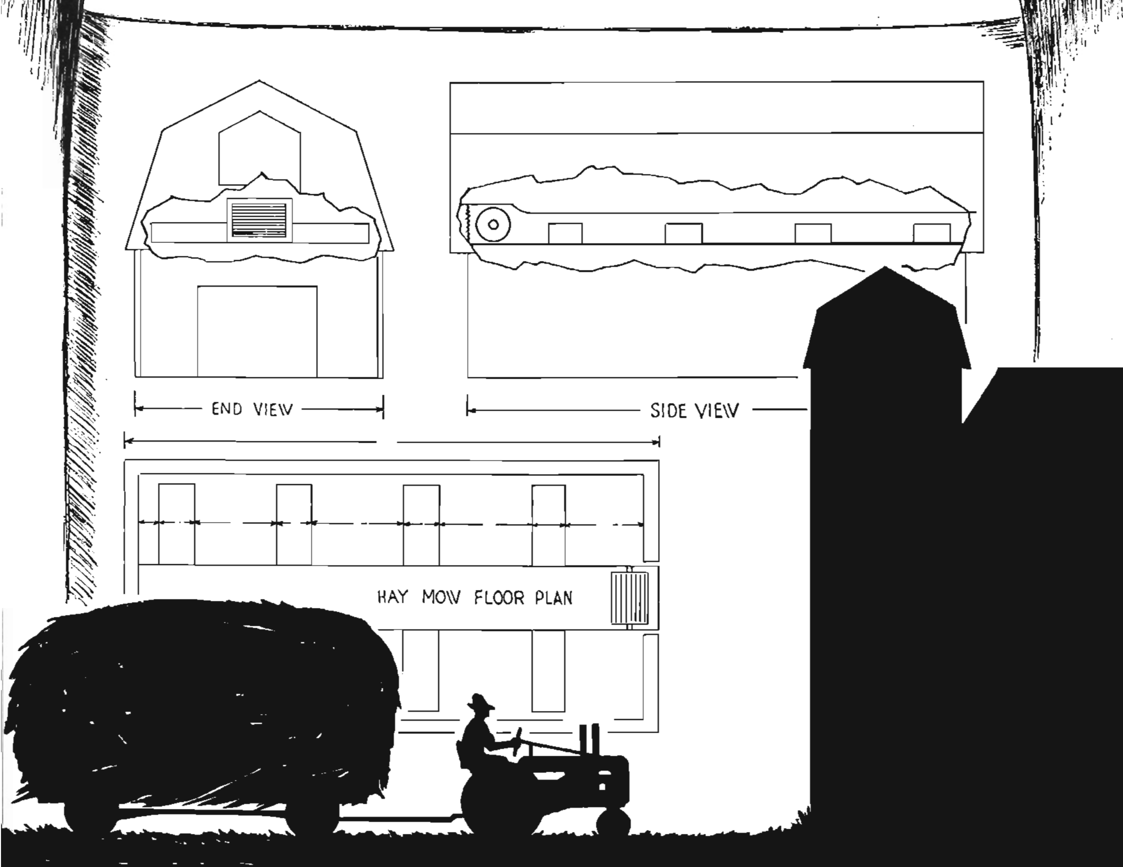
# Hay Drying in OREGON

By DALE E. KIRK

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## Foreword

Artificial drying offers one means of greatly reducing the serious losses of hay feed value suffered throughout the country each year. Leaching, bleaching, and leaf shattering can prevent the farmer from putting more than one-half the original feed value of the hay crop in the mow. Heavy rains on hay waiting to be cured in the field often result in nearly a total loss of the crop. Although artificial drying in the manner that is practical on the farm cannot eliminate all weather hazards, it can, by proper management, reduce field losses to a minimum.

This bulletin discusses the many types of driers and drying methods that are used commercially, as well as those that are believed to be practical for Oregon farms. The information given should be helpful in the selection and design of a proper system for any general farm layout. Special design problems should be discussed with the County Extension Agent or with a reliable dealer handling hay drying equipment.

The information presented in this bulletin is based largely upon research conducted at the Oregon Agricultural Experiment Station over the past 10 years. The author also has drawn upon the results of research conducted elsewhere, as well as on his observations of driers that are being used in the state, in order to present a more complete bulletin.

F. E. Price
Dean and Director

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## Summary and Reference Data

Artificial drying or finishing of hay is a practical method of reducing field curing losses in all parts of Oregon. The equipment required will vary somewhat in the different rainfall areas.

Artificial drying of hay on the farm or mow drying is a process in which only a small portion of the water originally in the green forage is removed artificially. The major portion of the water is evaporated in the field during a short wilting period. Only the remaining 10 to 20 per cent of excess moisture in the plant is removed in the drier. For this reason the mow driers often are referred to as hay "finishers."

Hay should be field wilted to 35 to 40 per cent moisture from the 75 to 80 per cent moisture content at the time of cutting before it is placed in a mow drier.

Mow-type driers or silo-type, circular hay keepers provide the most economical method of artificial drying. Portable and stationary high temperature dehydrators may produce a higher quality feed but not at a competitive cost.

Lateral duct and slatted floor mow-type drying systems perform equally well under proper management. There are numerous ways these systems may be built to accommodate different mow shapes. Circular hay keepers may be used for driers when no mow space is available.

Hay can be dried artificially on the farm either long, chopped, or baled. Many drying systems will handle it in any of the three forms without alteration.

Installation costs for a mow-type drier run from 18¢ to $1 per square foot of drying floor area. Commercially constructed metal duct units can be installed for the latter cost. Wooden hay keepers cost from $400 to $1,000 for a unit 24 feet in diameter and 20 to 30 feet high.

Costs for electricity usually run from $1 to $2 per ton of dried hay.

Fuel costs in heated air driers run from $1 to $5 per ton with a lower cost for electricity when heat is used.

Fan capacity to produce 15 to 20 cubic feet of air per minute (cfm) per square foot of floor area is recommended for mow driers. The fan should be able to produce this air against a static head of 1 inch of water. Most good fans will produce about 3,000 cfm against 1 inch static for each horsepower consumed. Any type of propellor, turbine, or vane-axial fan may be used if properly installed and is capable of producing the required air volume against 1 inch static head.

Air velocities should be kept below 1,000 feet per minute within the duct systems wherever practical. Intake opening or duct velocities should be less than 500 feet per minute and mow outlet velocities below 200 feet per minute.

Drier units are generally designed to be powered by a 5 horsepower (hp) or $7\frac{1}{2}$ hp electric motor. Larger units are usually powered by a tractor or stationary engine.

Supplementary heat is recommended for driers along the Oregon coast. This can be supplied by several types of direct and indirect fired heat generators burning liquid or gaseous fuels. An air temperature rise of 10° to 40° F. is recommended. Expected temperature rise can be calculated by equations—

$$\frac{133{,}000 \times \text{gallons of oil per hour} \times \text{efficiency of burner}}{\text{Cubic feet of air per minute}} = \text{Temperature rise in °F.}$$

$$\frac{94{,}000 \times \text{gallons of L.P. gas per hour}}{\text{Cubic feet of air per minute}} = \text{Temperature rise in °F.}$$

Driers must be loaded evenly over the air distribution system. Heavy fork loads or sling loads of long hay must be torn apart if they are to dry properly. Chopped hay should be leveled off without tramping.

Moisture content of hay samples can be checked by the use of several inexpensive methods which can be provided on the farm.

# *Hay Drying* in OREGON

DALE E. KIRK
*Assistant Agricultural Engineer*

High quality hay can be made only from good forage crops cut at the right stage of maturity and cured in such a manner as to conserve the leaves and the bright green color. In many parts of Oregon the climatic conditions make it impossible to cure hay in the field without loss of leaves and color. Some seasons, these losses are quite apparent as the forage becomes leached, bleached, or moldy due to rainy weather. During seasons of good drying weather, sizable losses of nutritive value and palatability due to sun bleaching and leaf shattering are more apt to go unnoticed.

The weather record for many parts of Oregon shows that hay cannot be field cured and placed in the stack or barn every year without standing a good chance of being rained upon. Losses resulting from such rains may range from moderate leaching to total losses due to mold and decay. Since any amount of exposure of hay in the field can cause reduction in carotene, protein, and palatability, shortening of this period of exposure is highly desirable.

Artificial drying is one means of reducing these losses to a prac-

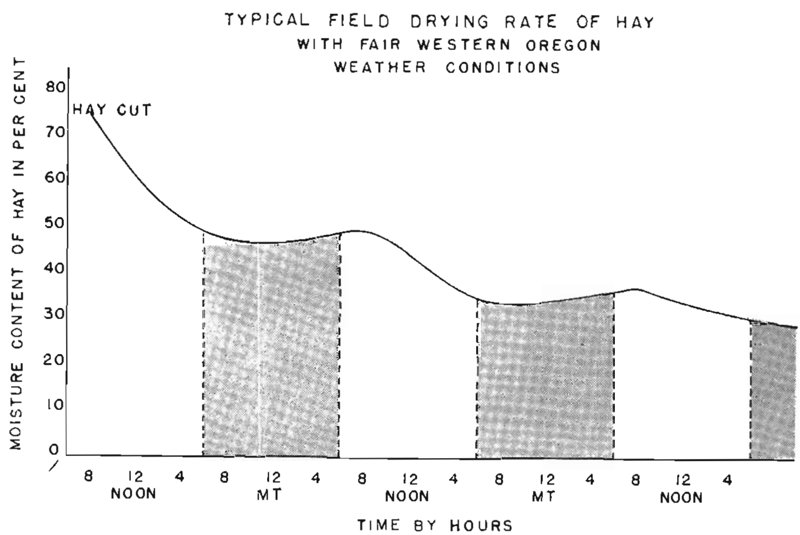



Figure 1. A typical curve showing the drying rate of most hays during some of the better drying weather typical of western Oregon.

tical minimum. Although the forage material can be dried immediately after it is cut, it is usually more practical to remove the greater bulk of the water by field curing and finishing the curing in an artificial drier. Figure 1 shows a typical field drying curve for hay cut during good drying weather. It can be seen that exposing the hay to the sun and wind immediately after it is cut reduces the moisture content very rapidly. After the material is well wilted to a moisture content of around 35 to 40 per cent, the water is removed much more slowly. The hay may have to be left in the field several days, or in extreme cases, several weeks before the moisture content can be reduced from 40 per cent to the 20 per cent figure which is generally considered necessary for safe barn or stack storage.

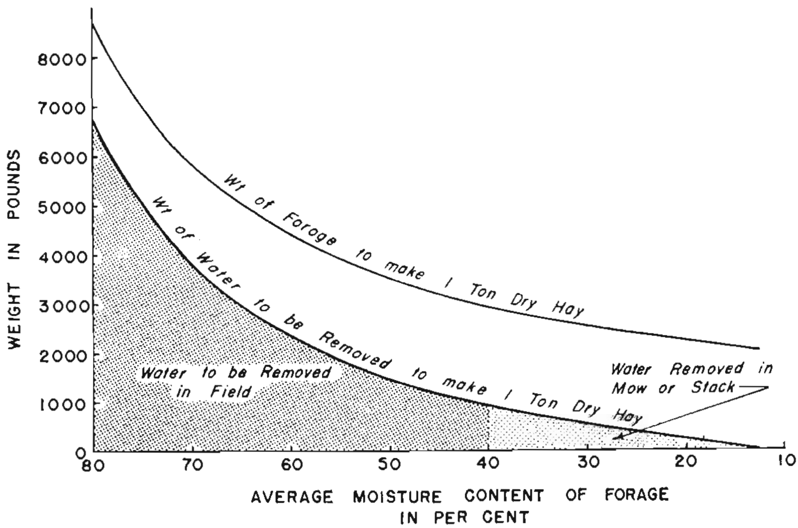



**Figure 2. Curve showing the weight of forage required and the weight of water to be removed to make one ton of dry hay.**

Figure 2 shows the relative weights of water that must be removed from hay at various beginning moisture contents to bring the material down to 20 per cent where it may be safely stored. It can be seen that field wilting for one or two days will leave most of the water in the field and a relatively small amount will have to be removed in the drier.

Artificial drying of hay crops has been successfully practiced on a commercial scale at various places throughout the United States for more than 20 years. It is only since about 1940, however, that artificial drying of hay on the farm has been practiced to any great extent. The first installations were made in the Tennessee Valley area and the practice has since spread to all parts of the country. Areas with even very light annual rainfall have found that some form of artificial curing is economical assurance against serious bleaching, mold, and leaf loss caused by showers during the haying season.

## History in Oregon

The first experimental mow-type drier was set up in Oregon in 1941 at Corvallis. This drier consisted of a motor, blower, and air duct system which distributed the unheated air beneath the mow filled with hay so that it could be forced up through the pile evenly. A similar unit was set up in Astoria later that summer. Due to the higher humidities prevailing in the coastal region, it was found necessary to later remodel the Astoria drier to use heated air which gave faster and more certain drying.

By 1949 when hay drying had progressed past the experimental stage, a survey of the number of driers in Oregon indicated that there were well over 30 in use. About one-third of these were commercially constructed circular metal hay drying and storage buildings, about one-third were mow-type driers utilizing some duct system on the mow floor and the remainder were of the homemade circular or silo type.

## Place of the Drier in the Forage Program

In the more humid areas such as the Oregon coastal region, the hay can be dried either chopped or long in any conventional storage unit but some form of supplemental heat should be used to speed up the rate of drying. In other parts of the state the use of heat is not required but its use will permit the operator to obtain a better grade of feed and cut down the necessary drying time.

Baled hay can be dried successfully by artificial means if the bales are not too tight or too green. This drying may be done on a mow duct or slatted floor system or the bales can be stacked in the form of a closed tunnel permitting the bales to form their own air distribution system.

Because of the wide variety of ways the principles of drying may be applied, some type of a drier can be designed to accommodate virtually any farm handling dry feed. For the farm operator harvesting and feeding long loose hay, the mere addition of a motor, blower, and duct system in the mow may satisfy his drying needs without causing any major changes in his harvesting practices or machinery. Operators equipped with silo filling machinery will probably wish to chop their hay before drying. This chopped hay can be handled with the same silage harvesting equipment and can be stored and dried in either a conventional drier-equipped mow or in a circular type hay drying and storage unit.

Stack drying, although an old practice in Europe, has not been practiced a great deal in the United States. With modern fans and heating units there is no reason why properly shaped stacks of forage cannot be dried on the ground prior to feeding or threshing for seed.

## Terminology

The terms "drier" and "dehydrator" may be used interchangeably but, through common usage among workers in the field, the terms have come to indicate a difference in the methods and equipment used. A drier is usually any mechanical arrangement for removing moisture from the crop by the use of induced or forced ventilation of unheated air. A dehydrator usually employs the use of supplemental heat applied either directly to the product itself or to the air forced through or over it. Since most farm driers are used to finish the drying process after the bulk of the water has been removed in the field, they are often referred to as "hay finishers."

## Commercial Type Dehydrators

### Rotary drum

The rotary-drum dehydrator is the type most commonly used in permanent installations in the United States. These are built in both the single or multiple concentric drum types. However, the

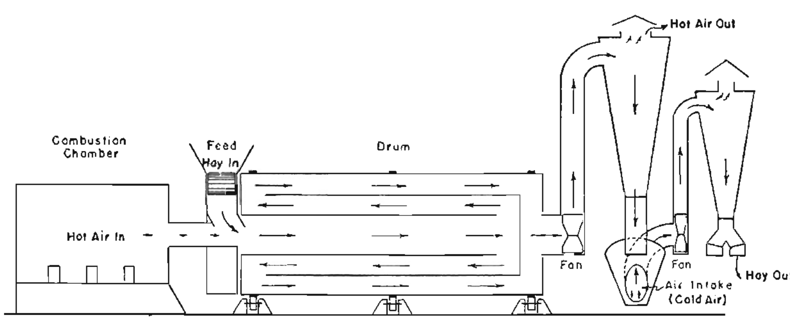



Figure 3. Schematic drawing of a multiple, concentric, rotary-drum dehydrator.

multiple concentric drum type is currently the most popular due to its compactness.

This drier is the parallel-flow type where the forage and the hot air or gases travel in the same direction. The fuel, which is usually oil or gas, is burned in a combustion chamber at one end of the slowly rotating drums. A fan is used at the discharge opening of the drums to create a suction which draws the products of combustion and the dried hay through the passages between the drums. The freshly cut green hay (with a moisture content from 65 to 80 per cent) is fed into the drums through an auger conveyor where it contacts the hot gas having a temperature from 1,300° to 1,800° F. The rapid evaporation of moisture from the green hay takes up the heat from the gases as they travel through the drums so that at the discharge end the air temperature is from 220° to 260° F. and the hay is below 150° F. To insure cooling and safe storage the hay is usually again picked up by a fan drawing cold air and blown through a cyclone collector either to be bagged or bulked.

Many permanent installations of this type are in use in the Midwest and a few are currently in use in the states of Washington and California. Portable models have been built on railroad flatcars and recently several portable units were constructed on rubber-tired wheels. One of these units was tested in 1947 and 1948 by the Oregon State College Agricultural Engineering Department to study its practicability for drying the forage crops produced in Oregon.

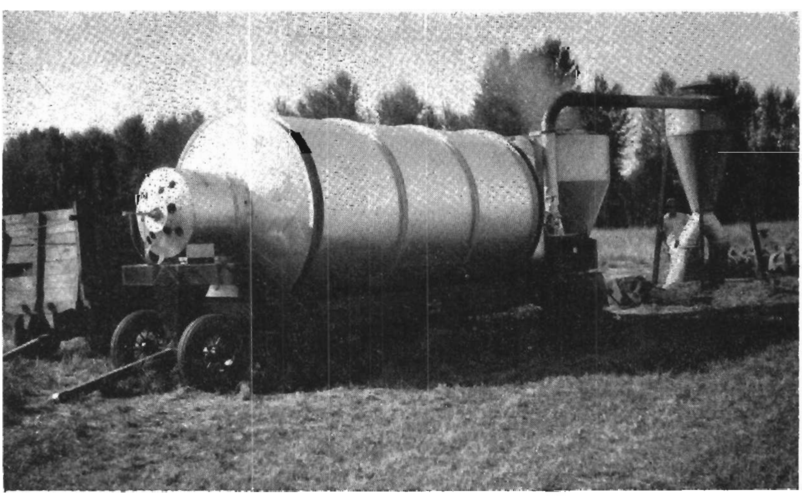


**Figure 4. Portable rotary-drum dehydrator being tested on alfalfa in Linn County.**

This dehydrator was able to turn out a very high quality of dried hay at a reasonable fuel cost. Its high initial cost and low drying capacity, however, made it appear impractical for producing dairy or beef feed on the farm. A typical test run yielded 690 pounds of dried hay per hour at a fuel consumption of 18 gallons plus 1¼ gallons of gasoline to operate the engine used to drive the drums, blowers, feed auger, feed conveyor, fuel pump, fuel atomizer, etc.

Later models of this machine, fitted with a larger drum and costing from $7,000 to $12,000, are reported to produce up to three-fourths ton per hour with a correspondingly higher fuel consumption. Even at this capacity, however, it would be difficult to process sufficient tonnage in a drying season to reduce the investment cost per ton to the point where the hay could be fed profitably to beef or dairy cattle. At present the output from these machines is going largely into feed concentrates for poultry, hogs, rabbits, vitamin pills, etc.

### Conveyor

Conveyor- or apron-type dehydrators are usually of the counter-flow type. The freshly heated air or the products of combustion from a flame pass through the machine in the opposite direction from the path of the forage. This exposes the driest material to the hottest and driest air. While this system is efficient in removing the last bit of moisture from the material, it also limits the temperature of the incoming air. The initial temperature in these dehydrators runs from 150° to 250° F.

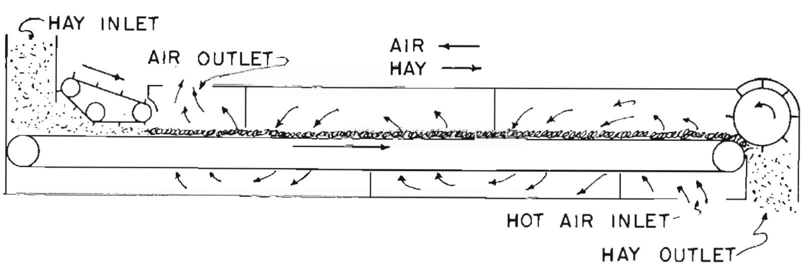



**Figure 5. Schematic drawing of counterflow, conveyor-type dehydrator.**

The conveyor system is one of the oldest successful methods of dehydration and is still in use at the present time. Due to the large investment in heavy equipment and moving parts, however, it has never had the widespread use and appeal enjoyed by the rotary drum types.

# Farm Type Driers or Hay Finishers

### Mow-type lateral duct

The basic lateral-duct system consists of a single main air tunnel with several smaller tunnels or lateral ducts branching from it. The air leaves the duct system through a narrow crack along the bottoms of the laterals. This system can be modified to fit practically any size or shape drying area. For the average rectangular-shaped mow, the most popular arrangement is a single main duct, running down the center of the long way of the area, with equal-length laterals branching out in pairs from each side.

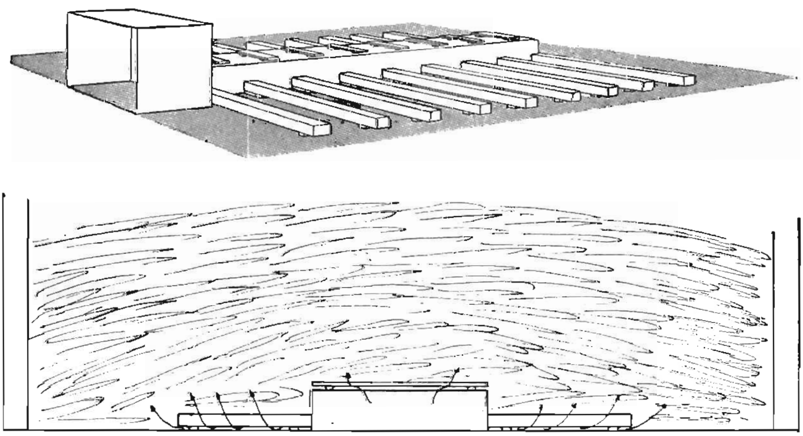
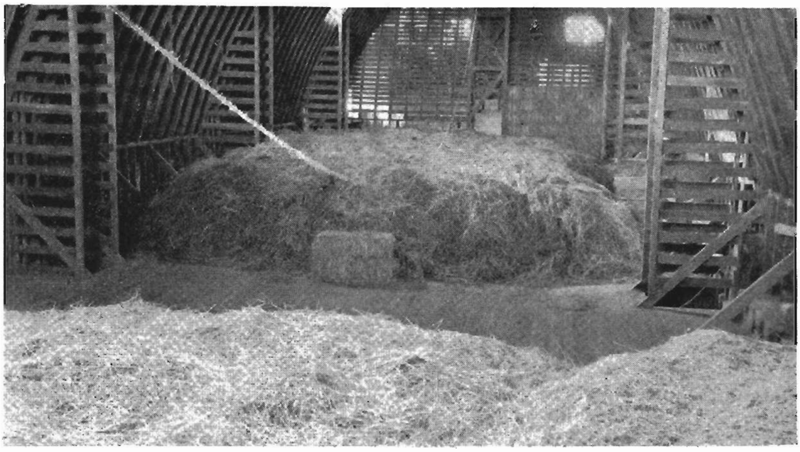


Figure 6. *Top*, lateral-duct system, with center main air duct. *Bottom*, section view of lateral-duct system with center main showing entrance of air into the hay stack.

When the system is not in use the laterals can be removed easily and stored elsewhere. It is usually not considered practical, however, to remove the main duct to temporarily clear the floor for other uses. Some of the advantages of this system are that the lengths of the laterals are held to a minimum and the system is symmetrical and balanced, making it simple to construct and easy to load properly.

Many operators prefer to use the side-main system. Its acceptance has been so great in Ohio where it was developed that it is often referred to as the Ohio system. This arrangement is especially adaptable to mows which have braces or low overhead clearance along the sides which make this space of little use for hay storage.



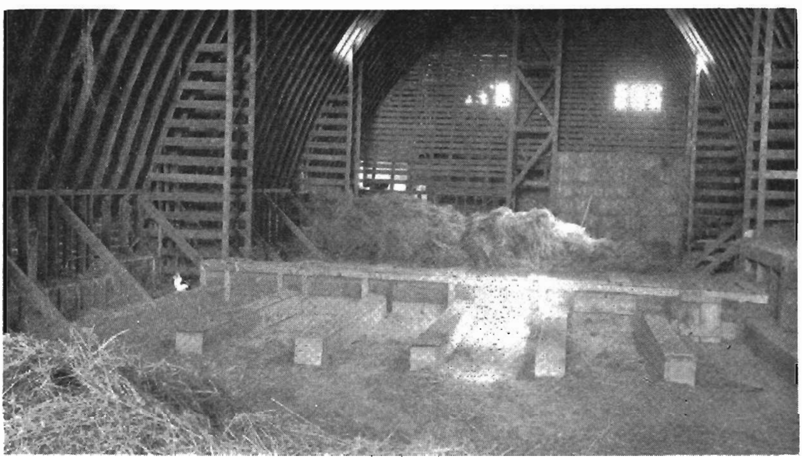


**Figure 7. Lateral-duct system with center main servicing one end of a large mow. *Top,* the drier with a load of hay in place. *Bottom,* the duct system after the hay has been removed.**

An advantage of this system is the ease with which the lateral ducts may be taken up and stored along the side of the barn as the hay is fed out. This leaves practically the entire drying area free from obstructions.

The side-main arrangement, however, is not generally recommended for mows over 30 feet in width. Greater widths require each lateral duct to supply air to a greater floor area than is practical

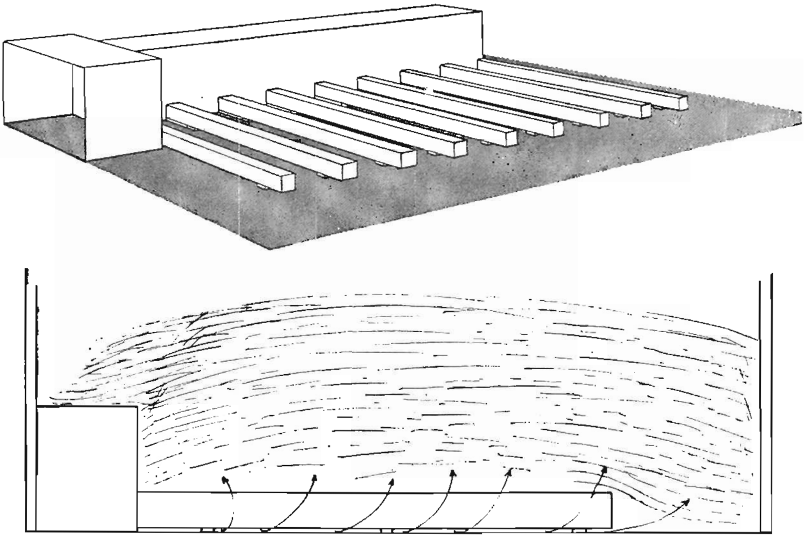


Figure 8. *Top,* lateral-duct system with side main air distribution duct. *Bottom,* section view of lateral-duct system with side main showing entrance of air into the hay stack.

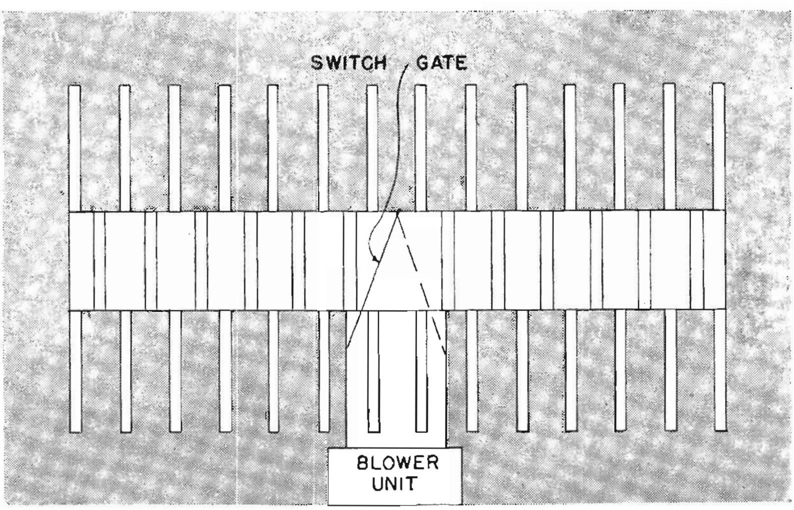



Figure 9. Lateral-duct system with divided main.

without increasing its cross sectional area. The greater lengths of the laterals introduce problems in air distribution along their entire length that tend to result in nonuniform drying throughout the hay stack. Where it is desirable to fit large mows with duct systems, it may be more practical to provide motor and fan capacity to handle only half the system at one time. By using a divided main (usually a center main) and a switch gate or sliding doors, this can be done without moving the motor and blower when alternate ends are used.

### Mow-type slatted floor

In some eastern states the slatted-floor system has become very popular. Virginia, in particular, has standardized on this system for most of its driers, and there are several of this type in use in Oregon. The slatted-floor air-distribution system has the same main duct as the lateral-duct arrangement. In place of the lateral ducts themselves, a false slatted floor is used to carry the air outward from the main duct. A side main or divided center main could be used equally well with the slatted floor.

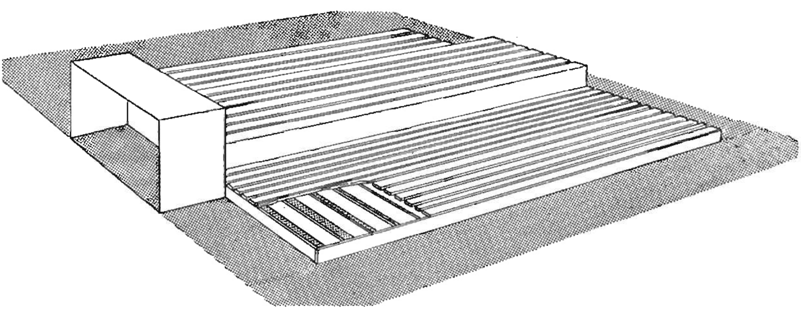


Figure 10. Slatted-floor system with center main duct.

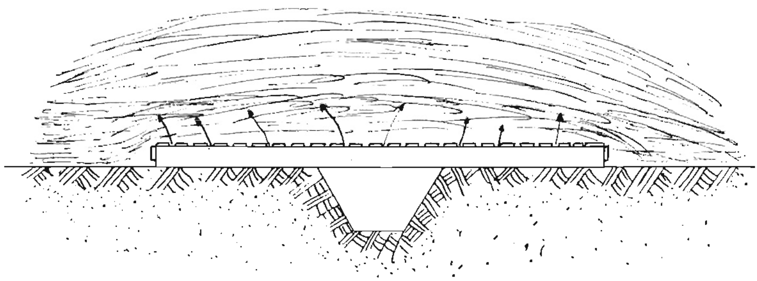


Figure 11. Slatted floor over an excavated main duct.

Where a supply of scrap lumber is available around the farm it can usually be used to better advantage on a slatted-floor system. The slats can be made of any narrow boards which are strong enough to support a man's weight as he walks over them. By constructing the floor in sections, it can be removed and stored along the sides of the mow. The air distribution beneath the hay is good with this system and it can be used for long, chopped, or baled hay.

Where the hay is to be dried outside in stacks or in a barn over a dirt floor, the slatted-floor system is probably simpler to construct and easier to use.

### High, narrow mows

Where the hay is to be cured in a high, narrow mow, a single main duct with no other air distribution system can be used. This duct can be made with a framework of 2 x 4 or 2 x 6 lumber and covered with cleats or a heavy wire mesh. This arrangement also has been used successfully for stack drying in the field.

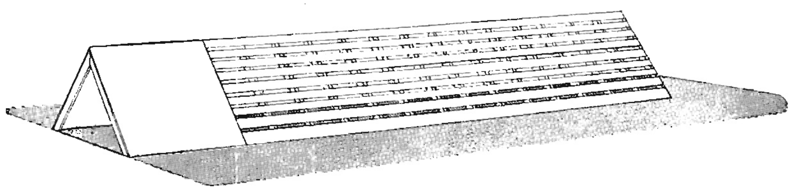


**Figure 12. Slatted A-frame duct for use in narrow mows or field stacks.**

### Silo or circular type

The circular-type hay keeper as shown in Figure 14 has become quite popular where adequate hay storage space is not already available. It consists of a round wall similar to a silo with openings through the wall for air passage. Figure 13 shows the vertical flue or air duct extending up the center of the structure which can serve as a chimney for drawing off accumulations of hot air if no fan is used. Where a fan is installed to speed up drying, as seen in Figure 36, the flue serves as an air duct from the

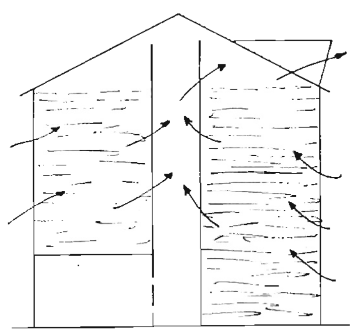


**Figure 13. Section view sketch of a wooden circular-type hay keeper showing the direction of air passage when drying is done by natural draft and the center flue serves as a chimney.**

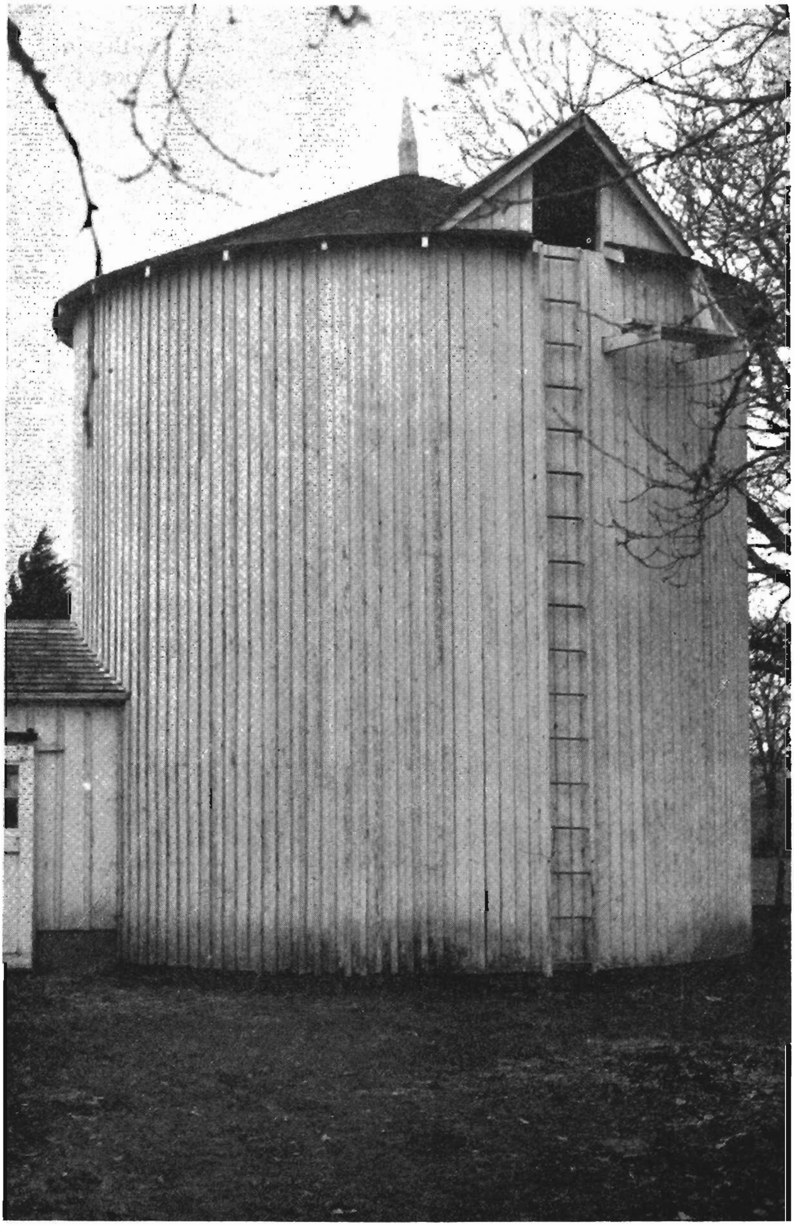


Figure 14. Wooden circular-type hay keeper 24 feet in diameter and 22 feet high.

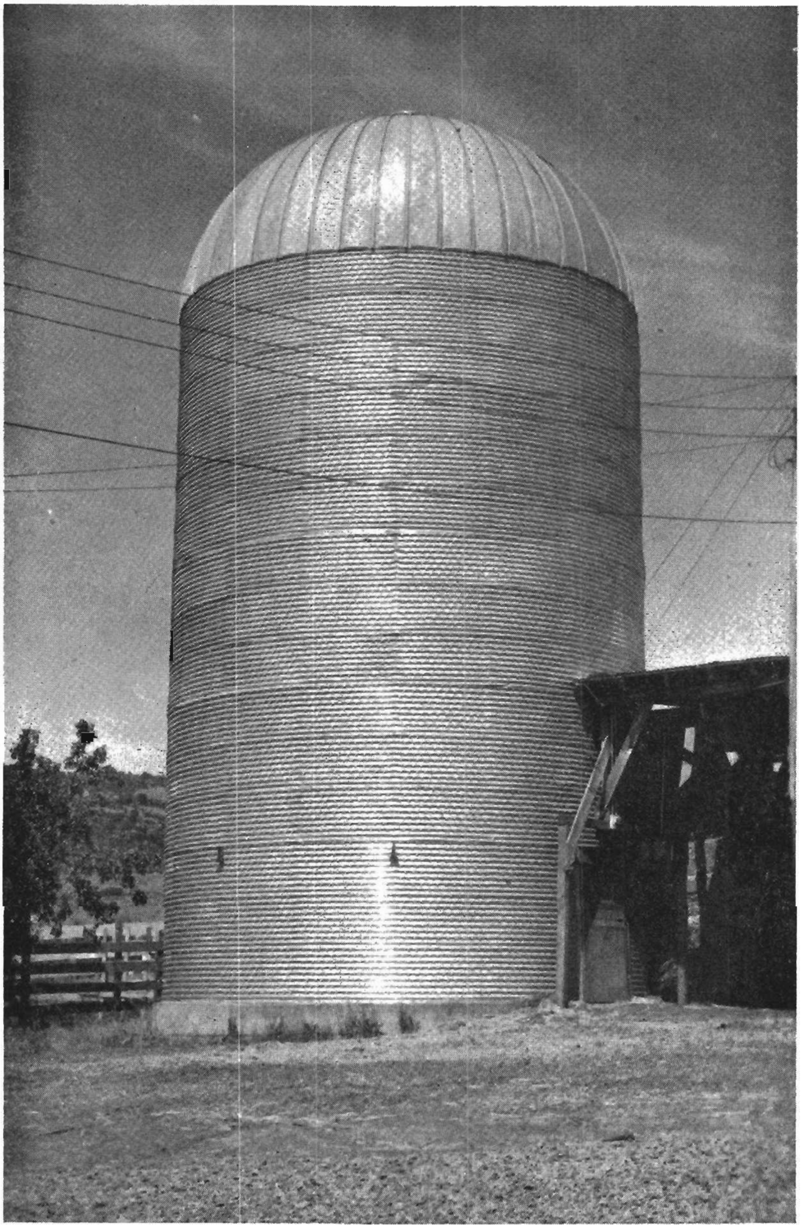


Figure 15. Commercially constructed steel circular-type hay keeper which is assembled on the farm.

fan to the hay. The flue also serves as a hay chute when hay is being fed from the keeper.

The circular hay keeper may be built of lumber from the plans shown on pages 36-38 or a commercially constructed metal unit as shown in Figure 15 may be purchased and assembled on the farm. Both operate on the same principle and are considered satisfactory only for curing and storing chopped hay.

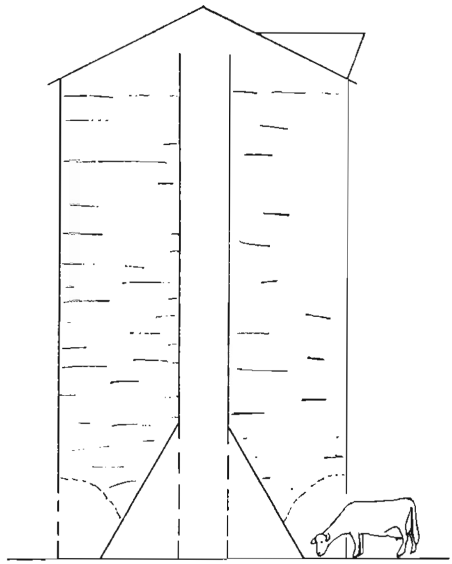


Figure 16. Section view of a circular-type hay keeper, showing the deflector cone for self feeding.

Several owners have erected deflector cones at the base of the center flue to near the bottom of the walls so that the unit can be used as a self feeder. For the self-feeding principle to function properly, the livestock must be able to reach to the base of the deflector cone.

At additional cost, the self-feeding arrangement can be obtained as a part of the commercially built metal units.

## Drying baled hay

Because of the many varying and uncontrollable factors connected with drying baled hay, the practice has not been generally adopted. However, baled hay has been artificially dried with complete success.

Where the farm operator has his own baler or access to good custom baling service and produces a fairly uniform amount of hay each year, he can probably use a baled hay drier to good advantage. A fairly good job of finishing off the drying of bales can be done on the regular long or chopped hay lateral-duct or slatted-floor system.

Where bale drying is to become a regular practice, it would be more desirable to utilize a motor and fan capable of producing more air and at higher pressures than is used for loose hay. Field-stack drying or stack drying under shelter can be accomplished by stacking the bales so as to form their own air duct system. A few heavy planks are required to support the top of the duct. Some wood framing or canvas tube is necessary to connect the fan to the duct and prevent excessive air leakage past the first few bales.

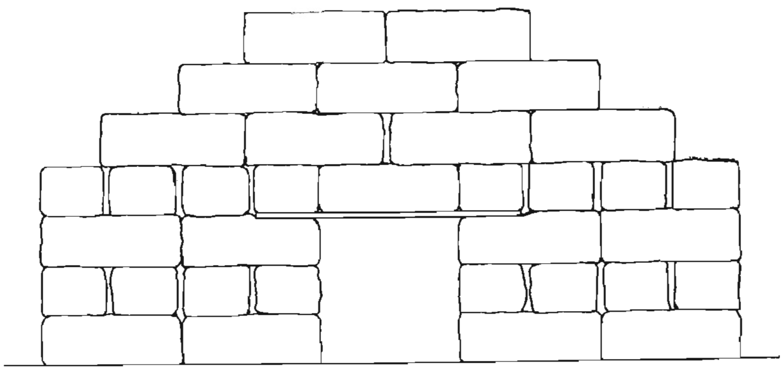


**Figure 17. Baled hay stacked to form own air duct for artificial drying.**

## Selection of Type of System

### Buildings

Where existing buildings are available, it is quite possible they can be used for mow drying with very little modification. They should have a good tight roof for rain protection and large windows or doors for exhausting the moisture laden air. It is quite essential that the floor be reasonably air tight. This is necessary to keep the air in the ducts from escaping downward instead of being forced up through the hay. If the present floor is not air tight, a covering of low-grade plywood or pressed fiber board might be used to cover the drying area.

Where the barn is less than 20 feet wide, a single open-type center duct would normally require the least labor and materials. In case the mow is more than 20 feet and less than 30 feet wide with roof braces or a low wall that interferes with loading the hay to the walls, a side-main system is suggested.

If the hay is to be handled long, a hay track or some other mechanical means should be provided for getting the hay up into the mow. Hand pitching would be practical for only very small quantities.

Where no storage buildings are available, it would be cheaper, usually, to provide hay storage capacity and drying in the form of one or more circular hay keepers. They might be of either the farm-built wooden type or the commercially built metal units.

### Feeding and cropping program

In general, artificial drying is practical only on farms having a fairly stable cropping and feeding program. Where large acreages of hay are grown for sale for a few years followed by some grain or row crop, the expense of setting up facilities for drying the entire hay tonnage for a few years usually would not be justified. Stack driers might be practical for one or two cuttings in some parts of the state where large acreages are involved.

Farms maintaining a rather uniform dairy or beef herd and producing their own hay, pasture, and perhaps silage fit very well into a hay-drying program.

### Field harvesting equipment and methods

The harvesting equipment available and the possible methods of hay handling must be considered in selecting a drying system. Circular hay keepers can satisfactorily handle only chopped hay. Mow-type driers can accommodate hay either long or chopped. Where field forage choppers, wagons, and blowers or elevators are already available for handling silage, it would appear most economical to store and dry the hay chopped.

Farms carrying small herds of 15 cows or less usually cannot justify the expense of owning chopping or baling equipment. If reliable custom or cooperative chopping is not available in the community, these operators will find mow drying of long hay in their present storage building the cheapest system to install and operate.

### Rainfall area

Experience has shown that different types of drying equipment and different drying methods are necessary in the varying rainfall areas of the state. To insure satisfactory drying in the coastal area, supplemental heat should be provided sufficient to raise the temperature of the air entering the hay at least 10° F. Additional heat would result in more rapid drying where it can be provided.

Circular-type hay keepers of either the metal or wood type are not considered practical in the coastal area unless they are protected from driving rains. The basic hay-drying and hay-handling features of the circular keeper might be used, but the structure would have to be provided with a tight outside wall to prevent spoilage losses from incoming rain.

In the Willamette Valley and along the southern counties of Oregon, any of the mow-type driers or hay keepers appear to be very practical. The use of supplemental heat in this area, however, can improve the quality of the finished product as well as speed up drying and thereby increase the capacity of the installation. East of the Cascade Mountains any of the drying systems may be used. Stack drying of clover hay prior to threshing for seed is practiced in Jefferson County. This reduces the threshing losses and permits the work to be done in damper weather.

### Power service

Power service to the farm must be considered if the drier is to be operated by an electric motor. Many rural lines with limited line and transformer capacity permit the use of motors of no greater than 5 hp. Other lines can handle up to 7½ hp on single-phase service. Where larger-capacity driers are desired, stationary engines or tractors can be used to power the blower. Whenever a gasoline or diesel engine is used, it is always well to utilize the waste heat from the engine to increase the temperature of the air entering the drying system. This can usually be done by placing the engine near the fan intake or by building a simple housing over the fan intake and engine.

### Costs

Construction costs will vary widely with the farmer's locality, access to scrap lumber, used equipment, etc. Most of the lumber in the mow-type drier in either the lateral-duct or slatted-floor system can be of very low grade or scrap material. Where all new material is purchased, the labor, materials, equipment, and wiring installation usually will cost between 50¢ and $1 per square foot of drying area. One Linn County farmer in the spring of 1950 constructed a lateral duct mow type drier 34 x 50 feet for as low as 18¢ per square foot, exclusive of his own labor. He was able to salvage a fan from a seed cleaner and use mostly scrap lumber. He did all of the work on the drier himself.

Commercially constructed systems with all metal main and lateral ducts cost about $1 per square foot of drying area. Labor cost for installing these systems is very low.

Wooden, circular hay keepers have been constructed at a cost ranging from $400 to $1,000. This latter cost was for a keeper 24 feet in diameter and 30 feet high. It was constructed in the spring of 1949 and included the cost of labor and new materials.

Electrical consumption for mow-type driers powered by electric motors usually runs from 50 to 100 kilowatt hours per ton of dried hay. At a rate of 2¢ per kilowatt hour this would result in a cost of $1 to $2 per ton for electricity. Where supplemental heat is used, the electrical cost goes down considerably and the fuel costs run usually from $1 to $5 per ton depending upon the type of fuel used, the moisture content of the hay at the time it was loaded, and depth and uniformity of loading.

## Design and Construction—Mow Type

### Feed requirements

The first step in determining the size of any drier is to review the total feed requirements of the herd or the expected annual tonnage to be handled if the hay is not fed on the farm. Where the herd is kept on pasture for half of the year and fed hay the other half, approximately 3 tons of hay per cow per year may be needed. Where silage is fed, and the cows are on pasture as many months of the year as possible, some dairymen are feeding in the neighborhood of ½ ton of hay per cow per year. For the purpose of setting up a hay drier design problem, assume a 10-cow herd is to be kept on hay and pasture only. This herd then would have a total hay requirement of 30 tons per year.

### Hay densities

The weight of the hay that will occupy a given volume will vary widely with the type of hay and the conditions under which it is stored. Table 1 lists the densities of most legume hays under several typical sets of conditions.

Table 1. DENSITY OF LEGUME HAYS

| Kind of hay | Density | Volume |
|---|---|---|
| | *Pounds/cubic foot* | *Cubic feet* |
| Field-cured long hay in shallow mow.. | 4 | 500 |
| Field-cured long hay in deep mow .... | 4.5 | 400 |
| Field-cured, chopped 2"* and blown in mow 10 feet deep .......................... | 5.4 | 370 |
| Field-cured, chopped 1" and blown in mow 10 feet deep .......................... | 6.5 | 310 |
| Field-cured to 35 per cent long hay mow finished ...................................... | 5 | 400 |
| Field-cured to 35 per cent, chopped 2" mow finished ................................ | 5.6 | 360 |

* Chopped 2" indicates the minimum length of cut. Average length of cut will usually be nearer to 4 or 5 inches.

From the table above, we see that long hay, well packed, will occupy a volume of about 400 cubic feet per ton. A 10-cow herd then, having an annual feed requirement of 30 tons, will require 30 tons times 400 cubic feet per ton or 12,000 cubic feet of hay storage volume. If chopping equipment were available and the hay were to be cut into 2-inch lengths or longer and mow cured in the barn, a volume of approximately 360 cubic feet per ton might be more accurate. In this case only 10,800 cubic feet of storage would be required.

### Depth of loading

The maximum depth to which hay may be loaded over the drying system depends upon many factors. Experience in Oregon as well as in other states, however, indicates that under average conditions long hay can safely be stacked about 8 feet high on the drier and chopped hay about 6 feet high. After the first stack is dried, a second batch may be placed over it to a depth of about 6 feet for long hay and 4 feet for chopped hay. The recommended depth for baled hay is 7 to 9 feet over the duct system, and the total depth of the stack should not exceed 12 feet.

### Floor area

If this 10-cow herd is to be fed long hay, then 30 tons of hay occupying 12,000 cubic feet might be placed 8 feet deep over the drier. Dividing the 12,000 cubic feet by 8 feet deep would give a floor area of 1,500 square feet. This is assuming that the entire crop is to be dried at one time. If the hay is to be harvested in two or three cuttings, the drying area can be reduced. If approximately 50 per cent of the crop is to be dried from the first cutting, then the

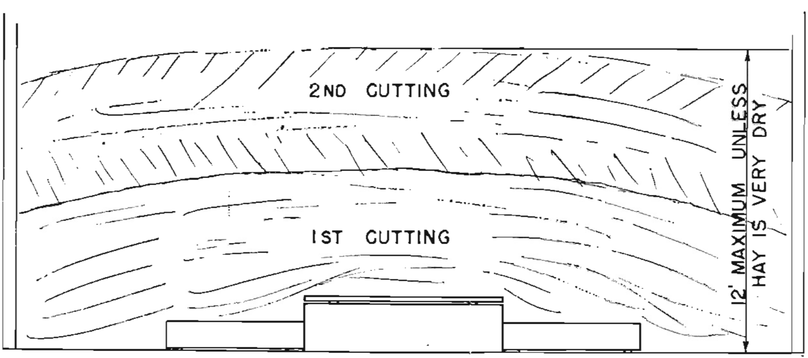



**Figure 18. Sectional sketch showing multiple loading over duct system.**

floor area required would be only 750 square feet. In this case the second cutting could be placed directly over the first cutting after it has been dried and the air forced through the entire stack. This is generally a safe practice since the drying weather is more favorable for the second cutting and the higher air velocities and the uniform air flow through the hay are not so critical. If the moisture content of the second cutting is 35 per cent or greater, however, it is usually desirable not to have the entire depth of the stack exceed 12 feet as shown in Figure 18.

**Air requirements**

Mow-type driers for either long or chopped hay should be provided with from 15 to 20 cubic feet of air per minute for each square foot of drying area. Where baled hay is to be dried, at least 20 cubic feet of air per minute for each square foot of drying area should be provided. Even greater volumes of air may be required if the bales are to contain more than 35 per cent moisture when loaded in the mow. The above minimum quantities of air have been found to be necessary in order to get sufficient air movement throughout the stack. When lesser amounts are used, the air will tend to bypass the more dense masses of hay and those spots are apt to dry too slowly and become musty. Greater quantities of air would cause faster drying but the cost of the equipment usually makes them impractical.

Looking back again at the mow-type drier for a 10-cow herd, we see that the drier was going to cover 1,500 square feet of floor surface. Multiplying 1,500 square feet by 20 cubic feet of air per minute per square foot of floor area gives a total air requirement of 30,000 cubic feet of air per minute. If this hay is to be dried in two or three cuttings, then multiply 20 times 750 to arrive at the 15,000 cubic feet of air per minute needed.

A satisfactory estimate of fan capacity in cubic feet per minute for circular-type hay keepers may be determined by multiplying the total volume of the keeper by two. For example, if the keeper, exclusive of the air shaft up the center, contains 5,000 cubic feet, a blower having an output of 10,000 cubic feet of air per minute would be satisfactory. This capacity will provide for two complete air changes through the hay each minute.

**Air velocities**

Whenever air is forced through a duct system, a certain amount of resistance to air flow is encountered due to friction of the air against the sides of the duct and due to turbulence. Larger ducts will permit lower air velocities and, therefore, lower friction but larger ducts cost more to construct and take up more valuable space in the mow. The smaller ducts, while less costly, create too much frictional resistance to the movement of air. Experience has shown that providing for a velocity of from 800 to 1,600 feet per minute strikes a favorable balance. Where practical, it is suggested that the design provide for a velocity of 1,000 feet per minute. This means that the first part of the main duct for a drier should have a cross sectional area large enough to permit the air to flow through it at a velocity of no greater than 1,000 feet per minute. If the drier requires 15,000 cubic feet of air per minute, divide 15,000 by 1,000 feet per minute to get a cross sectional area of 15 square feet. This can be provided by a duct 3 feet by 5 feet or 4 feet by 4 feet. Halfway along the main duct, approximately one-half the air already will have been discharged so that the cross sectional area of the main duct may be reduced by one-half. In actual practice, however, the main ducts usually are not reduced quite this fast. Many operators, in fact, prefer to maintain the full size of the central duct throughout the length of the drier. This permits them to crawl inside it to shut off parts of the slatted floor or lateral ducts when certain parts of the drier are not used, or when part of the stack is already dried.

Air velocities within the slatted floor or within the lateral ducts also should be held below 1,000 feet per minute. Higher velocities not only result in undue friction (which reduces the total amount of air delivered) but also creates problems in obtaining uniform distribution. High-velocity air tends to pile up at the end of the ducts or at the end of the slatted floor and to bypass the hay near the main duct.

## Air friction

When air tries to pass up through the hay it encounters considerable friction. This friction is dependent upon the tightness or the compactness of the hay and also upon the velocity of the air. Figure 19 gives the air-friction values for several typical hays and air velocities. These friction values are listed in terms of inches of water static head. The curve indicates that under typical conditions, a static pressure of 0.6 inches of water is required to force air through a hay depth of 10 feet at a rate of 20 feet per minute per square foot of floor area. This means that if a manometer or a glass U-tube partially filled with water were placed against the duct supplying this air, as shown in Figure 20, the pressure of the air inside the duct would raise the level of the water in the tube 0.6 inches. To this pressure must be added 0.2 to 0.4 inches of water

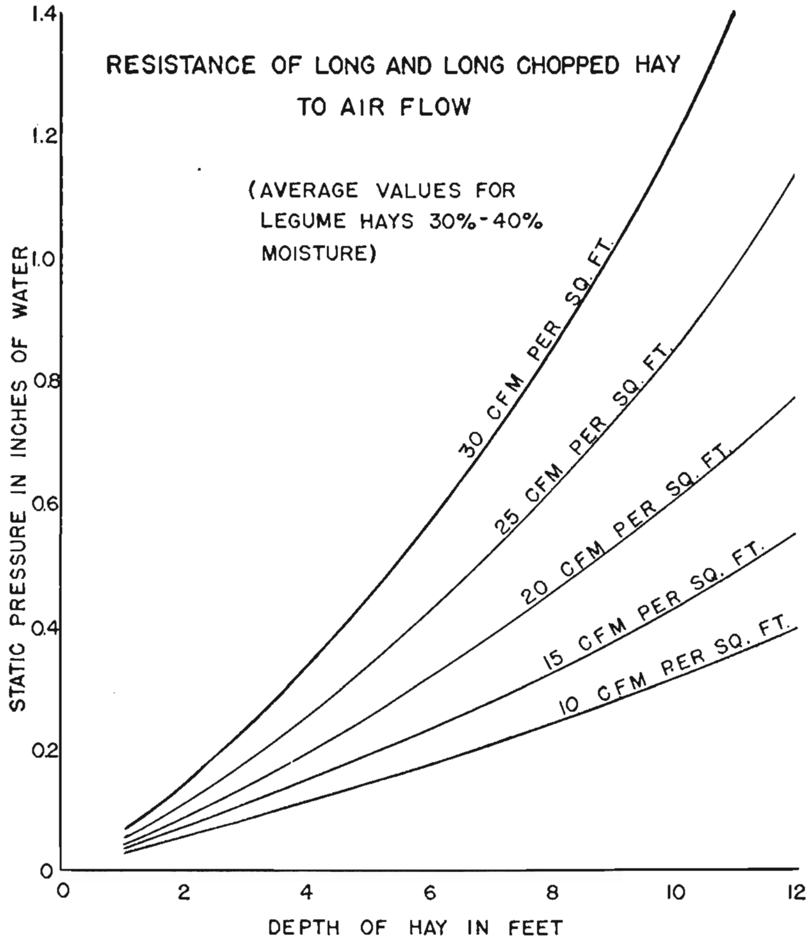



Figure 19. Typical curves showing resistance to air flow offered by long and long-chopped hay at different air-flow rates. These curves are representative of long hay lightly tramped and long-chopped hay not tramped.

friction head encountered within the duct system itself. A figure of 1 inch of static water, total static head, generally is used in making the fan selection and in working out the design of the duct system for long or chopped hay. Baled-hay driers are commonly designed to require that the air be supplied at a pressure from 1 to 2 inches of water static head.

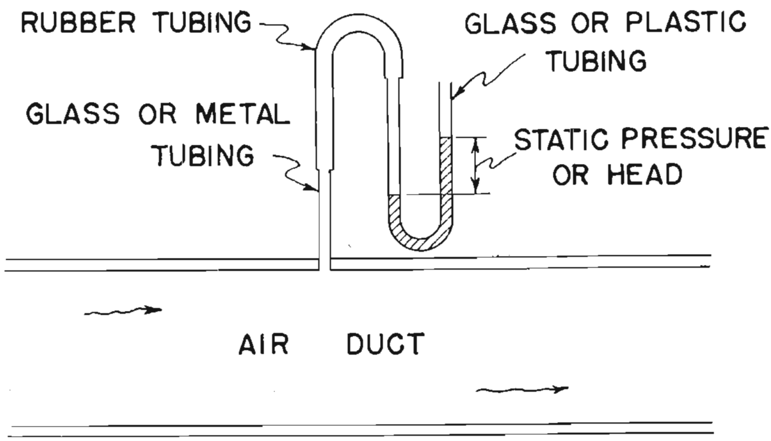



Figure 20. Manometer or U-tube arrangement for checking static pressure.

**Mow air inlets and outlets**

Since the air forced through the duct system must serve as the carrying medium for removing the moisture from the hay, some provision must be made for taking only fresh outside air into the fan and for discharging the moist air from the hay mow. If the fan has a chance to pick up some of the moist air that is discharged from the top of the stack, this air will be recirculated with little or no drying effect on the hay. It is desirable to have sufficient fresh-air openings to allow the air to come to the blower at a velocity no greater than 500 feet per minute. That is, this outside fresh-air opening should be about twice the size of the main air duct. Sufficient win-

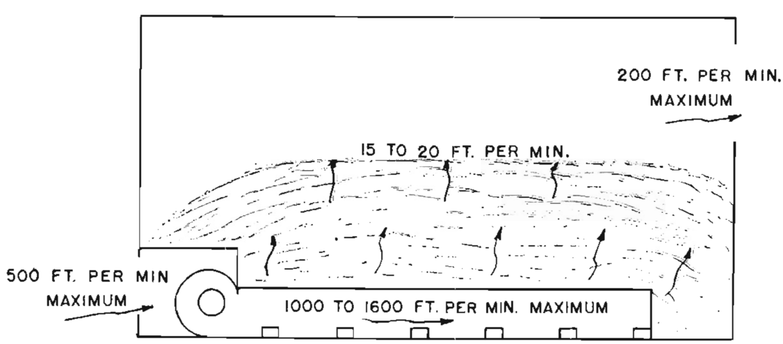



Figure 21. Sketch showing relative air velocities desired in various parts of the drying mow.

dow and door openings should be provided in the mow to allow the moist air to escape at a rate of no greater than 200 feet per minute. If the present openings are all on the windward side of the building, it would be well to provide a new opening on the leeward side of the barn. Very moderate wind velocities can create sufficient pressure within the mow to seriously reduce the discharge capacity of the drying fan.

### Lateral-duct system

In the design of a lateral-duct system one must consider the size and shape of the mow, hay depth, and the amount of air to be used. For the common rectangular mow, this plan may be used:

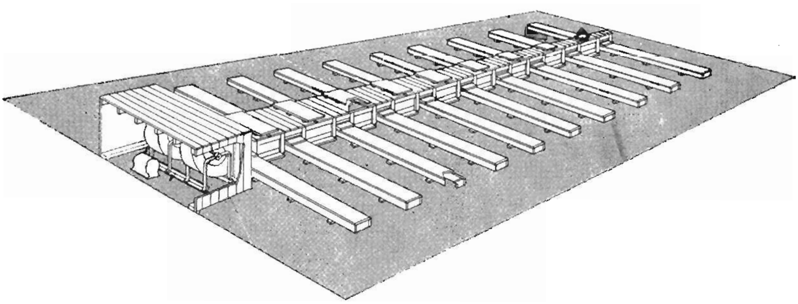


**Figure 22. Lateral-duct system with constant-height main duct for use with multivane-type fan.**

The main duct may be tapered or stepped down in size if the hay space is needed. In many cases, however, it is more convenient to build the duct full size throughout its length. This simplifies construction and permits a person to walk or crawl inside to close off part of the system when desired and to open the upper air gates when the hay becomes more than 4 or 5 feet deep over the main duct.

To insure air passage up through the heavily compacted hay directly over the main duct, a series of baffled openings should be provided as shown in Figure 23. The crack under these baffles should be about $\frac{3}{4}$ inch wide and the crack in the main duct beneath the baffle should be at least 2 inches wide. The lateral ducts are supported above the floor by 1 inch by 4 inch cleats. This provides the necessary opening to permit the air to escape from the lateral and enter the hay.

The small, lateral ducts should be not more than 4 feet apart on centers and should be kept 6 feet from each wall. If they are run closer to the walls, there will be too much air leakage along the

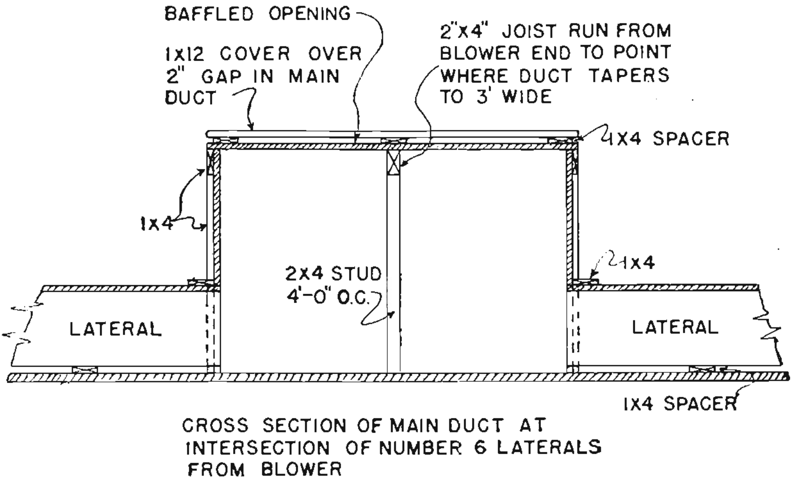



**Figure 23. Section view of main duct on a lateral-duct system, showing top baffled openings and construction details.**

floor and up near the walls. The hay stems and leaves tend to stratify in horizontal layers and it is much easier for air to pass along the floor or through the hay horizontally than to work its way vertically through the stack.

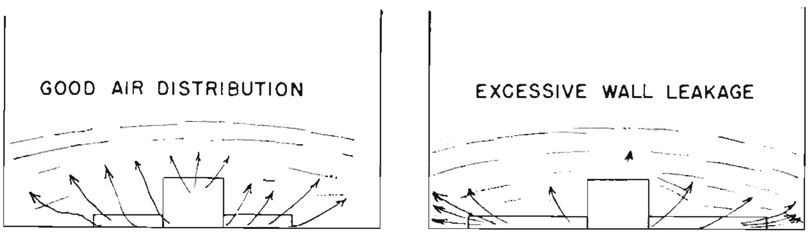



**Figure 24. Sketches showing air distribution pattern when lateral ducts are placed too near the walls.**

Where the fan discharge is near the openings supplying air to the first lateral ducts, the high air velocity from the fan may prevent air from feeding into the first few laterals. In some installations this high velocity past the laterals has resulted in a suction instead of a pressure at that point. To divert the necessary share of air into these first openings it may be necessary to use a simple air scoop, formed from a piece of heavy-gauge metal and fastened beside the lateral-duct entrance.

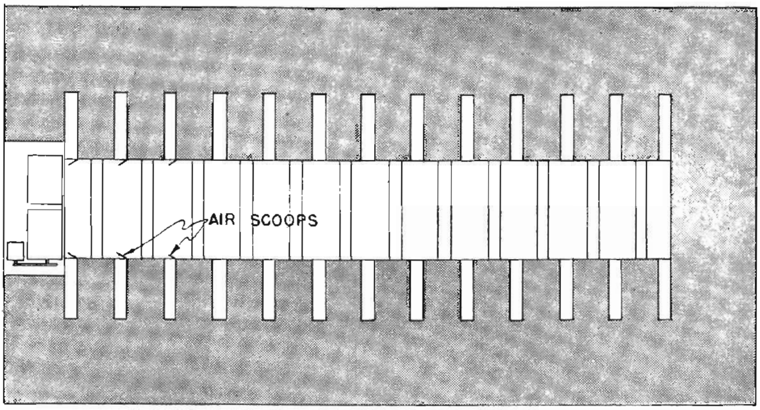



Figure 25. Plan view of lateral-duct system showing air scoops that may have to be installed in front of first few laterals. This main duct is constant width with the height tapered.

The entire construction of the duct system need be only reasonably airtight, permitting the use of scrap and odd-shaped lumber.

### Slatted-floor system

The same main duct arrangement is used with the slatted floor as with the lateral-duct system except the main duct with the slatted floor has a continuous opening along the bottom. Figures 26 and 27 show a plan for a system in a rectangular mow with the main duct

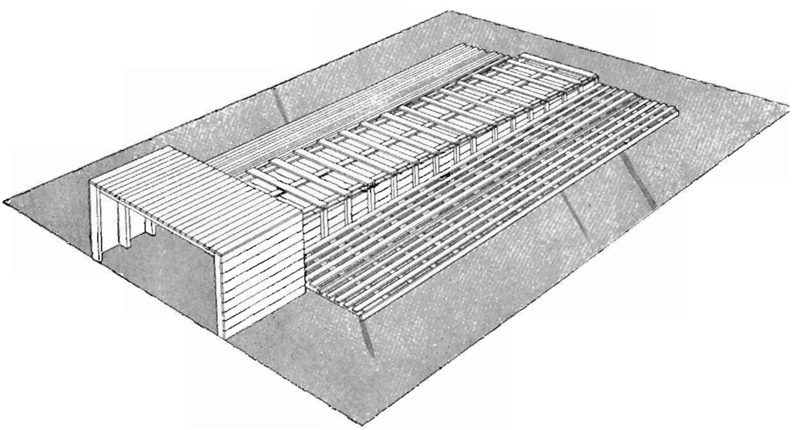


Figure 26. Slatted-floor system with constant width and tapering-height main duct.

in the center. Here again the slatted floor is kept 6 feet in from the wall or the edges of the proposed stack. If the slatted floor is to be removable, it is well to have it built up in sections approximately 6 feet by 8 feet or 4 feet by 6 feet.

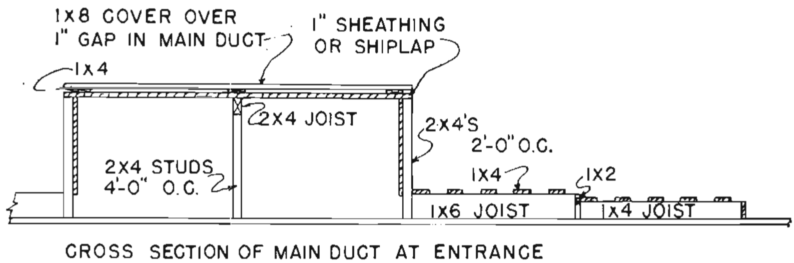



**Figure 27. Section view of main duct on slatted-floor system, showing methods of construction.**

Where a centrifugal-type fan is used, the air may be discharged at sufficiently high velocity to require air scoops for deflecting air into the first few feet of the slatted floor.

To make the system most effective when used for hay depths over 8 feet, the main duct may be fitted with extra side openings near the top.

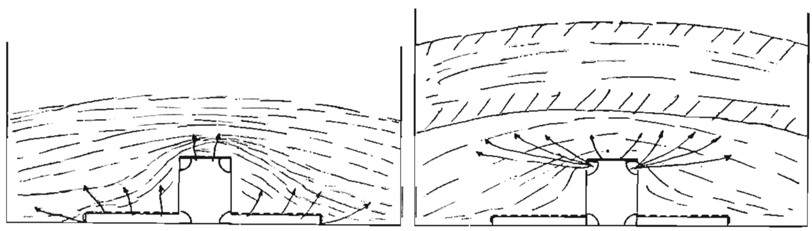


**Figure 28. Top-opening arrangement for obtaining better air distribution at greater hay depths. *Left*, the top doors are closed and the bottom doors opened for drying a shallow layer of hay. *Right*, the top doors are opened and the bottom doors closed to prevent excess leakage along the walls.**

When the second batch is loaded onto a batch that is already dried, the bottom doors to the slatted floor are closed off and all the air is discharged near the top of the main. This helps prevent excessive air leakage through the dried hay and up along the walls.

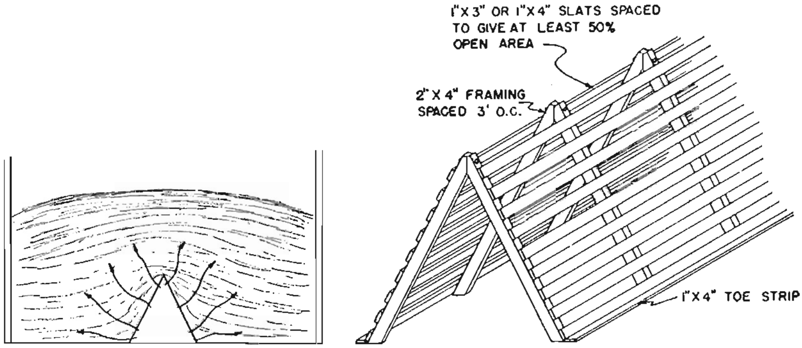



Figure 29. *Left,* cross section of A-frame duct showing its relative position in the mow and the region of air discharge. *Right,* a section of the A-frame duct showing method of construction. First 6 feet of A-frame should be tightly sheathed as shown in Figure 12.

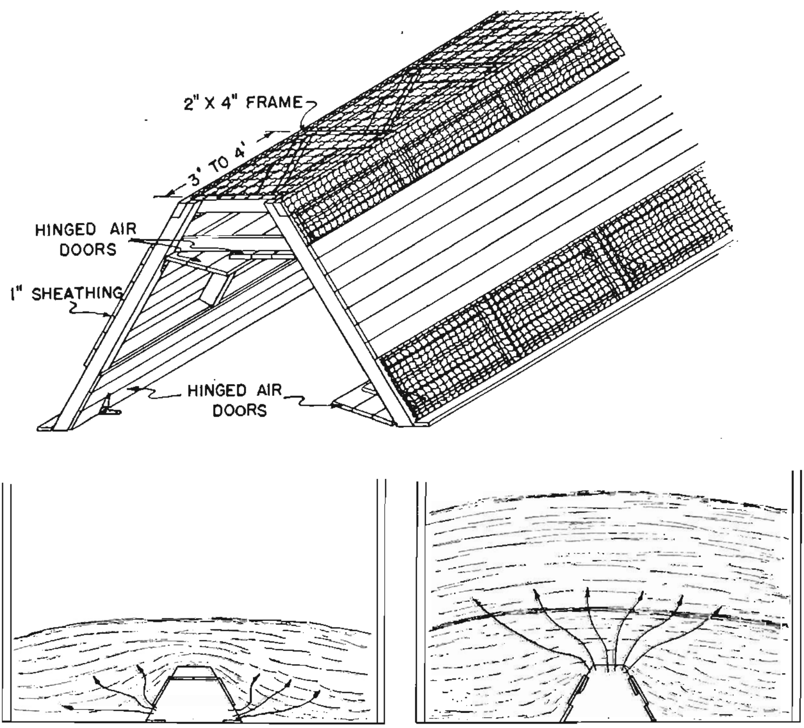



Figure 30. *Top,* a section of the modified A-frame duct showing hinged air-door arrangement and method of construction. *Bottom left,* cross section showing upper doors closed and lower doors opened for drying first loading. *Bottom right,* same duct with lower doors closed and upper doors opened for drying second loading or deeper stacks.

**"A" type or single main-duct system**

The single main duct may be used successfully with either narrow mows or for outdoor stack drying of hay or seed crops prior to threshing. For narrow mows a duct similar to the ones shown in Figure 29 or 30 may be used.

Where the hay is all cured from one cutting, the simple "A" duct with air openings over its entire surface would be adequate. An arrangement similar to that shown in Figure 30 is being used in parts of Pennsylvania for drying full or partial loads. The upper gates can be closed and the lower gates opened when 6 feet of hay or less is being dried. For greater depths both sets of gates would be opened unless the hay on the bottom was already dried. In this case, only the upper gates would be opened.

Any single-duct system should be set in about 6 feet from the end of the stack to prevent air leakage.

## Design and Construction—Stack Drying Systems

Stack drying in the field can be done with any of the duct systems. However, the excavated main beneath a lateral-duct or slatted-floor system as shown in Figure 10 permits building a more uniform stack. Where the hay is to be threshed for seed the temporary low-type "A" frame shown in Figure 31 has many advantages. The

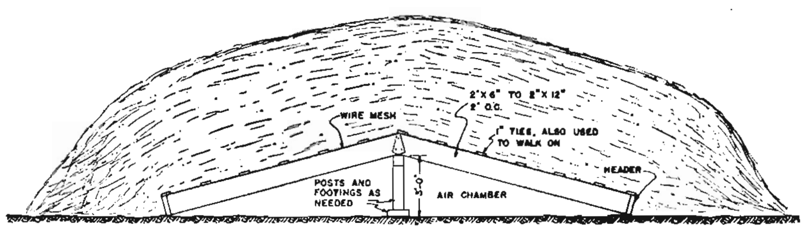



**Figure 31. Low-type A-frame which can be quickly erected and disassembled with very little waste of lumber. Useful primarily for drying seed crops in small stacks with heated air in the field.**

frame can be built from 2 x 6, 2 x 8, 2 x 10, or 2 x 12 common lumber without cutting the pieces if they are somewhere near the same length. The frame is covered with chicken wire or hog wire held in place with staples or wooden cleats nailed to the 2-inch members. A few cleats should be nailed across the 2-inch members to tie them together and to provide footing for a man walking over the frame. This arrangement can be erected very quickly in the field and most of the materials salvaged with very little damage to them.

# Design and Construction—Circular Type

The farm-built wooden circular hay keeper shown in Figure 13 generally is constructed 24 feet in diameter and either 20 or 30 feet high. Capacities will vary from 20 to 30 tons for the 20-foot models and from 30 to 50 tons for the 30-foot keepers depending upon length of chop, type of hay, moisture content, etc. Hay is blown or elevated through a dormer provided in the roof. The central flue or shaft, shown in Figures 32 and 33, serves as a chute when the hay is pitched from the top of the stack into a feed cart at the base of the shaft.

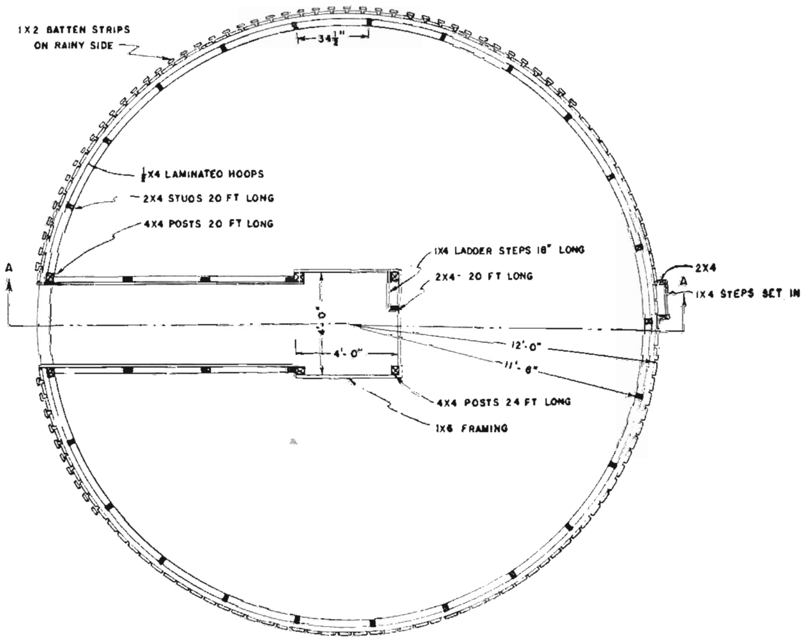



**Figure 32. Plan view of circular-type wooden hay keeper.**

## Method of construction

By constructing the center shaft first and erecting it in position on the concrete base, it can be used to help support the wall as it is being constructed. The wall studs are set in place on the circular foundation and temporarily held in place by braces to the center shaft. The hoop layers shown in Figure 34 are then bent around the studs and nailed in place.

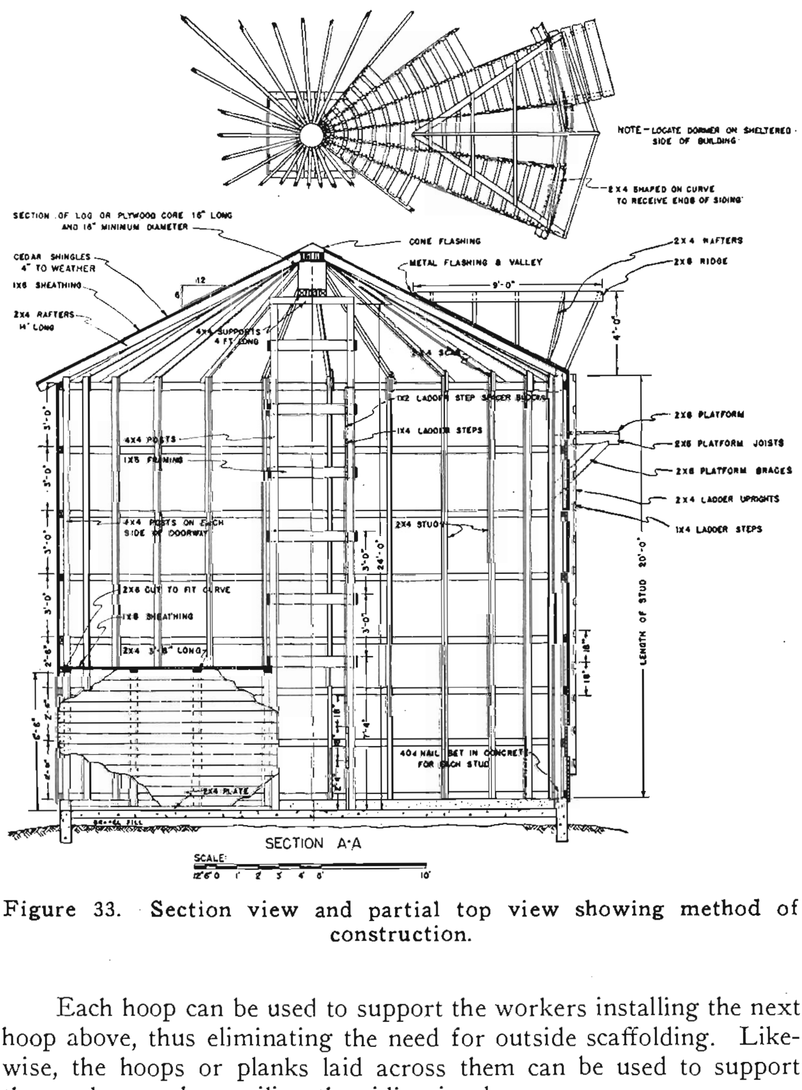



Figure 33. Section view and partial top view showing method of construction.

Each hoop can be used to support the workers installing the next hoop above, thus eliminating the need for outside scaffolding. Likewise, the hoops or planks laid across them can be used to support the workmen when nailing the siding in place.

Cracks at least ⅜ inch wide to permit air movement should be provided between the siding boards. If the lumber is very green, this may be reduced to 3/16 inch at the time the boards are nailed down. In higher rainfall areas, the cracks on the windward side should be protected with a 1 x 2 or 1 x 4 bat spaced ¼ inch from the siding. The spacing can be obtained by the use of double-head nails

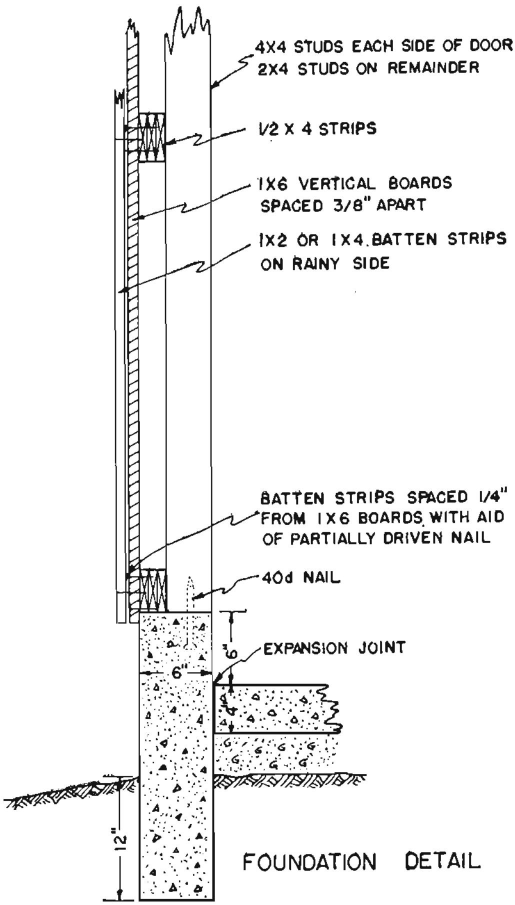



**Figure 34. Section detail of wall construction.**

or by driving spacer nails into the siding with the heads left projecting ¼ inch above the surface.

## Natural-draft drier

Due to its open-slatted outer wall and center air chute the keeper is able to do a fair job of drying by natural draft. As heating in the hay takes place, the air in the center duct becomes warmer and tends to rise up and out of the duct, which acts as a chimney. The air rising up the chimney creates a pull which slowly draws the warm air out of the hay. Fresh air, in turn, is pulled into the hay through the cracks left between the outside vertical wall boards. Since no point within the hay is more than 5 feet from either the center duct or the outside wall, slow formations of heat can be carried off without danger of fire or spoilage if the hay has not been tramped.

If the hay is chopped long and contains 25 per cent to 30 per cent moisture, it can be cured by natural draft in all parts of the state except the coastal region in extended foggy weather. This would be hay that is nearly cured in the field but just a little too wet yet to store baled or put into a stack.

**Forced draft—cold air**

With a few additions, this keeper can be converted into a forced-draft drier using either cold or heated air. The blower and motor are located in the doorway, with the blower or fan arranged so as to blow air into the short alley and up the center chute. A simple plug made of plywood or 1-inch boards is placed in the chute about 4 feet below the level of the hay. A 2-foot canvas skirt around the edges of the plug helps keep the air from escaping past its edges. This plug prevents the air from escaping up the chute and forces it to pass horizontally through the hay and out the cracks in the outer wall.

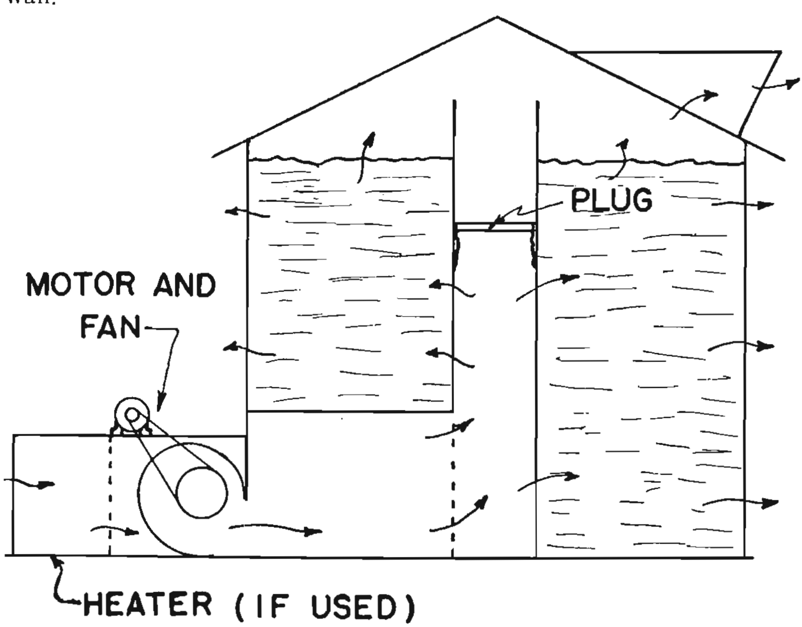



Figure 35. Section view showing air plug and air path when motor, fan, and possibly a heater unit are used.

## Forced draft—heated air

If the air is to be heated, the heating unit can be placed in a duct or tunnel ahead of the fan. The air is pulled through the tunnel across the heating unit into the intake of the fan and then into the center chute where it is forced through the hay.

## Bill of materials

For building a circular-type keeper 24 feet in diameter and 20 feet high, the following materials would be required:

| Item | Quantity | Size | Length | Board measure |
|---|---|---|---|---|
| | | *Inches* | *Feet* | *Board feet* |
| Studs | 23 | 2 x 4 | 20 | 307 |
| Ladders | 3 | 2 x 4 | 20 | 40 |
| Duct studs | 3 | 2 x 4 | 14 | 28 |
| Rafters | 25 | 2 x 4 | 14 | 350 |
| Dormer rafters and plates | 5 | 2 x 4 | 14 | 47 |
| Duct joists | 1 | 2 x 4 | 12 | 8 |
| Duct plates | 2 | 2 x 4 | 10 | 14 |
| Studs | 2 | 4 x 4 | 20 | 53 |
| Center posts | 4 | 4 x 4 | 14 | 75 |
| Center posts | 4 | 4 x 4 | 10 | 54 |
| Roof supports | 1 | 4 x 4 | 8 | 11 |
| Roof supports | 1 | 4 x 4 | 12 | 16 |
| Dormer ridge | 1 | 2 x 6 | 10 | 10 |
| Platform | 2 | 2 x 6 | 16 | 32 |
| Duct header | 1 | 2 x 6 | 4 | 4 |
| Shaft framing | 6 | 1 x 6 | 12 | 36 |
| Duct-top sheathing | 6 | 1 x 6 | 10 | 30 |
| Duct-side sheathing | 26 | 1 x 6 | 12 | 156 |
| Siding | | 1 x 6 | 20 or random | 1,520 |
| Roof sheathing | | 1 x 6 | Random | 650 |
| Ladder steps | 4 | 1 x 4 | 12 | 16 |
| Batten strips and ladder spacers | 65 | 1 x 2 | 20 | 217 |
| Hoops, lineal feet | 1,850 | ½ x 4 | | |
| Shingles, squares | 7 | 5/2-16 | | |
| Shingle nails, pounds, 3 d | 24 | | | |
| Nails, pounds, 8 d | 100 | | | |
| Nails, pounds, 16 d or 20 d | 20 | | | |
| Nails, pounds, 40 d | 3 | | | |
| Concrete foundation, yards net | 3 | | | |
| Concrete floor, yards net | 5 | | | |
| Cone flashing | | | | |
| Dormer flashing | | | | |
| Rafter center support log, 16" diameter | | | | |

These figures are for net quantities required. Additional allowance for waste and overrun should be made on concrete, sheathing, siding, etc.

If the keeper is to be built 30 feet high, additional siding must be provided and 4 x 4 studs should be used. Also some type of wooden bracing or external guy wires should be provided to prevent the structure from twisting when empty.

## Fan and Duct Pressures

Hay-drying fans are called upon to provide sufficient push to overcome the resistance of air movement through the duct system and through the hay. The measure of this push may be referred to as the total pressure maintained in the duct system. Total pressure may be divided into two parts. One, which is referred to as static pressure or static head, is comparable to the measure of the pressure in an inflated automobile tire except that the values are a great deal lower. The other component of total pressure is velocity pressure or velocity head. This might be compared with the pressure created by the wind within an airport windsock.

Most of the measurable pressure within a drying duct system is static head. The discharge velocity from some hay-drier fans may be sufficiently high to create a fair amount of velocity head. Before the air has traveled very far along the duct system, however, the fast-moving air will have spent its impact against the slower-moving air within the duct and will have converted most of its energy into static head. Therefore, when referring to the pressures against which a hay-drier fan is expected to operate, we generally refer to static head only. The realm of these pressures is very low and the unit of measure is inches of head of water. Figure 20 shows how static pressures may be determined.

## Equipment Selection

### Fan types and characteristics

The three types of fans in general use on hay driers are the propeller, multivane, and the vaneaxial flow. Each type has different operating characteristics and there is some variation in cost.

*Propeller type:*

The propeller fan of the 4-, 6-, or 8-bladed type is a low-pressure fan but is quite satisfactory for use against the static pressures normally encountered in hay driers. A well-designed propeller fan will not change its horsepower requirement materially when the

—Courtesy Aerovent Fan and Equipment Company.

**Figure 36. Six-blade, 36″ propeller-type fan properly installed in an A-frame duct. Note the safety screen for the protection of personnel and the fan itself.**

static pressure against which it is working is raised or lowered. Figure 37 shows a typical performance curve of one 48-inch, propeller-type, hay-drying fan.

The main disadvantages of this type of fan are the noise it creates and the hazard it creates to itself, livestock, and personnel if not properly installed. Propeller fans must be well shielded to reduce the personal hazard to those working around them. The shield or screen should be small enough to prevent the entrance of birds, cats, poultry, etc. Several propeller fans in the Northwest have been completely shattered by felt hats, cats, and chickens that have come in contact with them. Their cost is somewhat less than the vaneaxial fan and is quite comparable with the cost of the multivane type.

For hay drying work, one should not confuse the propeller fan with one of the many types of common disk-impeller fans, quite

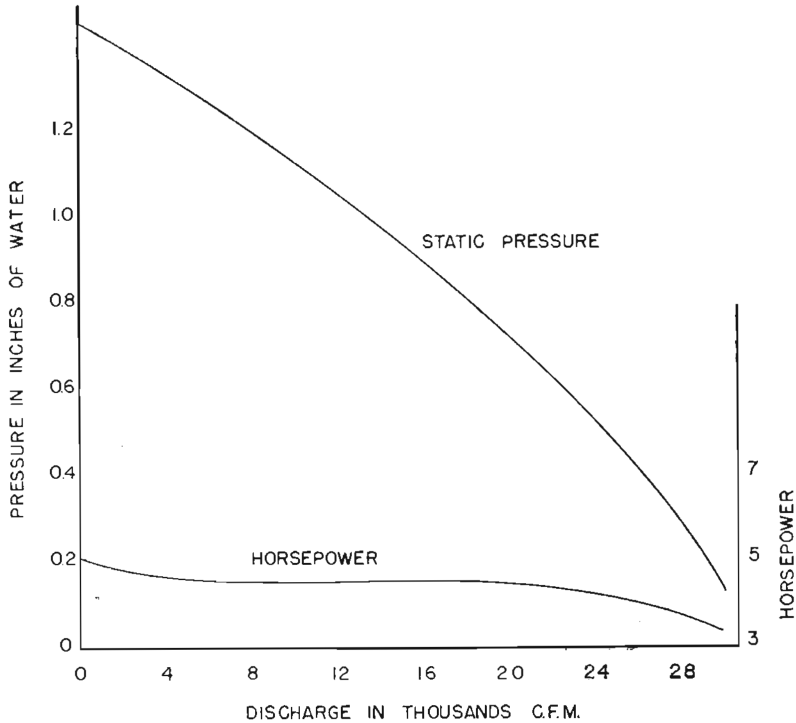
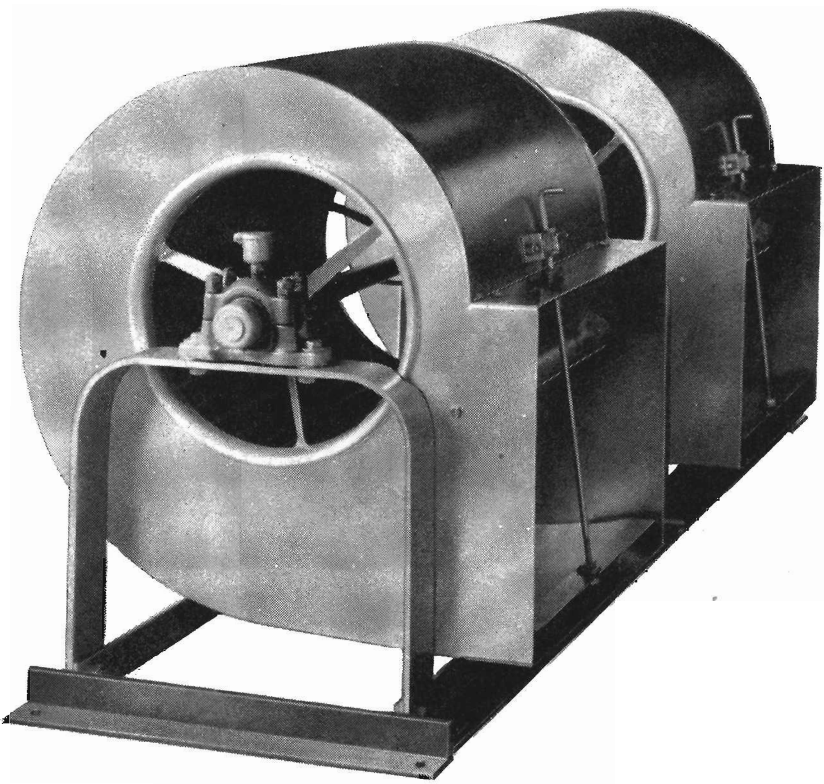



**Figure 37. Typical performance curve of 48" diameter propeller-type fan at one speed. Note that as fan operates against lower pressure the air discharge increases but the horsepower requirement stays uniform over a wide range.**

generally used for exhausting air from a building or for circulating air within a room. These fans usually have several flat or slightly curved blades and generally are not suitable for operating against hay-drier pressures. If performance test curves are available on a particular fan in question, its suitability can be determined by checking its air output and power requirement when operating against $\frac{3}{4}$ to 1 inch static water pressure.

*Multivane type:*

The multivane fan is often referred to as a squirrel-cage blower. The vanes on the rotor or squirrel cage are curved either forward or backward, with respect to the direction of rotation. Forward-curve fans generally are less expensive and are used more commonly

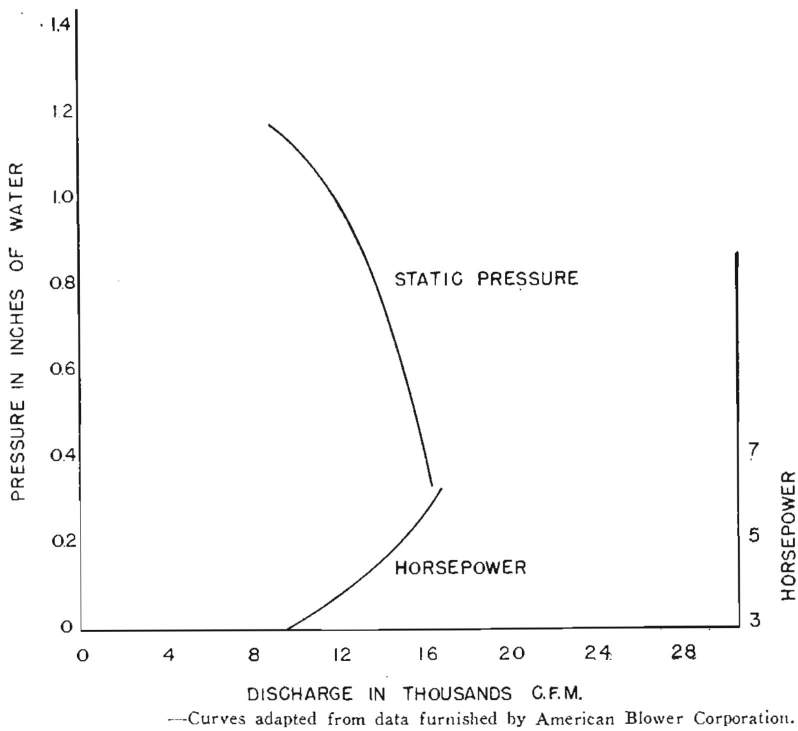


—Courtesy American Blower Corporation.

**Figure 38. Two double-width, double-inlet, forward-curve multivane fans, mounted on common shaft and base for hay drying application. Note the adjustable scroll-type dampers that can be used to throttle the fan discharge for controlling horsepower requirement.**

on hay driers. They are obtainable in either single width with a single inlet or in double width with double inlets.

Some manufacturers offer two double-width, double-inlet fans on a common shaft and base for ease in handling and installing. Either the heavy-gauge industrial-type fans or the lighter-gauge units are satisfactory. Forward-curve fans are basically slow speed, high volume, relatively low-pressure units. They are capable of operating against much greater static heads than the propeller type. Their chief disadvantage is their tendency to require more power when the static head is reduced. The power requirements may be figured closely when the fan is operating against 1-inch static head, such as when the drier is heavily loaded with hay. If the fan is operated against a partial loading of hay, the static head will be reduced, the discharge volume will increase, and the power requirements will increase. If a motor has been selected to barely supply the power requirements of the fan when operating against full 1 inch of water static head, then it will become overloaded when the static head is reduced. This can be corrected by throttling either the intake or outlet of the fan or by reducing the fan speed. From a practical standpoint it is usually advisable to have the motor about 10 per cent underloaded at full hay-drying depth to allow for some variation in static head and then throttle the fan inlet or outlet for radical reduction in hay depth. Several manufacturers supply an adjustable damper on the fan as shown in Figure 38 for convenient throttling of the discharge as needed to compensate for low hay depths. By careful adjustment of the damper the motor can be kept loaded to



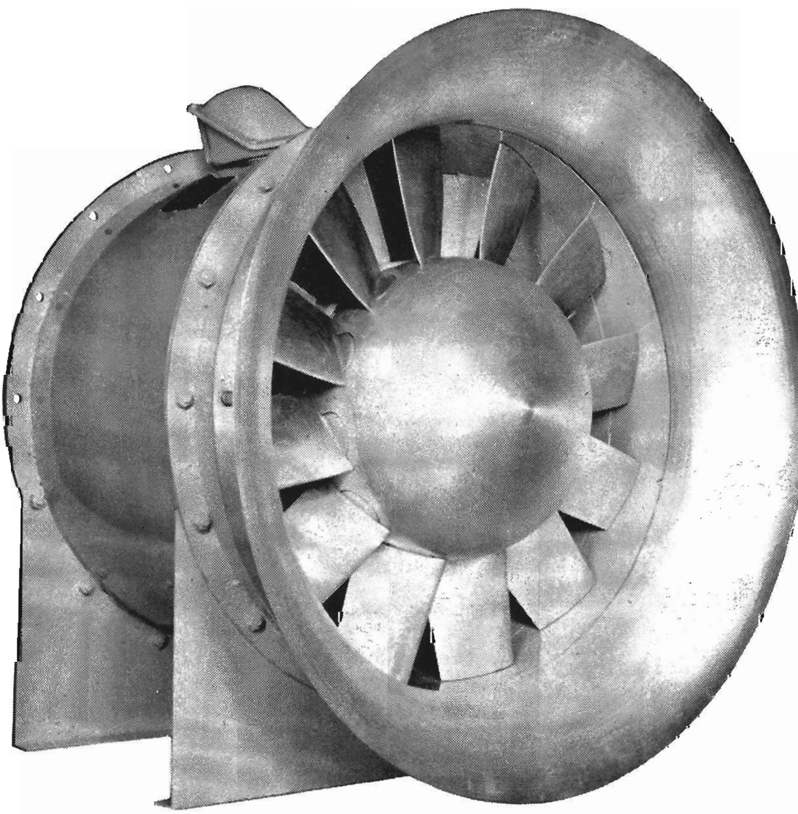

—Curves adapted from data furnished by American Blower Corporation.

**Figure 39. Typical performance curve of a forward-curve, multivane hay-drying fan at one speed. Note the increase in horsepower demand with a decrease in static pressure, necessitating the use of some type of discharge control.**

full capacity and the fan kept delivering at maximum capacity for all depths of loading. Figure 39 shows a section of a typical performance curve of a multivane-type hay-drying fan. Companion curves covering other ranges of static pressure, horsepower, and discharge capacity can be obtained for the same blower operated at different speeds.

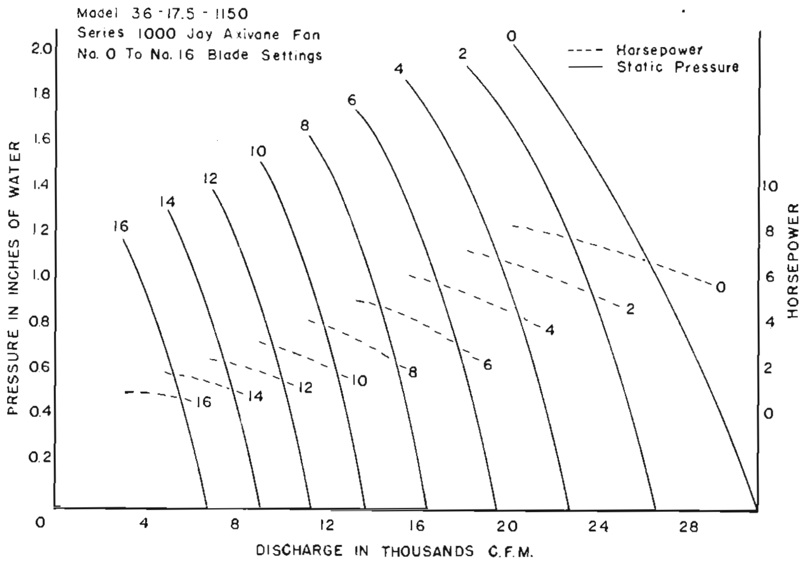
*Vaneaxial-flow type:*

Vaneaxial fans have desirable operating characteristics and are convenient to install. They are very efficient and have no tendency to overload the motor when the static head is reduced. As shown in Figure 40, the motor is directly connected and enclosed within the



—Courtesy Joy Manufacturing Company.

**Figure 40. Vaneaxial flow-type fan with adjustable pitch blades. Note the compact arrangement obtained by connecting the fan directly to the motor.**




Curves adapted from data furnished by Joy Manufacturing Company.

**Figure 41. Performance curves of one model of vaneaxial fan at different blade-pitch settings. Note the wide range of performance characteristics available with the same fan at one speed by using various blade settings.**

center of the fan, therefore, no pulleys, belts or belt adjustments need be provided. Figure 41 shows the performance curves of one type vaneaxial fan at various blade settings. This fan can be used to handle a wide range of air volumes with varying static pressures at constant shaft speed by changing the pitch of the blades. In general, the original cost of the vaneaxial fan is somewhat higher than for propeller or multivane types.

When selecting a hay-drier fan, the performance data for that particular unit should be checked carefully whenever possible. Most fan dealers will be glad to assist in determining the proper type, size, shaft speeds, etc., that will give the most satisfactory performance under individual operating conditions.

*Power requirements:*

Electricity is generally the cheapest source of power to drive the drier fan. Since only single-phase service is available on most farms, the size of the motor that may be used is limited. Single-phase motors over 5 hp are very expensive and many rural lines cannot accommodate a size larger than 7½ hp. The maximum size of mow drier that should be built may be the size that can be serviced adequately with a 5-hp or 7½-hp motor unless engine power is used. Most well designed fans will require about 1 hp for each 3,000 cubic feet of air per minute delivered against 1 inch static head.

### Electric motor controls

The electric motor should never be installed without some form of overload protection. This is generally a magnetic switch fitted with the proper sized heater strips for that particular motor. Extra controls such as thermostats and humidstats are not recommended. They are expensive, difficult to keep properly calibrated, and result in little, if any, better drying than can be obtained by manual control.

### Belts

Short center V-belt drives are most commonly used when the fan cannot be directly connected to the motor.

The following number and sizes of V-belts may be used for average belt velocities and pulley diameters used in drier installations:

3-hp motors: two A-section or one B-section belt.
5-hp motors: two B-section belts.
7½-hp motors: three B-section belts.

### Pulleys

A slight change in the speed of some types of fans can greatly change their output and power requirements. Pulley sizes, therefore, should be very carefully selected to give the proper fan rpm. V-type pulleys should always be specified by pitch diameter. This is the effective diameter of the belt as it wraps around the pulley.

If a V-belt is run over a V-pulley, the pitch diameter will be less than the outside diameter of the pulley (as shown in Figure 42). Where a V-belt is run over a flat pulley, the pitch diameter will be greater than the outside diameter of the flat pulley. The accompanying table shows how much to add or subtract for this difference in diameters.

| V-belt size | Flat pulley (Add to outside diameter to get pitch diameter) | V-pulley (Subtract from outside diameter to get pitch diameter) | Combination A and B section V-pulley (Subtract from outside diameter to get pitch diameter) |
|---|---|---|---|
| | *Inches* | *Inches* | *Inches* |
| A | .4 | .25 to .375 | .76 |
| B | .5 | .5 | .36 |

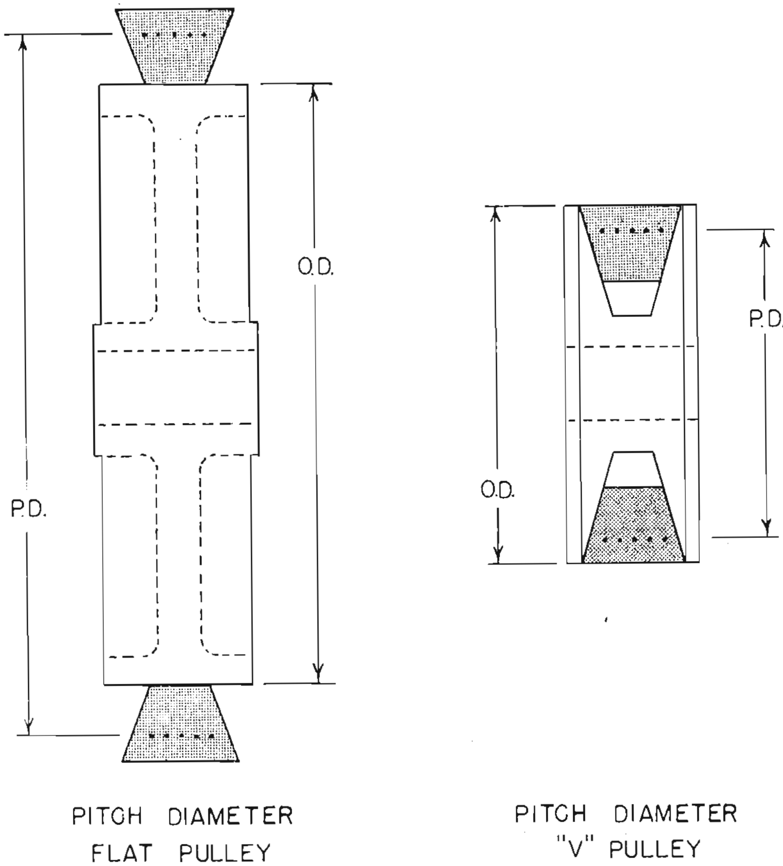



**Figure 42. Relative differences in pulley outside diameter and pitch diameter with V-belts used over V-type and flat pulleys.**

Where the ratio between the motor pulley and blower pulley is greater than 3 to 1 it is usually more economical to use a V-pulley on the motor and a flat pulley on the blower.

When the motor speed is known and the fan speed is specified, the pulley ratio is then determined. For instance, a 1,750 rpm motor operating a fan at 500 rpm would give a ratio of 3.5 to 1. The pulley sizes selected then must have the reverse of this ratio. If a 4-inch-pitch-diameter pulley is used on the motor, then a 14-inch-pitch-diameter pulley would be needed on the blower.

## Heating systems

Supplemental drying heat (in addition to the natural heat generated by the hay) should be provided for any driers installed along the coastal region of Oregon.

Whether the use of heating units is desirable and economical in other localities will depend upon such factors as how much field wilting or curing is done, how rapidly the hay is to be dried, and how much drying is to be done in humid or rainy weather.

*Types:*

There are numerous oil-burning heating and blower units on the market. These are of both the heat-transfer and the direct-combustion types. The heat-transfer units burn the fuel in a combustion chamber and force the hot gases from combustion through pipes over which the fresh air is blown. The fresh air is heated and goes into the hay while the gases from the combustion of the air and fuel are vented out through a chimney or exhaust and do not enter the hay.

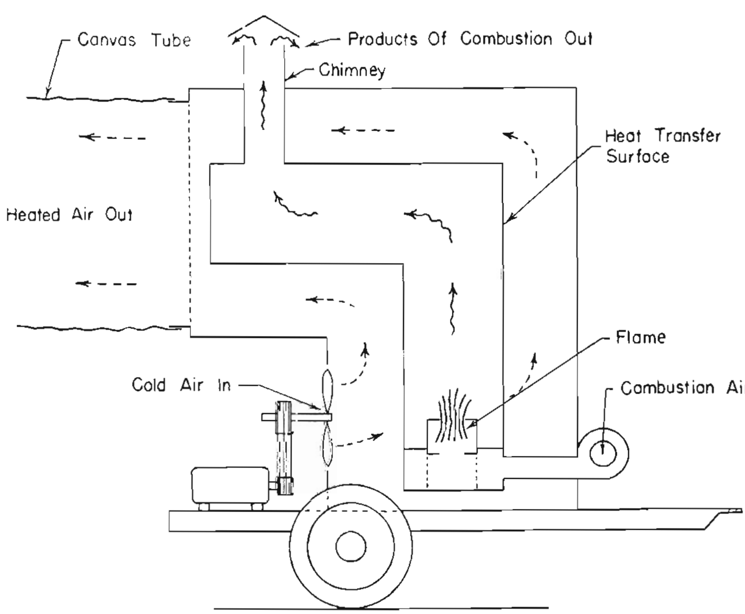



**Figure 43. One type of portable heat-transfer heater unit.**

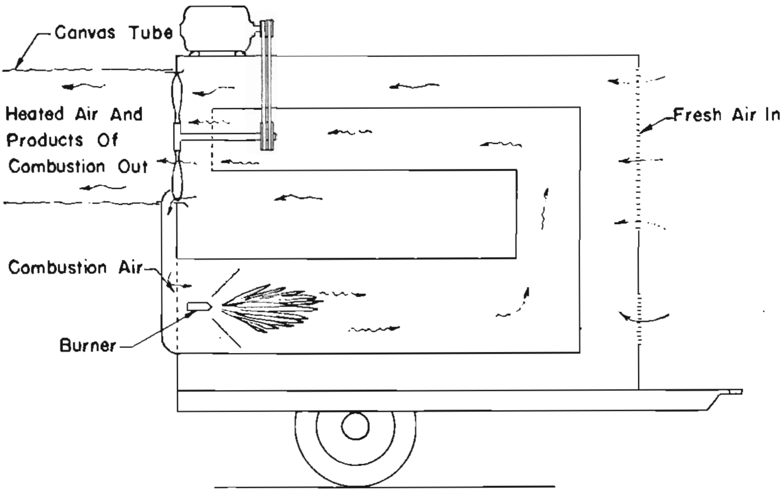



Figure 44. One type of direct-combustion heater unit.

Direct-combustion units draw the gases from combustion directly into the air stream and force them into the hay.

Either type of unit will perform satisfactorily if properly handled and adjusted. The direct-combustion units are more efficient since no heat is lost through an exhaust. If the flame is properly adjusted there is no objectionable soot or oily residue left in the hay. The air through these heaters should be well baffled or screened, however, to minimize the possibility of some bit of burning material being blown into the hay stack. Also, faulty burners or improper adjustment can result in serious damage to the hay.

The heat-transfer types lose some heating efficiency through their exhaust but have no problem of soot or oil deposits in the hay unless the unit is allowed to rust or burn out to the extent that considerable leakage develops. If properly constructed, they are much less apt to pass a piece of burning material into the air stream where it can enter the hay.

Neither unit is entirely fireproof and should always be placed at least 8 feet away from the main hay drier duct entrance. This minimum distance offers some added protection against live embers entering the stack.

Where the fan in the heating unit is not large enough to provide sufficient air to the duct system, an additional cold-air fan may be used. Better mixing and more uniform air temperatures can be obtained by pulling the heated air and the auxiliary cold air together through the one large drier fan. Where the one fan is not large enough to handle all the air the two fans must both feed into the main duct individually. In this case a turbulence box or a square turn (not curved or streamlined) should be provided in the main duct. This will cause some added resistance to the air flow but it is necessary to obtain practical mixing of the heated and cold air.

Where natural or city gas is available, considerable heating may be done by direct combustion with very little expense for equipment. The lighted jet may be placed in a suitably screened duct near the fan intake and practically all the heat from the fuel can be utilized. The same arrangement may be used for liquified petroleum fuels in the butane and propane groups if the proper burners are provided. In case these fuels are used, the local distributor should be contacted for help in arranging a suitable combustion chamber and supplying the burners.

No heating unit should be used unless it is equipped with a high-temperature cut-off which will shut off the fuel supply in case of fan failure.

*Temperature rise:*

The more the air is heated, the faster will be the rate of drying. Large heaters, however, are not usually justified for the short operating season because of the increased investment costs. Temperature rises of from 10° to 40° F. are considered most practical and will cut the drying time down to ½ to ¼ the time required to dry with unheated air.

The temperature rise that may be obtained from various heating systems may be estimated quite closely if the hourly fuel consumption rate and the total fan capacity are known. Where diesel or light stove or burner oils are used, the temperature rise may be obtained by multiplying 133,000 times the gallons of oil consumed per hour and dividing the product by the fan capacity in cubic feet per minute. This figure should be multiplied by the efficiency of the unit, which usually runs between 75 and 90 per cent for the heat-transfer units and around 90 to 97 per cent for the direct-combustion types.

Commercial L. P. gas is generally a mixture of propane and butane. Where this mixture is used, the temperature rise may be obtained by multiplying 94,000 times the gallons of liquid gas consumed per hour and dividing this product by the fan capacity in cubic feet of air per minute. When the burner is properly set up the efficiency of L. P. gas will be nearly 100 per cent.

## Operation

### Staggering of cutting

Only as much hay as can be placed in the mow drier in one or two days should be cut at any one time. This minimizes the risk of having a large quantity of hay being caught in the field by bad weather and also tends to stagger the load on the drier. If some of the hay on the drier is nearly cured before the balance of the load is brought in from the field, the total water content on the drier at any one time is reduced materially.

### Wilting period

The time required for field wilting will, of course, vary with the weather conditions, the type of crop, and the moisture content of the hay that the drier can handle. Again, the capacity of the drier will be influenced by the length of cut, the depth to which the hay is piled, the quantity and temperature of air supplied to the drier, and the outside weather conditions. In general, however, if an unheated air drier is to be fully loaded, it is usually well to let the hay wilt down to a moisture content below 40 per cent. Small quantities of wetter hay might be brought in and successfully dried if necessary to avoid field spoilage due to bad weather. Also, it is quite practical to mix a few wet loads of hay in with other loads that are below 35 or 40 per cent—so long as the total average moisture content does not exceed the 40 per cent figure. Extreme care should be taken to spread these wetter loads over the entire surface of the drier and not to allow the wet hay to be bunched in small areas.

During periods of reasonably good drying weather, two or three days of field curing should be sufficient to have the hay ready for the mow drier. Many operators have found that on good days they can cut one day and haul the hay into the drier the following afternoon. In any event the material should be brought in while still tough enough to prevent leaf shattering.

### Loading the drier with long hay

When loading long hay onto a mow-type drier, care should be taken to hoist the material in small fork or sling loads. Any heavy loads of moist hay that are dropped from the track at the top of the barn will need to be broken up and scattered evenly over the duct system to permit uniform drying. If a second bumper block or similar arrangement on the track equipment can be made for lowering the fork or sling loads down near the drier before dumping, a great deal of hand pitching can be avoided. By dropping the loads down near the drier and swinging them into position before dumping, the hay will not have to be moved and packing will be minimized.

The stack should be built up evenly with no hard or open spots to dam or channel the air flow. Extra care should be taken not to pack the hay too tightly directly over the main duct. As the hay settles, this area becomes more dense than the rest of the stack and tends to dry much more slowly.

### Loading with chopped hay

If chopped hay is to be mow dried, it is recommended that the material be chopped to a length of at least 2 inches. This means that the chopper should be adjusted so that the feed mechanism advances the forage at least 2 inches between successive passes of the chopping knives. Hay cut to this length pitches easily, does not pack excessively on the drier, and is well accepted by the livestock. Any type of mechanical elevator or blower may be used to load the drier. A few inches of long hay should be placed over the slatted floor or lateral duct system to prevent the chopped hay from clogging the air outlets. As the hay is elevated or blown onto the drier it should be distributed evenly and kept leveled off. This can be done by periodically shifting the direction of the blower pipe or by use of deflector boards suspended over the drier. Under no circumstances should the chopped hay be walked upon or tramped as it is being loaded on the ducts or slatted floor. Tramping the moist, chopped hay will result in dense areas which the air cannot sufficiently penetrate. These spots will be slow to dry and probably will become musty. When necessary to get on the stack in order to level it off, a long plank or stepladder might be laid upon the hay to help distribute the weight.

### Fan operating schedule

The drier fan should be started as soon as the first load of hay is placed on the drier. The fan should be kept in steady operation for at least 48 hours after the last load has been brought in. During the next three or four days, the fan might be shut off during rainy or foggy periods. The hay may start to heat, however, and mold may develop if the fan is left off more than 6 or 8 hours at a time. After the hay begins to feel dry on the top of the stack, the fan may be shut off for several hours and then restarted. If there are any wet spots left in the stack, the warm air can be noticed rising above these areas and drying should be continued for another day or two. Even after it is believed that the stack is completely dried it is well to start the fan every 3 days for the following week or two in order to insure that no hot spots develop. The same general procedure should be followed for operating a drier using heated air, except that the time required for drying will be much less.

# Methods of Checking Moisture Content

## Oven method

The use of an oven is probably the simplest and most foolproof method of checking hay moisture. Where a kitchen oven is used the thermostat should be set to operate at about 250° F. The samples of approximately 200 grams can be weighed on a torsion balance as shown in Figure 45 or on a diet scale reading in grams or ounces. Ordinary 15 to 30 pounds capacity household scales or baby scales

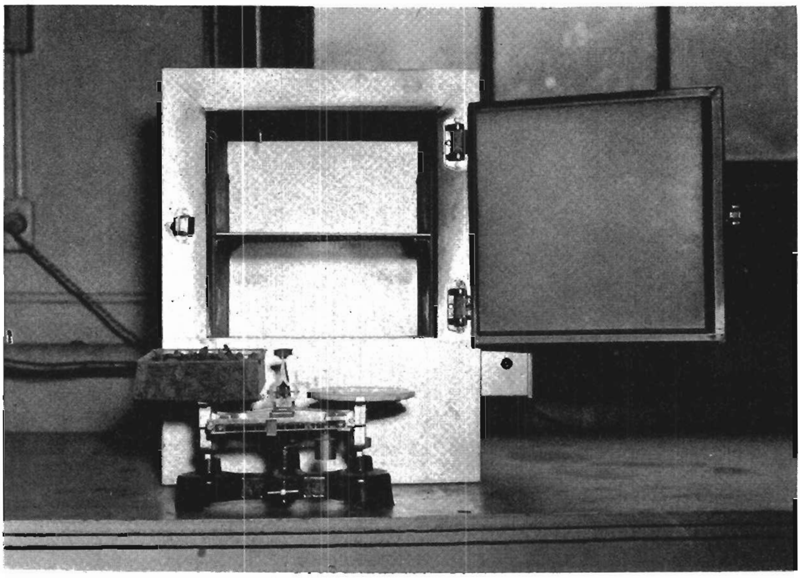


**Figure 45. Thermostatically controlled oven with air vent in top. Note wire basket of finely cut hay being weighed on the torsion balance in the foreground.**

are satisfactory for rough determinations if large samples of at least 2 pounds are taken. The sample should be cut in ¼-inch lengths, placed in a wire basket or cake pan, carefully weighed and placed in the oven with the vent open or the door left ajar. Each sample should be left in the oven for several hours or until it stops losing weight. The moisture content of the original sample can be determined by dividing the loss in weight by the net weight of the original wet sample. This figure multiplied by 100 will give the per cent moisture of the wet sample.

### Commercial oven testers

There are several moisture testers on the market that contain a small oven with a heater and fan unit for fast drying. Most of these testers provide a set of built-in scales which are calibrated to read off moisture content directly. The unit shown in Figure 46 can make determinations on hay in 45 minutes or less.

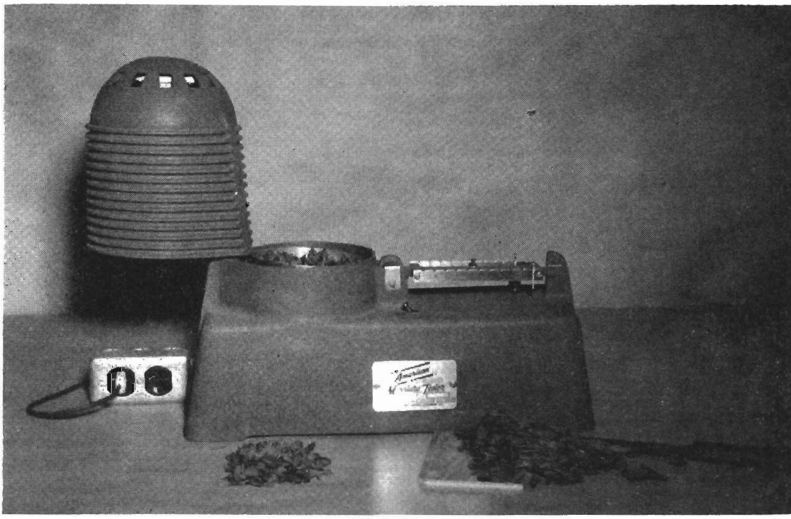


**Figure 46. Moisture tester with fan, heater, and built-in scales for more rapid determination.**

### Exhaust pipe ovens*

The use of an exhaust pipe oven provides a simple method of determining moisture content rapidly in the field. The "oven" consists of a piece of light metal tubing 4 to 5 inches in diameter and 10 to 12 inches long. One end of the tube is left open and the other end is tapered down to the size of a split collar which can be clamped to the exhaust pipe of a car, truck, or tractor. A perforated baffle may be placed at the base of the taper to serve as a diffuser for the exhaust gases. Also, a ball of steel wool placed in the taper will help spread the velocity of the exhaust. In most cases, however, drying will be sufficiently uniform without the aid of these diffusers.

Additional equipment needed with the oven is shown in Figure 47. The sample container can be made from a juice can by cutting out both ends and splitting it down the side. A torsion balance or a

* Adapted from Michigan Agricultural Station Quarterly Bulletin, Vol. 30, No. 2, pp. 158-166 inclusive, November 1947.

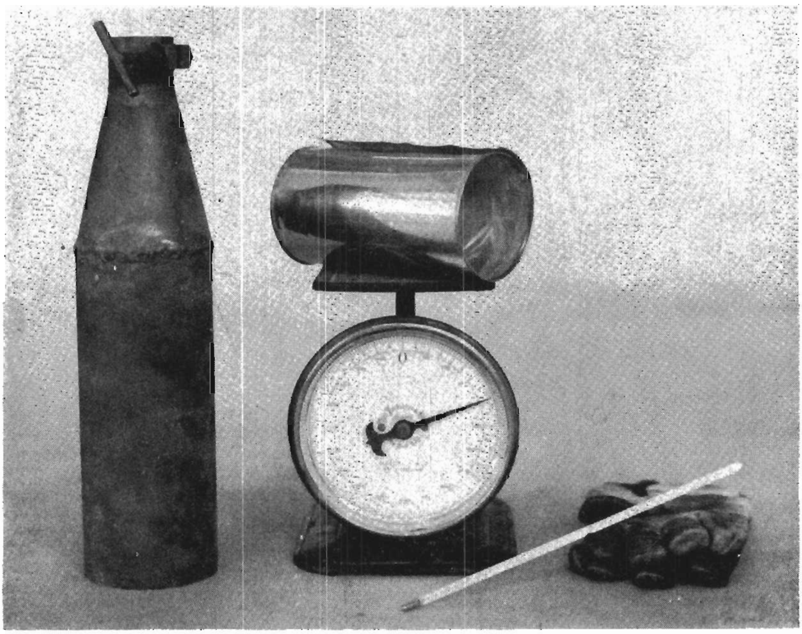


Figure 47. Exhaust-pipe oven, sample container, diet scales, glass-stem thermometer, and pair of gloves used for making rapid moisture determinations in the field.

diet scale may be used to weigh the samples. The scale should be accurate to 1 gram or to 1/10 ounce. A slim, glass-stem thermometer is helpful in checking exhaust temperatures until the operator learns the proper engine throttle settings. A pair of gloves is needed for handling the sample container.

The sample container is first placed on the scale and its weight noted. A representative sample of long hay is selected carefully and folded over two or three times before being placed in the sample container. Allow space for free circulation of the exhaust through the hay. Any projecting stems or leaves that might fall loose should be trimmed off before the sample is weighed. Carefully weigh the sample and the sample container. With the engine idling and the exhaust pipe hot, place the sample and sample container in the oven. Set the engine thrott'e at a fast idle and check the temperature at the center of the sample as shown in Figure 48. For rapid drying, the engine should be operated at sufficient speed to maintain a temperature of about 280° F. or 140° C.

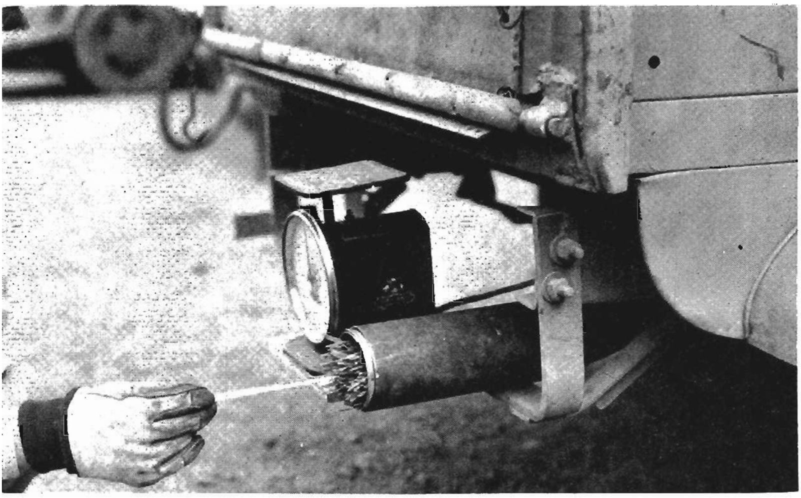


**Figure 48. Checking exhaust temperature to help obtain proper throttle setting.**

At the end of each minute the sample and sample container should be removed and reversed in the oven to promote more uniform drying. At the end of 4 or 5 minutes, the sample and container should be weighed each minute when it is reversed. As soon as it fails to show an appreciable loss in weight between readings, it can be considered sufficiently dried. Six to ten minutes usually is sufficient to dry most samples when the hay has been well wilted in the field.

By dividing the total loss in weight of the sample by the net weight of the green sample the moisture content can be determined. Multiplying this figure by 100 will give the per cent of moisture in the green sample.

## Calcium carbide method*

The calcium carbide method of moisture determination works very well on materials containing between 20 and 60 per cent moisture. Commercial testers utilizing the calcium carbide method of moisture extraction are on the market in the form of portable kits similar to the one shown in Figure 49. If a person wishes to make up his own kit, one can be assembled from the following materials:

- A scales or balance with a 300-gram capacity, accurate to 1/10 gram.

* Adapted from paper by R. Q. Parks, assistant in agronomy, Ohio Experiment Station, "A Rapid and Simple Method of Determining Moisture in Forage and Grains."

- A supply of finely ground calcium carbide.
- A teaspoon.
- A large knife for cutting the hay samples.
- Three cans for test samples. Sixteen-ounce soil-sample cans, about 3¾ inches in diameter and 2½ inches in depth, are the most satisfactory.

**Figure 49. Moisture-determination kit using calcium carbide for extracting the water from the sample.**

The lids of the cans should be drilled with 6 holes ⅜ inch in diameter and covered with a piece of filter paper glued to the inside of the lid. This filter paper will keep the carbide dust in the can but will allow the water vapor to escape.

The moisture test may be made as follows: Set the scales on a level surface and balance. Cut a representative handful of hay into ¼-inch lengths. Place the can and its lid both open side up on the scale and weigh out 30 grams of hay sample into the can. Weigh 81 grams of calcium carbide into the lid, using the teaspoon to handle the calcium carbide. Record the total weight of the can, hay, lid, and calcium carbide.

Carefully pour the calcium carbide over the hay sample, being very careful not to spill any outside the can. If the sample appears to be below 50 per cent in moisture, the lid may be placed directly on the can, pressed down firmly, and the can shaken until the contents begin to heat. If the sample is quite wet, one should wait several minutes after the calcium carbide is poured over the hay sample before placing the lid over the can, otherwise the rapid evolution of heat and steam will probably blow off the lid and cause charring or burning of the sample. After the can has cooled it should be shaken again to see if any more heat can be generated. As soon as the can remains cool upon shaking, weigh the can and contents and record the weight.

Subtract this weight of the can with its contents from the initial weight of the can with its wet contents to obtain the loss in weight. The moisture content of the original sample may be determined from the accompanying table.

MOISTURE CONTENT OF 30-GRAM SAMPLE

| If the loss in weight is: | The moisture in the sample was: | If the loss in weight is: | The moisture in the sample was: |
|---|---|---|---|
| *Grams* | *Per cent* | *Grams* | *Per cent* |
| 2 | 14 | 11 | 53 |
| 3 | 18 | 12 | 58 |
| 4 | 22 | 13 | 62 |
| 5 | 27 | 14 | 66 |
| 6 | 31 | 15 | 70 |
| 7 | 35 | 16 | 74 |
| 8 | 40 | 17 | 79 |
| 9 | 44 | 18 | 83 |
| 10 | 49 | | |

Always dispose of the contents of the can where livestock cannot reach it. This test can be conducted in 30 minutes or less and is sufficiently accurate for most field purposes.

**Toluene distillation method**

The toluene distillation method is a relatively fast and accurate method of determining moisture content of materials throughout their moisture range. It can be quite dangerous, however, and is a very definite fire hazard unless properly conducted by competent persons with the proper equipment. The apparatus for this method is shown in Figure 50. A 1-liter pyrex distilling flask is used to hold the hay sample and toluene. This flask is connected to a 20- or 30-milliliter moisture trap. The moisture trap is in turn connected to a glass condenser, connected with a cold water supply. If the hay is fairly dry, weigh out 25 grams of the sample cut into ¼-inch lengths

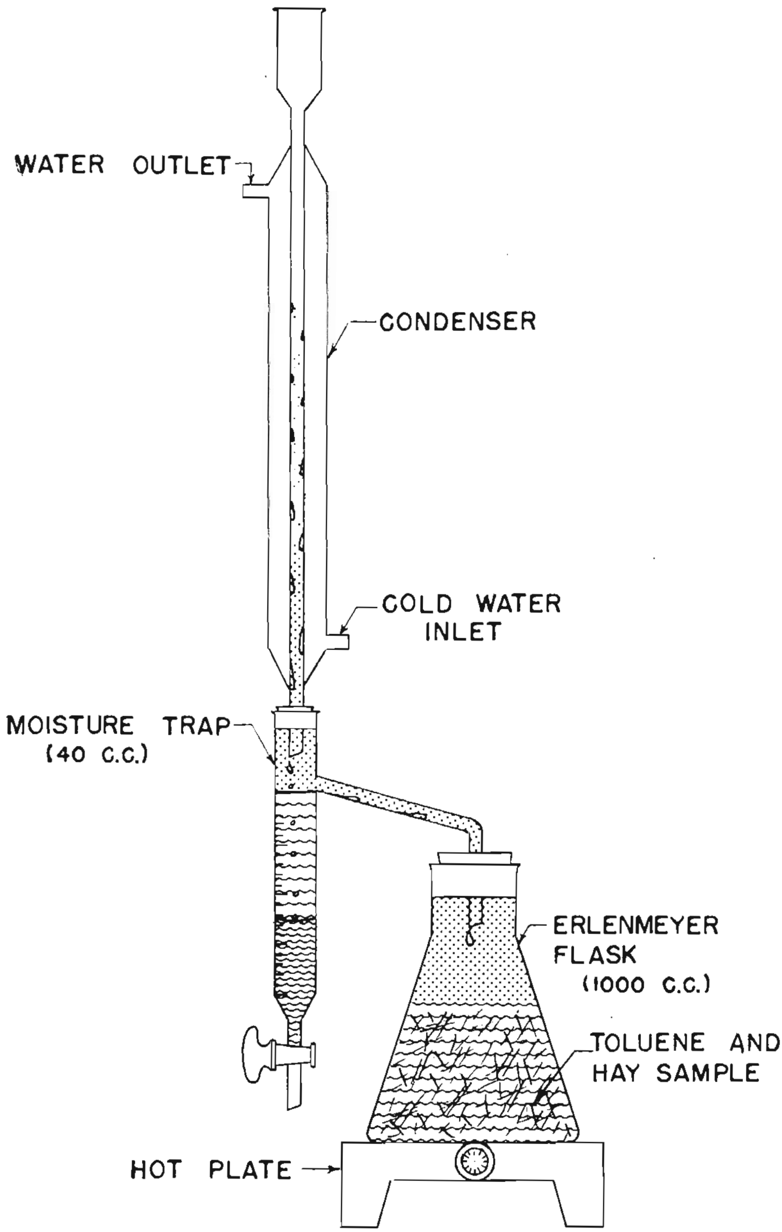



Figure 50. Arrangement of apparatus for determining moisture content of hay by distillation with toluene.

and place it in the 1-liter flask. If the hay is quite wet, a 50-gram sample should be used. Add sufficient toluene to cover the sample completely. Fill the moisture trap with toluene and connect it to the condenser and to the flask. Bring the toluene and the flask to a boil and distill slowly—about 2 drops per second—until most of the water has passed over and become caught in the moisture trap. Do not boil too rapidly or the toluene vapor will not allow the condensed liquid to return to the flask and it will be forced over the top of the condenser. When all of the water is apparently distilled over, read the quantity of moisture collected in the moisture trap. If 50 grams of sample had been used, then each cc or milliliter of water in the moisture trap will represent 2 per cent of moisture in the original sample. If 25 grams of samples had been used, then each cc of water will represent 4 per cent of moisture in the original sample. For most hays the entire procedure of sampling can be done in 30 to 45 minutes.

Extreme caution should be taken in handling the toluene as it is highly inflammable. If the spent sample is to be disposed of by burning, it should be done a safe distance from any building or other combustible material.

### Oil-bath method*

The oil-bath method for checking moisture content is relatively quick, safe, and easy and, as shown in Figure 51, requires very little equipment not found around the home.

The equipment and materials needed are as follows:

- ▶ Diet scale or torsion balance accurate to 1 gram.
- ▶ Thermometer reading to 200° C. or 400° F.
- ▶ Tall metal container, about 1-quart capacity.
- ▶ Concave or dished-in cover for the metal container. This lid should be perforated to allow the moisture to escape and should be fitted with a hole for inserting the thermometer.
- ▶ Circular piece of hardware cloth or screen to fit into metal container. A hole should be punched in the center of the screen just large enough to allow the thermometer bulb to project through, but not large enough for the thermometer stem.
- ▶ Supply of vegetable oil such as corn or peanut oil used in cookery.

The hay sample should be selected carefully and cut into $\frac{1}{4}$- to $\frac{1}{2}$-inch lengths. Weigh out 50 grams of the sample and place it in the metal container. (The size of the sample to be taken may have

* Adapted from method described by Mr. S. T. Dexter in Michigan Agri. Exp. Sta. Quarterly Bulletin, Vol. 31, No. 2, Nov. 1948.

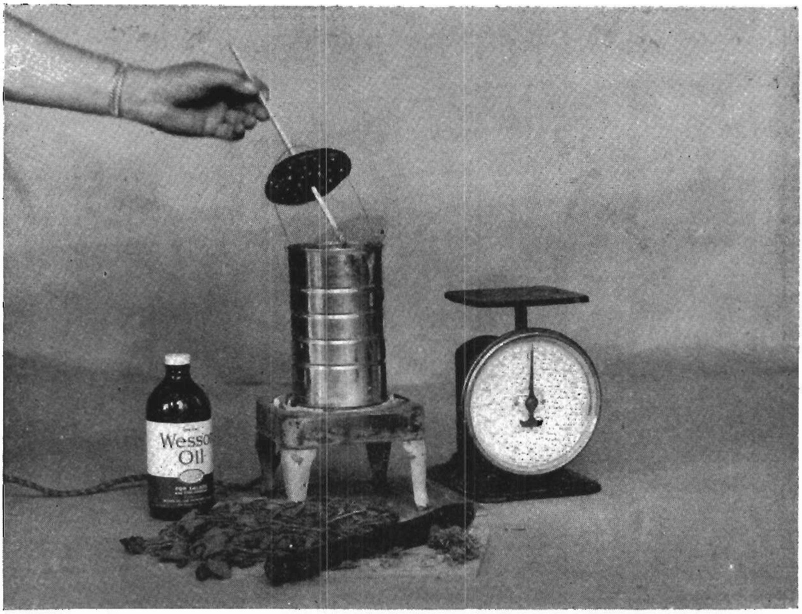



**Figure 51. Equipment used for determining moisture content by the oil-bath method.**

to be varied depending upon the dryness of the sample and the size of the container.) Pour in about 200 grams of vegetable oil, or enough to cover the sample. Place the screen over the sample and place the lid on the container with the bulge downward. Insert the thermometer through the lid and fit the bulb into the hole or socket in the screen to press the sample under the oil. Note the total weight of container, sample, lid, screen, and thermometer.

Heat the oil and sample to 145° C. or 293° F., pushing the thermometer down occasionally. As soon as the oil is up to temperature, which usually takes 15 to 20 minutes, place the container back on the scale and note the total weight again. If steam is still being given off it is well to wait a minute or two until there is no change in weight.

The difference in the beginning and the final fotal weights gives the weight of the moisture lost from the sample. By dividing the net weight of the original sample into the weight of the moisture lost the moisture content of the sample may be obtained. Multiplying this result by 100 will give the per cent moisture of the original sample.