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PROBLEMS RELATED TO BIN-TYPE DRYERS

G. Burns Welch[1]

When grain and seeds are dried several feet deep, as done in a bin, the fan must be capable of delivering the required volume of air at sufficient pressure (static pressure) to force the air through the entire layer or volume of seeds. Thus, being able to estimate the static pressure necessary for forcing a given volume of air through a layer of seeds is an important factor in selecting a fan for a bin-type dryer. There are also occasions when someone may wish to evaluate an existing drying system to determine the volume of air moving through a volume of seeds or determine the maximum depth at which seeds can be placed in a bin and have a certain airflow per cubic foot of seeds. The following problems will illustrate how the static pressure and airflow can be determined in the design of bin-type drying systems, how the airflow per cubic foot of seeds can be determined in a bin dryer while in operation, and how to determine the maximum depth that seeds can be dried in a bin with any particular fan and desired airflow.

In all previous literature dealing with airflow in bin type dryers, the volume of air has been referred to as cubic feet of air per bushel of grain. The unit bushel often caused some confusion in the calculations, especially in determining the volume of air per square foot of floor area which is a necessary value in using Shedd's chart for determining static pressure. In this paper, the bushel unit has been eliminated and the airflow will be referred to as cubic feet of air per cubic foot of seeds. This will simplify the calculations. A comparison of airflow rates per cubic foot and per bushel of seeds is shown in Table 1.

Problems

Problem I

(a) Determine the static pressure and total airflow for drying rough rice 6 feet deep in a round bin 21 feet in diameter if the desired airflow is 4.5 cfm/cu ft of rice.

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Table 1. Comparison of airflow rates.

cfm/cu ft	cfm/bushel
2	2.5
3	3.75
4	5.0
5	6.25
6	7.5
7	8.75

(b) Select a minimum size fan suitable for this installation.

Analysis of Problem. The first step in the solution of this problem would be to determine the static pressure necessary to force the required volume of air through the rice. The static pressure can be determined by using Shedd's Chart (Figure 1). An important point to notice in using Shedd's Chart is that the vertical scale requires the airflow to be indicated in cfm per square foot of floor area. The airflow per square foot of floor is simply the volume of seeds above each square foot multiplied by the desired airflow per cubic foot of seeds. For each foot of seed depth, there is one cubic foot of seeds above each square foot of floor.

Once the static pressure and the required total airflow have been determined, we then refer to the performance data for different sizes of fans and find the one that will provide the required airflow at the computed static pressure.

Solution

1. Determine airflow per square foot of floor area. This can be accomplished by the formula: Depth of seeds in feet X cfm/cu ft = cfm/sq ft, 6X4.5   = 27 cfm/sq ft.

2. Determine static pressure per foot of seed depth. Refer to Shedd's Chart (Figure 1).   Find 27 cfm/sq ft on the vertical scale and then move horizontally until you intersect the rough rice curve (Point A). From this point, move downward to the horizontal scale and read the static pressure dropper foot of seed depth, .58 inches water column. Determine static pressure for 6 foot depth by the formula:

    Pressure drop/ft X depth of seeds = total static pressure .58 X 6 = 3.48 inches water column.

Because the static pressure will vary with the quantity of other materials smaller than the principle seeds present in the seed mass, some designers have found from experience that it is often advisable to use a safety factor of 1.2 or 1.3 of the value found from Shedd's Chart to allow for the additional air resistance caused by the small foreign material in the seed mass.

Using a safety factor of 1.3, we get 3.48 X 1.3 = 4.52 inches water column.

3. Determine the total airflow. To find the total airflow, we must first compute the total volume of seeds in cubic feet which can be found by using the formula:

RESISTANCE TO AIR FLOW THROUGH GRAINS AND STORAGE COMPONENTS

FIG. 1 RESISTANCE OF GRAINS AND SEEDS TO AIR FLOW

Figure 1
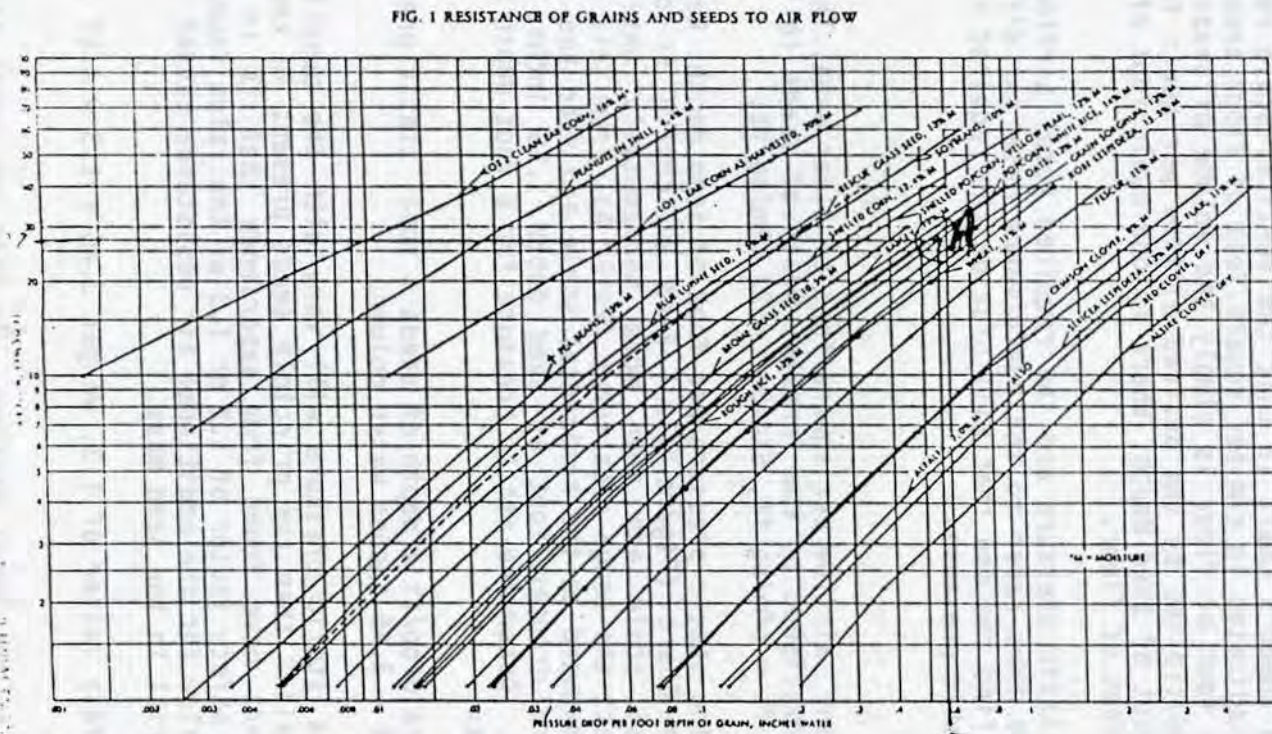
NOTES: This chart gives values for a loose fill (not packed) of clean, relatively dry grain.

For a loose fill of clean grain having high moisture content (in equilibrium with relative humidities exceeding 85 percent), use only 80 percent of the indicated pressure drop for a given rate of air flow.

Packing of the grain in a bin may cause 50 percent higher resistance to air flow than the values shown.

When foreign material is mixed with grain no specific correction can be recommended. However, it should be noted that resistance to air flow is increased if the foreign material is finer than the grain, and resistance to air flow is decreased if the foreign material is coarser than the grain.

REFERENCE: Resistance of Grains and Seeds to Air Flow, C. K. Shedd, AGRICULTURAL ENGINEERING, vol. 34, September, 1953.

(radius of bin)^2 X 3.14 X depth = volume of seeds in cubic
feet
(10.5)^2 X 3.14 X 6 = 2077 cu ft of seeds
Now the total volume of air can be determined by the
formula:
Number of cubic feet of seed X cfm/cu ft = total cfm
2677 X 4.5 = 9346 cfm

Specifications of the Drying Fan. Now that we have computed
the static pressure and the total airflow, we have the specifications
for selecting a fan that would be suitable for this installation. The
fan must have a capacity of 9346 cfm at a pressure of 4.52 inches of
water column.

4. Select a minimum size fan that would meet the above
specifications.

To select a fan, we have to refer to the performance data for
various sizes of fans and select the one that has a capacity equal to
or slightly larger than the given specifications. Table 2 is a
typical example of performance data for six different sizes of fans.

The static pressure is shown in the horizontal column at the
top. Under each static pressure is the volume of air in cfm that each
fan will deliver at that pressure. To select our fan, we look down
the column under 4 inches until we come to a figure near and greater
than our total airflow which is 9396 cfm. The third figure down is
10,300 which is the first greater figure. But our computed static
pressure is 4.52 inches, which is between 4 and 5 inches, so we must
interpolate to find what the airflow would be at 4.52 inches. That is
done in the following manner:

Static Pressure	Air Flow
4 inches	10,300 cfm
5 inches	9,400
Difference	900 cfm

From 4 inches the static pressure 4.52 is .52 of the distance
to 5 inches. So:

900 X .52 = 468 cfm

You will notice that the airflow decreases as the static
pressure increases. Therefore, the 468 cfm will be subtracted from
the airflow at 4 inches. Thus, the airflow at 4.52 inches is:
10,300 - 468 = 9823 cfm actual airflow

Table 2. CECO Model F Fan Performance Data.

Model	RPM	Free del.	CFM at various static pressures								
			1"SP	2"SP	3"SP	4"SP	5"SP	6"SP	7"SP	8"SP	9"SP
F18153	1750	3850	3400	2840	2330	--	--	--	--	--	--
F22303	1750	5550	5200	4625	3950	3400	2450	--	--	--	--
F25503	1750	8100	7550	7000	6400	5700	4750	--	--	--	--
F27103	1750	13450	12700	11900	11100	10300	9400	8450	7350	--	--
F27153	1750	17650	16800	15900	14950	14000	13000	11850	10550	--	--
F30203	1750	19700	19200	18550	17850	16950	16000	15000	13750	12200	10500

Comparing actual airflow with our total airflow, we see that 9832 cfm is only 486 cfm greater than the required airflow of 9346 cfm. This is close enough to be acceptable. Now, moving to the left, we find that Model F27103 fan is the one that would be selected.

Problem II

Rice is being dried 7 ft deep in a round bin 24 ft in diameter. The drying fan is a CECO 20 horsepower Model F30203. Determine the airflow per cubic foot of seed when the fan is operating.

Analysis of Problem. The airflow specifications for a fan are specified by indicating the volume of air the fan will deliver at different static pressures. This information is given in the literature provided with the fan by the manufacturer. The performance data for the above fan are given in Table 2.

In Table 2 of fan performance data, we can see that the 20 horsepower fan will deliver 18,550 cfm at 2 inches of static pressure, 15,950 cfm at 4 inches of static pressure, and so on to 10,500 at 9 inches of static pressure. So one means of estimating the volume of air a fan is delivering during operation is to measure the static pressure the fan is working against and then refer to the table of performance data and find the cfm for that particular static pressure. The cfm per cubic foot of rice can then be determined by dividing the total volume of air by the volume of seed or grain being dried.

Solution

1. Using a manometer (U tube) measure the static pressure under the perforated floor of the bin (Figure 2).

2. We will assume that in this case the static pressure is 5 inches of water column.

3. Referring to the performance data, we find at 5 inches of static pressure the 20 horsepower fan will deliver 16,000 cfm.

4. Determine the cubic feet or rice in the bin.
   πr^2 X depth of seed = number of cu ft of rice
   $3.14(12)^2$ X 7 = 3165 cu ft of rice

5. The airflow per cubic foot per minute is found by:
   Total volume of air ÷ total volume of rice = cfm/cu ft of rice

   16000 ÷ 3165 = 5 cfm/cu ft of rice

BIN

MANOMETER

PLASTIC TUBE

FAN

SEED

PLENUM

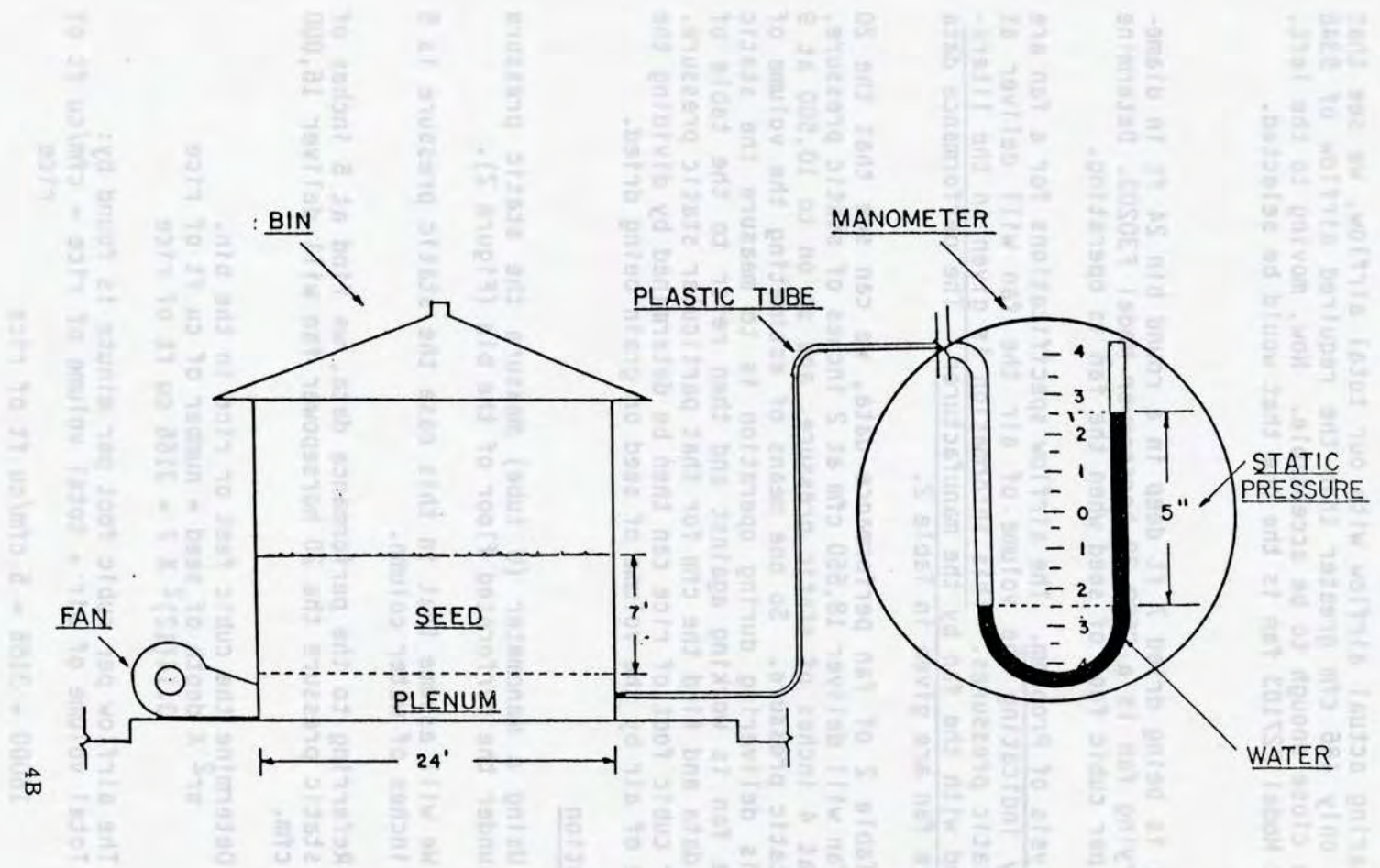STATIC
PRESSURE

WATER

7'

24'

5"

4B

Figure 2.   Diagram showing how the static pressure can be measured under the floor
of a bin drier.   The static pressure is equal to the sum of the readings
above and below zero.

Problem III

A metal bin 27 ft. in diameter is equipped with one 20 horse-power centrifugal fan and a perforated floor. The wall height above the floor is 16 ft. To what maximum depth can the bin be filled with rice for drying, if an airflow of 5 cubic ft per minute per cubic foot of rice is desired? Use a safety factor of 1.3 with Shedd's Chart.

Analysis of Problem. Here, we have a drying bin and fan already installed. There is some unknown depth to which rice can be put in the bin and the fan will force air through the rice at the rate of 5 cfm/cu ft. If the depth is less or more than this particular unknown depth, the airflow will be greater or less than the 5 cfm/cu ft, respectively. Our problem is to find the particular depth at which the airflow will be 5 cfm/cu ft of rice.

To solve our problem, we will use the method of trial solutions. In doing this, we will choose some depth and then determine the static pressure and total volume of air we would have if the airflow was 5 cfm/cu ft. Once these values are obtained, we would then refer to the performance data for the fan and find the volume of air the fan will deliver at the static pressure determined above for the particular depth chosen. At the maximum depth, the total volume of air as determined for that depth and the volume of air given in the performance data for the static pressure at the depth chosen should be almost equal. If the volume of air required for the depth chosen is greater than that given in the performance data for the respective static pressure, the depth is too great. If the volume of air required for the chosen depth is less than that given in the perform-ance data for the respective static pressure, the depth is too shallow. After determining whether the depth is too great or too shallow, a new depth is chosen toward the maximum allowable and the calculations repeated. This process is repeated until the required airflow and the airflow delivered by the fan are almost equal. When the airflows are equal, the maximum depth has been found.

Solution. The performance data for the 20 horsepower are given in Table 2.

Step 1. To begin our trial solution, we will assume that the rice is 5 ft. deep and then determine the static pressure and total airflow for this depth.

A. Determine static pressure for 5-foot depth and 5 cfm/cu ft of rice.

(1) Airflow per square foot floor area is:
5 X 5 = 25 cfm/square foot of floor area.

(2) Refer to Shedd's Chart and find pressure drop per foot of depth of seed. On the chart, we find that for 25 cfm/sq ft, the static pressure is .52 inch per square foot of depth.
For the 5-foot depth, the static pressure is:
.52 X 5 = 2.6 inches.

(3) Using a safety factor of 1.3, the total static pressure becomes: 2.6 X 1.3 = 3.38 inches of water column

B. Determine the total air volume for the 5-foot depth of rice.

(1) Find volume of rice in bin.
(radius)^2 X 3.14 X depth = number of cubic feet
(13.5)^2 X 3.14 X 5 = 2861 cu ft of rice

(2) Find total volume of air.
2861 X 5 = 14306 cubic feet per minute

C. We have found that for the 5-foot depth of rice the required static pressure and total volume of air are 3.38 inches and 14306 cfm, respectively. Our next step is to refer to the fan performance table and find the amount of air the fan will deliver against 3.38 inches of static pressure.

Looking at the fan performance table, you will see that the airflow for 3.38 inches of static pressure is not given. We must interpolate between 3 and 4 inches of static pressure. This is done in the following manner:

Static Pressure	Air Flow
3 inches	17,850 cfm
4 inches	16,950
Difference	900 cfm

Now, from 3 inches static pressure, 3.38 is .38 of the distance to 4 inches static pressure. So: 900 X .38 = 342

You will also see that as the static pressure increases, the volume of air decreases. Therefore, the 342 cfm will be subtracted from the airflow for 3 inches of static pressure. Thus, the airflow for 3.38 inches of static pressure is:

17,850 - 342 = 17,508 cfm actual airflow

Comparing the actual airflow and the required air, we see that the actual airflow is greater (17,508 > 14,306). This means that the depth of rice in the bin could be increased. So, we would assume a greater depth and work through the same procedure again.

Step 2. Assume a depth of 6 feet.

A. Determine static pressure for 6-foot depth and 5 cfm/cu ft.

(1) Airflow per square foot of floor area is 5 X 6 = 30 cfm/sq ft of floor area.

(2) Referring to Shedd's Chart, the static pressure per foot of depth is .62 inches.

(3) For 6-foot depth, the static pressure is .62 X 6 = 3.72 inches.

(4) Using a safety factor of 1.3, we get:
3.72 X 1.3 = 4.836 inches of water column, the total static pressure

B. Determine the total air volume for the 6 foot depth of rice.

(1) Find volume of rice in bin
$(13.5)^2$ X 3.14 X 6 = 3,433 cu ft of rice

(2) Find volume of air
3,433 X 5 = 17,165 cfm

C. The static pressure and required airflow for 6-foot depth of rice are 4.83 inches and 17,165 cfm, respectively.

(1) Refer to fan performance table and interpolate.

Static Pressure	Air Flow
4 inches	16,950 cfm
5 inches	16,000
Difference	950 cfm

950 X .83 = 788
16,950 - 788 = 16,162 cfm actual airflow at 4.83 inches static pressure.

(2) Comparing the actual airflow with the required airflow, we find that the actual airflow is less than the required airflow (16162 < 17165). This tells us that the 6-foot depth is too much. We now select another depth between 5- and 6-foot depth and solve again.

Step 3. Assume depth of 5.75 feet.

    A. Determine static pressure for 5.75-foot depth and 5 cfm/cu ft.

        (1) Airflow per square foot of floor area is:
5.75 X 5 = 28.75 cfm/sq ft of floor area

        (2) Referring to Shedd's Chart, the static pressure per foot of depth is .60 inches.

        (3) For 5.75-foot depth, the static pressure is
.60 X 5.75 = 3.45 inches

        (4) Using safety factor of 1.3, we get:
3.45 X 1.3 = 4.48 inches of water column, the total static pressure

    B. Determine the total air volume for the 5.75-foot depth of rice.

        (1) Find volume of rice in bin.
$(13.5)^2$ X 3.14 X 5.75 = 3290 cu ft

        (2) Find total volume of air.
3290 X 5 = 16450 cfm

    C. The static pressure and required airflow for 5.75-foot depth are 3.48 inches and 16450 cfm, respectively.

        (1) Refer to fan performance table and interpolate.

Static Pressure	Air Flow
4 inches	16,950 cfm
5 inches	16,000
Difference	950 cfm

950 X .48 = 456
16,950 - 456 = 16,494 cfm actual airflow at
4.48 inches of static
pressure.

(2) At the 5.75-foot depth, the required airflow
is 16,450 cfm while the actual airflow is
16,494 cfm. Thus the actual airflow is 44
cfm greater than the required airflow. With
the two values of airflow this close, we can
say that the maximum depth would be 5.75
feet.

Supplemental Heat and Heater Capacity

The following problems pertain to determining the amount of
heat needed to increase the temperature of the drying air and how to
estimate the heating capacity of the heater required.

During periods of high humidity (75% RH and above), the drying
rate can be increased by raising the temperature of the drying air
which will, in turn, lower the relative humidity of the drying air.
Questions often asked are: (1) to what temperature must the air
temperature be increased in order to lower the relative humidity to
some desired percentage, and (2) how to determine the amount of heat
and size of heater necessary to increase the air temperature to the
desired level.   The following problem will illustrate how these
determinations can be made.

Problem IV

During the fall harvest season, the weather is damp.   The
dry-bulb temperature is 70F and the relative humidity is about 85%.
With these conditions, to what temperature would the air temperature
need to be raised to lower the relative humidity to 50%?

Analysis of Problem.   Here we have a condition of high
humidity and wish to lower the relative humidity by increasing the air
temperature.   One may wonder why an increase in the air temperature
will cause the relative humidity to decrease. This occurs because air
will expand in volume when heated and will, thereby, increase the
water holding capacity. Since the actual amount of moisture in the air
during heating remains constant while the water holding capacity is
increased, the percent relative humidity will decrease.   Thus, the
heated air is capable of absorbing more moisture as it flows through
the layer of seed and will increase the rate of drying.

Solution. To find the temperature to which the air tempera-
ture will be increased, we will use a psychrometric chart.   The
solution is obtained in the following steps illustrated in Figure 3.

PSYCHROMETRIC CHART

MISSISSIPPI STATE UNIVERSITY
MISSISSIPPI AGRICUTURAL AND FORESTRY EXPERIMENT STATION
SEED TECHNOLOGY LABORATORY
MISSISSIPPI STATE, MISSISSIPPI
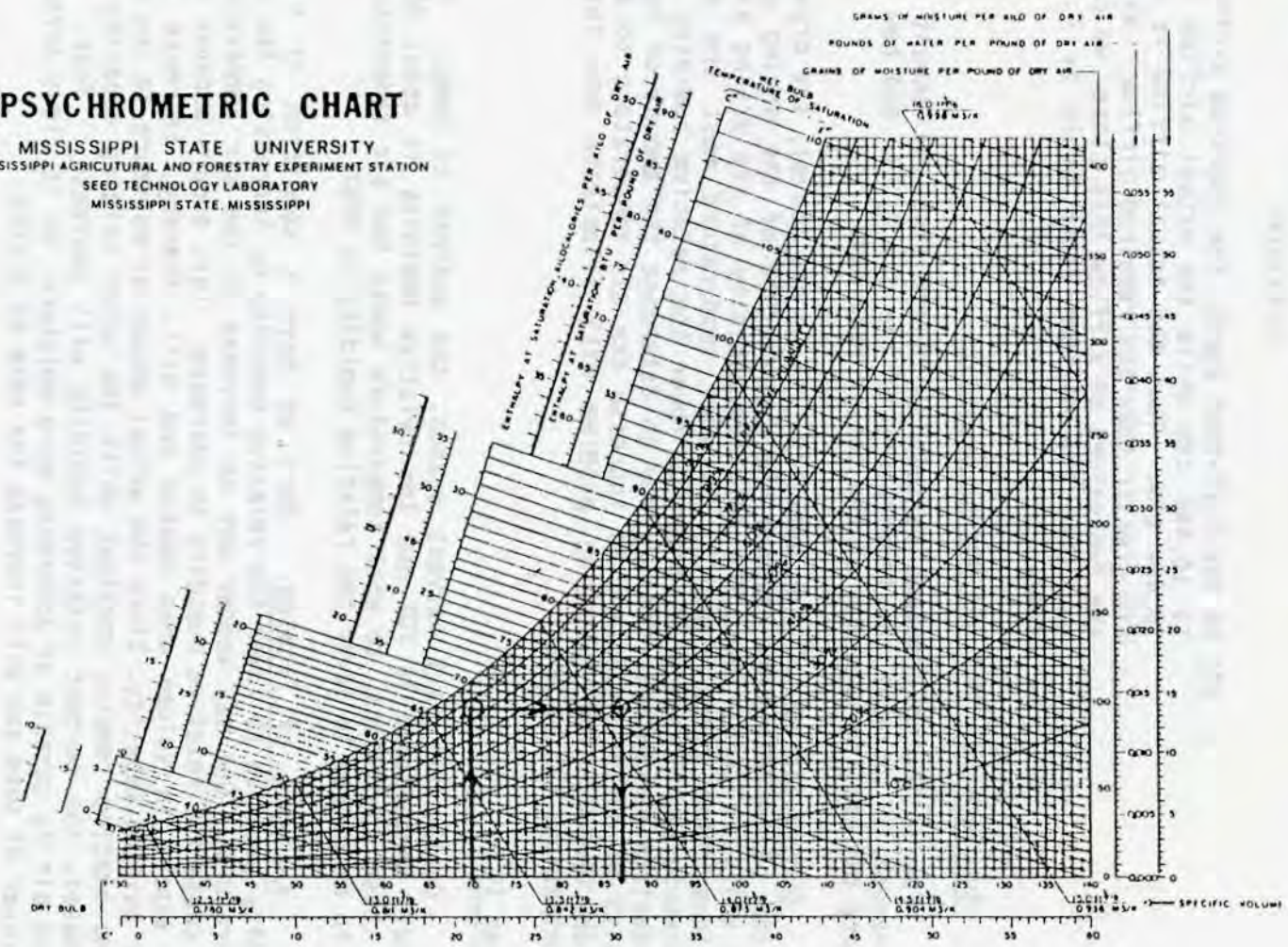
NOTE: THIS CHART IS TAKEN FROM A PUBLICATION BY THE CARRIER CORPORATION.

Figure 3

1. Find present air temperature 70F on bottom horizontal scale.

2. Move up vertically to the point representing 85% relative humidity midway between the 80 and 90% relative humidity curved lines.

3. From the point found in Step 2, move horizontally to the right to intersect the desired relative humidity percent line, 50%.

4. From the point of intersection found in Step 3, move down vertically to the horizontal temperature scale and read 87F. The temperature to which the air temperature must be increased in order to lower the relative humidity to 50%.

If the heater in a drying system is controlled by a humidistat, it will maintain whatever temperature is necessary to low the relative humidity to the desired level.

Problem V

A 20 horsepower fan is delivering 16000 cfm of air to a drying bin.

(a) How much heat is needed to increase the air temperature from 70F to 90F?

(b) If the gas heater is 80% efficient, what would be the input rating of the heater?

Analysis of Problem. The unit of heat is the British thermal unit, BTU. The capacities of heaters are expressed as the number of BTU input or output per hour. Thus, the problem is to determine the number of BTU needed per hour to raise the air temperature 20F. This would be the output rating of the heater.

Solution.

(a) The amount of heat needed to raise the temperature of 16000 cfm of air 20F can be determined by the following formula:

cfm x temp. difference x 1.08 = BTU/hour
16000 x 20 x 1.08 = 345,600 BTU/hour

(b) The number of BTU determined in part (a) above would be the output of the heater. The BTU input can be found by dividing the output by the efficiency. Thus, we have:

$$\frac{output}{efficiency} = input$$

$$\frac{345600}{80\%} = 432,000 \text{ BTU/hour output rating of heater}$$

A heater of this size or larger would be needed.

COTTONSEED MINI-COURSE