter, the distance from the center duct should be about 7 to 8 feet. For a three-ring stack, the duct should be 8 feet high, and for a two-ring stack, 4 feet high.

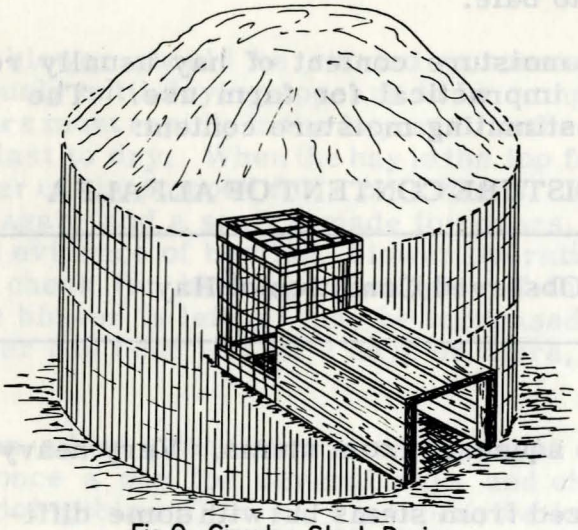


Fig. 9–Circular Stack Drying.

The air supply duct from blower to vertical center duct can be built of 1-inch boards nailed to a framework of 2x4's or 2x6's. The duct should be covered with building paper to prevent air leakage. The cross-sectional area of this duct should be at least as large as the fan discharge opening.

When hay is placed in rings, filling should continue as rapidly as possible. Drying cannot be started until the stack has been completed unless a false top is placed temporarily in the vertical center duct. A false top should be so located that the length of air path through the hay will be approximately the same in all directions.

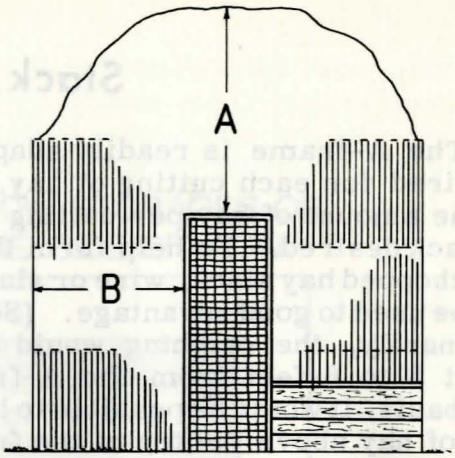


Fig.10-Hay Thickness "A" Should Be 1 to 2 Ft. Greater Than Thickness "B".

Operational Instructions

WHEN TO PLACE HAY ON DRYING SYSTEMS

For chopped hay, a common practice is to cut in the morning, only the amount of hay that can be handled during the day. Raking into windrows is begun as soon as the hay has wilted. The hay is allowed to cure in the windrow until it has dried to about 40 to 45 per cent moisture. Chopping is then started and the hay delivered without delay to the drying system.

Long hay is handled on about the same schedule but can be placed on the drying system at 45 to 50 per cent moisture, since it offers less resistance to air flow.

For baling, the hay should remain in the windrow until the moisture has been reduced to about 35 per cent before starting to bale.

Accurate methods of determining the moisture content of hay usually require an appreciable length of time, making them impractical for farm use. The following guide, while not exact, may be helpful in estimating moisture content:

GUIDE FOR ESTIMATING MOISTURE CONTENT OF ALFALFA

Approximate Moisture* (Per Cent)	Observed Condition of Hay
70-75	Freshly cut.
50-55	Well wilted.
45	Juice can easily be squeezed from stems. Very heavy to handle.
40	Juice can be squeezed from stems but with some difficulty.
35	Juice can barely be squeezed from stems by twisting.
30	Leaves rattle and begin to shatter.
25	Slightly tough. Considerable leaf loss.
20	Safe storage as long hay in barn or stack.

*Wet basis.

HANDLING CHOPPED HAY

Recommended lengths of cut for chopped hay are 4 to 6 inches or more. Long cuts are desirable to permit more uniform flow of air through the hay.

The use of drag-type elevators on field choppers and to deliver hay from trucks or trailers to drying system has been found most effective in the saving of leaves. Blower-type elevators tend to blow away this valuable part of the hay, both in the field and at the stack. In a barn the loss is not as great as it is outdoors.

Hay slings have been successfully used for handling long hay and chopped hay. With this equipment the uniform distribution of hay on the drying system can be accomplished by placing successive loads on different areas of the distribution system.

PLACING THE HAY ON THE SYSTEM

Uniform distribution of the hay on the drying system is of prime importance for successful operation. In general, hay should not be tramped at all. Tramping may be necessary around a post or brace or along the walls to prevent undue air loss. If it is necessary to walk on the hay, wide boards or a ladder should be used to form a walkway. A rake or rake-fork may be helpful in distributing the hay uniformly without tramping.

It is generally recommended that not more than 8 feet of chopped hay, or 12 feet of long hay, be placed on the drying system at the first filling. This filling should be dried before more hay is added. Additional fillings of not more than 6 feet of chopped hay, or 10 feet of long hay, may be successfully dried. Total depths of 14 feet of chopped hay or 22 feet of long hay have been successfully dried in 2 or more fillings.

OPERATION OF THE DRYING SYSTEM

The blower should be started as soon as hay is placed on the system and operated continuously until drying appears to be complete. This may be a week or more. Drying occurs most rapidly in the hay next to the air distribution system. The outer layers are the last to dry. When the hay in the top foot feels dry and no damp areas are found, the blower can be stopped for 3 or 4 hours. At the end of this time the blower should be started again and a search made for odors, warm spots and other signs of heating. If there is evidence of heating, blower operation should be continued another day or two, and the check for heating repeated. If there is no evidence of heating, the length of time the blower is left off may be increased. When no signs of trouble are found after the blower has been left off 2 days or more, the curing can be considered finished.

As an added precaution after drying is considered complete, it is well to start the blower once a day for several days and check for signs of heating. The few minutes spent in doing this will be very inexpensive insurance against unnecessary hay spoilage.

DRYING BALED HAY

Drying baled hay with forced air is generally more difficult than is the drying of long hay or coarse chopped hay. Several methods of placing the bales on the system have been used. These methods are: (1) tight-pack; (2) space-stack; and (3) random.

For the tight-pack method it is recommended that the baling be done when the hay moisture is not more than 30 per cent. The bales may be stacked close together on a slatted floor system or placed directly on floor joists that are spaced about a foot apart, making slats unnecessary. Air flow should be at least 30 cfm per square foot of floor area. Static pressures range from about 3/4 to more than 1 inch water column. The bales should be stacked not over 4 tiers high and placed across each other in alternate tiers.

In space-stacking the bales are placed on edge and spaced 2 to 3 inches apart. Alternate layers are stacked with bales at right angles to those in the adjacent layers. This arrangement blocks air loss due to "chimney" effect and allows air circulation around each bale. Baling may be done when the hay has 30 to 35 per cent moisture. Up to 6 tiers may be stacked on the air distribution system at one time.

Random loading of bales on the drying system is sometimes practiced to save time and labor. Bales can be unloaded with an elevator or fork and allowed to remain where they fall. Baling is done at 30 to 35 per cent hay moisture and drying results are about the same as for space-stacking.

Any of the above methods may be used in drying baled hay on an A-frame, if care is taken to provide uniform thickness of hay on the sides and top of the frame.

Drying With Supplemental Heat

Supplemental heat for hay drying will not ordinarily be warranted in Nebraska, because weather conditions are favorable for drying with unheated air.

Heated-air equipment should be given consideration if a large volume of hay and grain is involved. The use of heated air increases the capacity of a drying system by producing more rapid drying and by increasing the effective hours of operation per day, regardless of weather conditions.

For drying with heated air, equipment costs and operating expenses will be greater than with unheated air. Fire hazards may be a serious problem unless heated air equipment is properly installed and operated. If heated air is used it is advisable to check the fire risk coverage of insurance policies.

Heat units are available for direct or indirect heat. Both types should have safety controls for protection against overheating and combustion troubles. A spark arrestor is essential in a direct-heat unit.

New Storage Structures

If new hay storage structures are to be built, consideration should be given to possible use with forced-air drying. Obstructions such as hay chutes, posts and braces are objectionable in storages where forced air drying is to be done. Use of self-supporting roofs or truss construction will give unobstructed storage area. Such areas make hay handling easier and an air distribution system can be readily installed.

Circular structures, similar to silos, are being used in some areas for hay storage. Such structures may be adapted for forced-air drying by installing a central air duct, as shown in Fig. 11. The outside walls of the structure may be perforated to permit air flow through the wall, or a false inner wall may be used so that free air movement around the outside of the hay is possible. The central duct should have a series of doors at various levels, as shown in Fig. 11, or some form of movable "plug" in the duct, as shown in Fig. 12. The doors must be closed, or the plug located, so as to prevent excessive air loss through the top of the hay when the storage is partially filled.

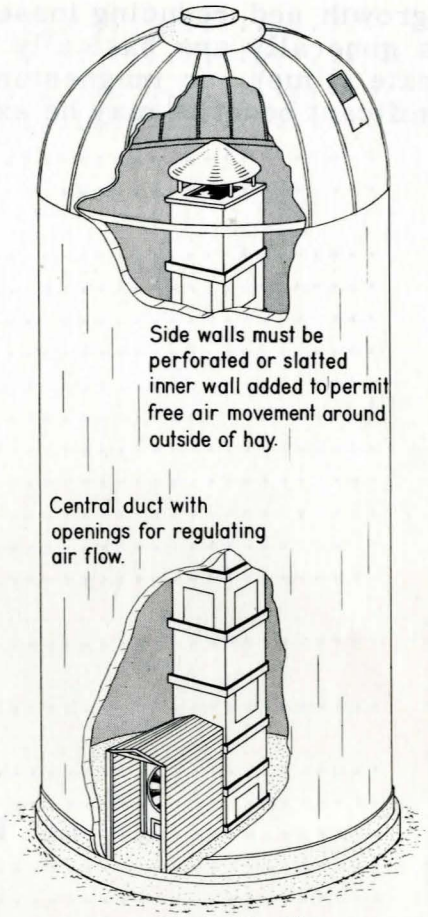


Fig.11-Circular Hay Storage Adapted For Forced Air Drying.

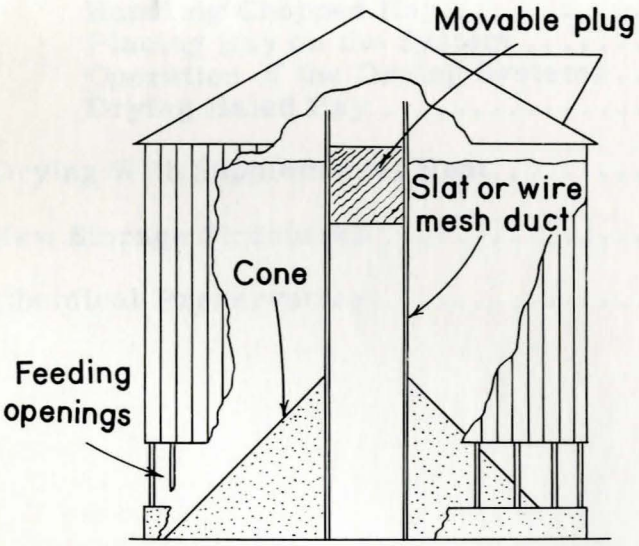


Fig.12-Circular structure adapted for forced air drying and self feeding.

Storages for chopped hay can be adapted for self-feeding. With circular storages, this may be done by installing a cone in the bottom of the structure and providing feeding openings through the sidewalls, as shown in Fig. 12. In ground level storages of usual types, movable feed racks may be used. These racks are moved to allow animals to reach the stored hay.

Chemical "Preservatives"

Various chemical compounds have been offered for sale for the purpose of preventing mold growth and reducing losses in hay stored at high moisture content. These compounds generally are basically sodium bicarbonate (baking soda), mixed with calcium carbonate (lime), or magnesium carbonate. Various experimental reports indicate no significant benefits may be expected from the use of these compounds.

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