HUMIDITY REQUIREMENTS DURING THE EARLY STORAGE PERIOD

by
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How important is high relative humidity (RH) in potato storages during the first four to eight weeks of storage? It is generally stated that when potatoes are first placed in storage they should be cooled as quickly as possible to 50°F and the relative humidity should be maintained above 90% (1, 3, 6) . 2/ This is the period of suberization and high relative humidity promotes the wound healing process. In addition to the requirements during the suberization period the influence of relative humidity on weight loss must be considered. Some fairly recent data (4) show that the rate of weight loss in storage is highest during the first two months. The first month is normally the highest. This work also indicates that the influence of relative humidity on weight loss diminishes during the third or fourth month and thereafter.

Data by Cargill et. al. (2) demonstrate the influence of relative humidity on weight loss during a 300 day storage period for potatoes held at 40°F. The cumulative weight loss in percent for Kennebec potatoes at 80% RH was more than double the weight loss at 95% RH. The weight loss of Russet potatoes was almost double. Other recent work (5) found relative humidity to be far more important in determining weight loss than temperature. Under carefully controlled relative humidity conditions near 100% they found essentially negligible weight loss in a 20 week storage period at either 5°C, 7.5°C, or 10°C.

Pressure bruising is another problem which is likely associated with low relative humidity conditions. Pressure bruising is related to dehydration of the tuber in conjunction with the pressure due to the depth of the potato pile. This occurs most frequently near the air input ducts at the bottom of the potato pile indicating the influence of relatively dry ventilation air.

Bruising of potatoes during harvesting and handling is one of the primary factors responsible for deterioration in quality. It has been well established that tuber temperature is an important factor in bruising. Potatoes harvested after October 15 in the Columbia Basin are frequently too cold. The indications are that harvesting should be initiated by September 15, if possible, in order to avoid large numbers of bruised potatoes going into storage. September night air temperatures in the Columbia Basin are not, on the average, sufficiently low to provide the cooling necessary. Evaporative cooling can be used to supplement that available from the night air. Good humidification and evaporative cooling go hand-in-hand.

It is certainly true that the optimum temperature and relative humidity conditions, particularly relative humidity in excess of 90%, can not often be obtained on a practical basis. Economic, climatic, and engineering limitations govern the extent to which these optimum conditions can be approached. However, the design and management of the ventilation and humidification systems can have considerable influence on the conditions in a potato storage. One aspect of this system, namely humidification, is discussed in the remainder of this paper.

Fall 1972 Measurements

Temperature and relative humidity measurements were made in several potato storages during the fall of 1972 in order to obtain at least a partial evaluation of the conditions in existing storages. Two storages were instrumented prior to filling. In these storages wet and dry bulb

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2/ Number in parenthesis refer to appended references.

temperatures were measured in the intake air stream and at three locations in the discharge ducts from the plenum chamber. In order to determine the temperature and relative humidity distribution within the plenum the discharge air conditions were measured at locations directly in front of the fan, at the midpoint down the length of the plenum, and near the end of the plenum.

The temperature measurements were made using wet and dry bulb thermocouples. Data were recorded with a multipoint recorder which allowed automatic recording of all temperatures at any time interval desired. Data were taken on each storage for a period of approximately one day and one night. The fans and humidification systems were left on continuously during this period and all the air was brought in from the outside. This was done in order to evaluate each systems capability for humidification and evaporative cooling during the period when outside air is used to cool the potatoes.

Figures 1 and 2 are typical of the results obtained in the two storages instrumented. Storage number one used banks of spray nozzles across the cross section of the plenum for humidification. Storage number two used a combination of centrifugal atomizers and spray nozzles for humidification. Several things must be taken into consideration when evaluating these data. The outside ambient temperature was quite high at the time the measurements were taken. This, plus the storage of heat in the exterior walls of the plenum, no doubt had some influence on the temperature of the air. Some rewarming of the air may have occurred as it moved down the length of the plenum. Since no potatoes were present in the storages the resistance to air flow was less than under normal operation and therefore the air flow rate was greater than normal. This probably influenced the operation of the humidification systems somewhat. Even considering these possible adverse affects, neither of these systems was providing the amount of humidification or evaporative cooling that is desirable. Lack of uniformity of air properties in the plenum was also a problem. The system in storage number one performed somewhat better than in number two. System number one added larger quantities of water and also had a larger area of contact between the water and the air stream. These differences likely accounted for the better performance. It is important to note that, even though an inadequate amount of water was provided by system two, excess free water was a problem. This is to be expected since not all of the water introduced will be evaporated by the air stream. Provisions must be made for handling the excess water.

Data were collected on several other storages during the fall season. This was done by placing recording hygrothermographs in each fan house upstream from the fan and in the plenum after the air had passed through the humidification system. In general it was found that most humidification systems were not adequate. This was especially true during the early fall period when some outside air was being introduced.

The discussion of the results of this preliminary evaluation of humidification systems has so far pointed out only the negative aspects of the findings. While the systems studied did not provide optimum results they were of considerable benefit. The system in storage number one did provide approximately half of maximum possible cooling and did add 20% to 30% to the relative humidity of the intake air. This system should allow the introduction of outside air into the storage for three or four additional hours each day during the early portion of the storage period. This additional fan operation time should prove quite beneficial in removing the field heat and the early season heat generated by respiration from the potatoes. The primary problems noted in existing systems were inadequate water supply and lack of contact time between the water and the air. As long as humidification is done in the plenum chamber the problem of lack of contact time will continue to be a problem.

Amount of Water Required

The question of how much water is required to obtain the necessary humidification often arises. This, of course, depends upon the conditions of the incoming outside air and on how much return air is mixed with the outside air. Answers to this question can be obtained quite simply from a graph of the properties of moist air at various conditions of temperature and humidity. Such a graph is called a "psychrometric chart". Figure 3 is an example of a typical psychrometric chart. These charts are readily available from a number of sources. The one shown is published by Carrier Corporation. Your local air conditioning supplier should be able to tell you where to obtain copies.

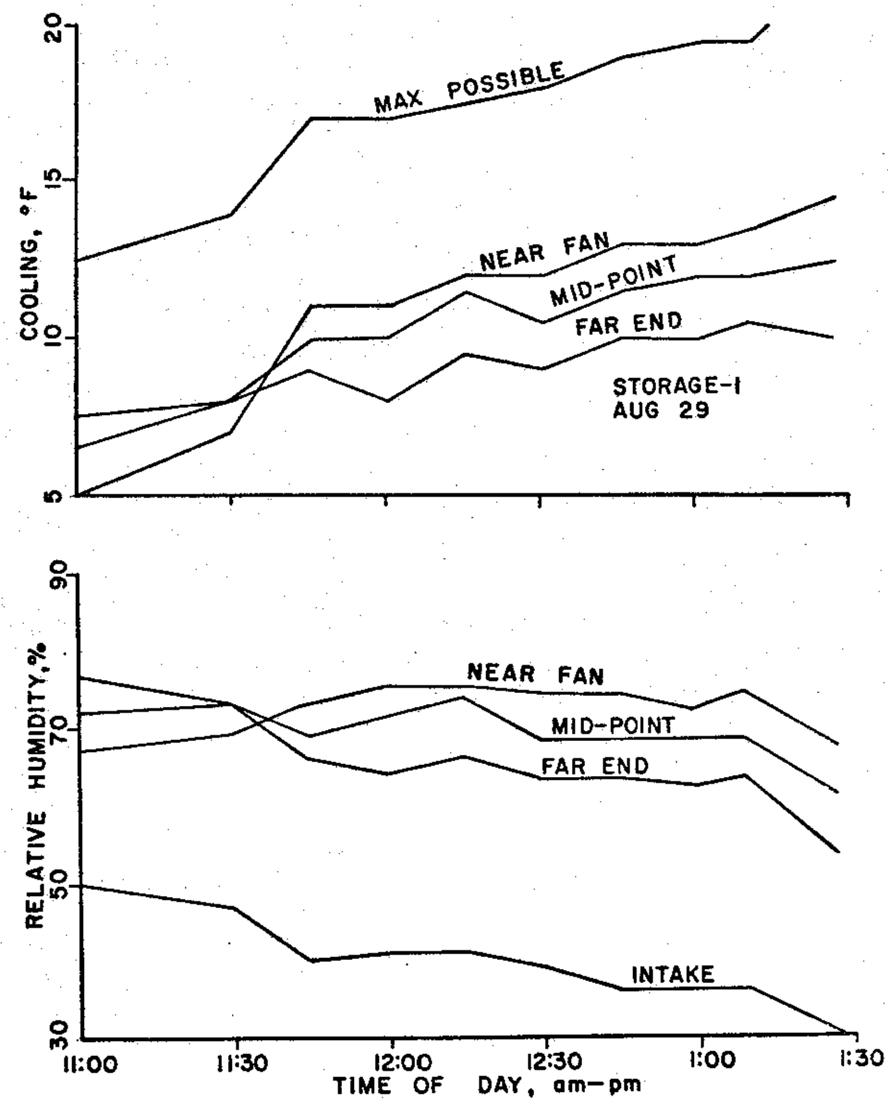


Figure 1. Representative curves of relative humidity and evaporative cooling in the air plenum of storage number one.

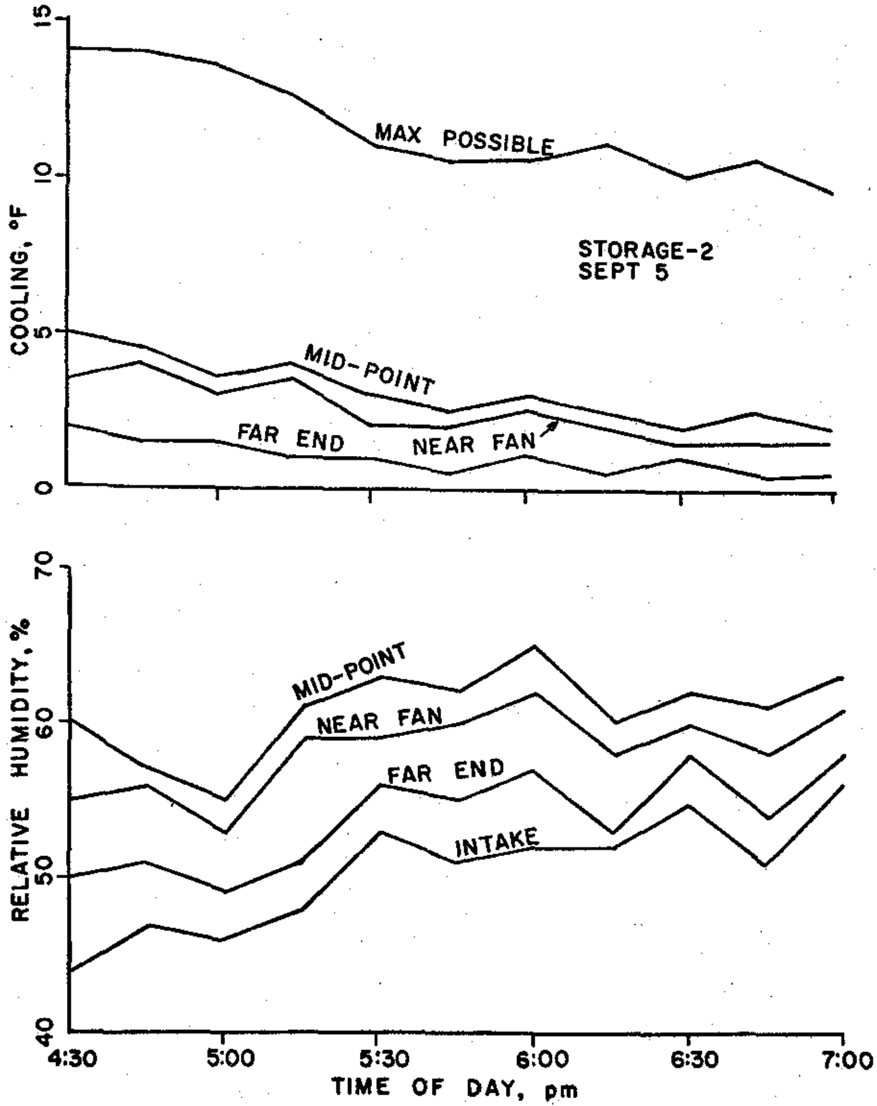
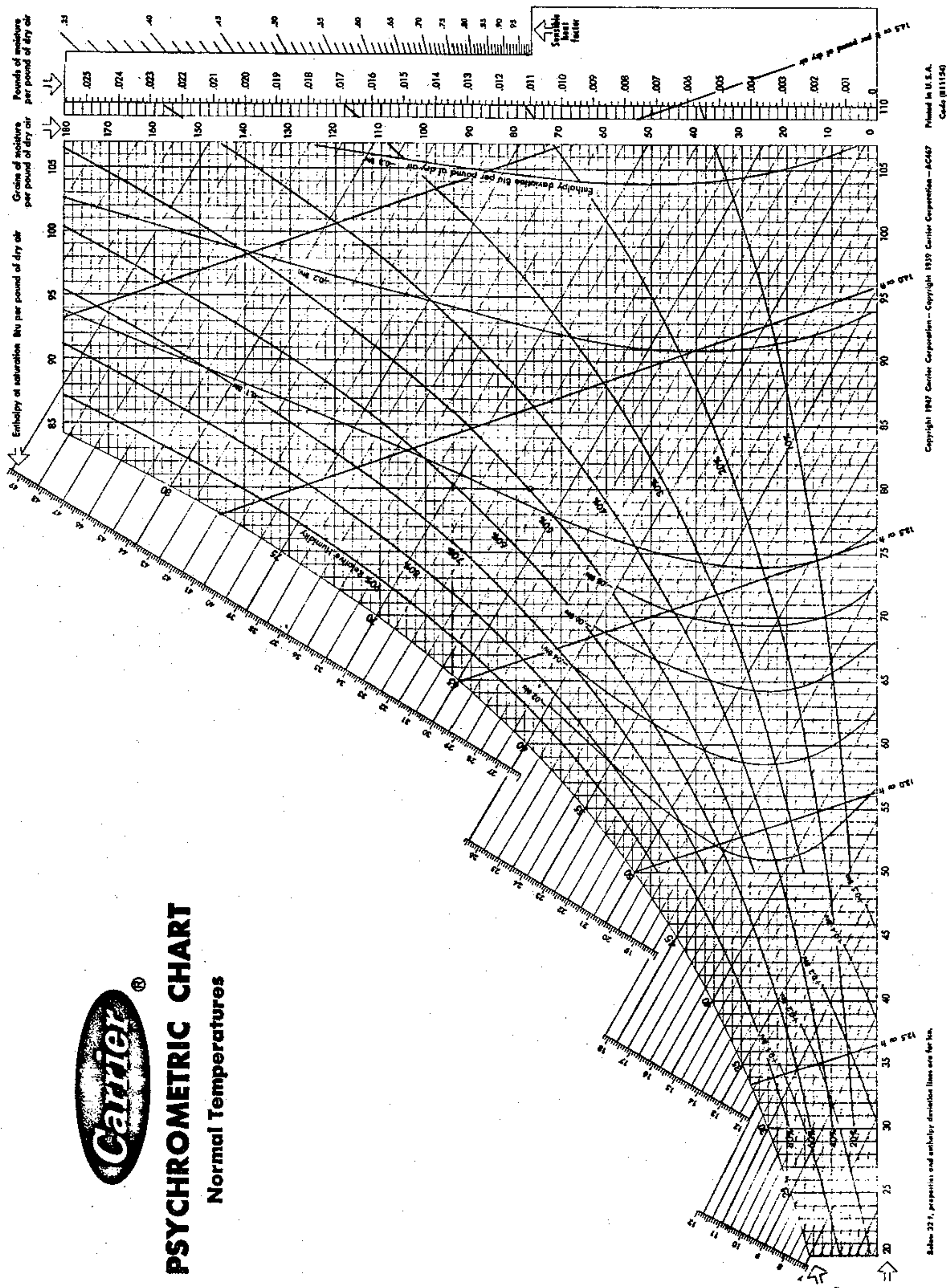


Figure 2. Representative curves of relative humidity and evaporative cooling in the air plenum of storage number two.

Figure 3. Example of psychrometric chart



The properties of moist air which are pictured on the psychrometric chart are dry bulb temperature, wet bulb temperature, percent relative humidity, total heat content (enthalpy), weight of the water vapor in one pound of dry air (absolute humidity) and the volume of the air-vapor mixture per one pound of dry air. If any two of these properties are known they determine a point on the chart called a state point and all other properties can then be read from the chart. This paper will discuss how to use the chart to determine the amount of water which must be added by a spray or atomizing type humidifier to reach the desired relative humidity. Much additional information can be determined, such as the quantity of heat which must be added or removed to warm or cool a given amount of air and the final conditions of a mixture of air streams of different conditions.

The base plot of the chart is dry bulb temperature in degrees F versus absolute humidity in pounds of water per pound of dry air. Figure 4 shows a diagram of this plot. The family of curved lines on the body of the plot are lines of constant relative humidity. The upper line shown represents 100% relative humidity which is the saturation condition of air. That is, it contains all of the water vapor it is capable of holding at that temperature. Wet bulb temperature is another property of air which must be used in determining water requirements. Figure 5 shows the position of lines of constant wet bulb temperature on the chart. When air is humidified by the addition of spray water the final condition of the air-water mixture will fall somewhere on a line of constant wet bulb temperature. This is not exactly true but for the kinds of systems discussed the answers obtained are very close to correct.

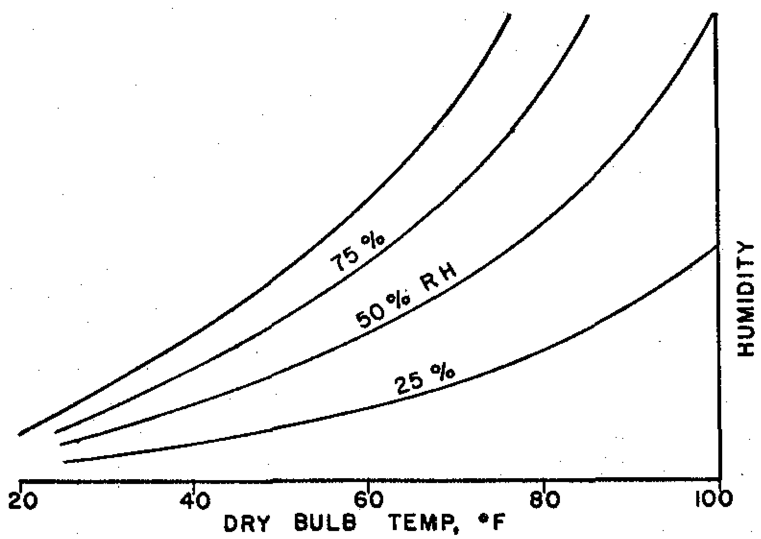


Figure 4. Base plot of the psychrometric chart

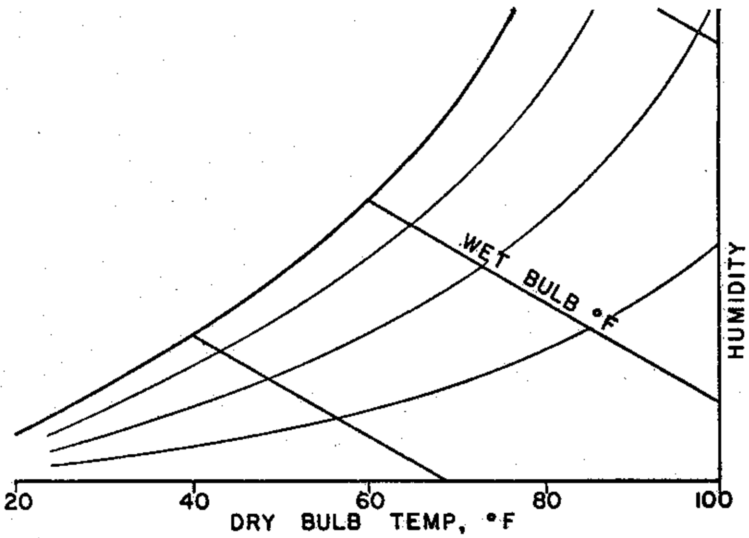


Figure 5. Lines of constant wet bulb temperature shown on the psychrometric chart

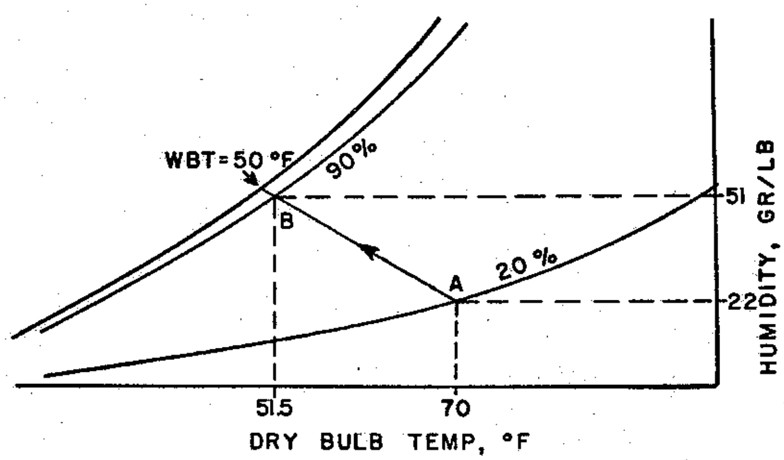


Figure 6. Example of humidification with a spray water system. Change in air properties follow a line of constant wet bulb temperature.

Consider the example shown in Figure 6. Air initially at 70°F dry bulb and 20% relative humidity (RH) is to be humidified by a spray water system to 90% RH. The properties of the entering air at state point A, as determined from the psychrometric chart (Figure 3), are 70°F DB, 20% RH, 50°F WB, and an absolute humidity of 22 grains of water per pound of dry air. 7000 grams of water equals one pound. As the spray water evaporates into the air stream the condition of the air changes and essentially follows the 50°F WB condition line. With an adequate amount of water and sufficient contact time the condition reaches point B. The properties of the air at state point B are 51.5°F DB, 90% RH, 50°F WB, and 51 grains of water per pound of dry air. Each pound of air initially contained 22 grains of water and finally contained 51 grains of water. This means that for each pound of dry air introduced into the system the difference between 51 and 22 or 29 grains of moisture must be added. It is important to note that in the process of humidification the air has also been cooled from 70°F to 51.5°F. This is known as evaporative cooling. In order to determine the amount of water which must be added for each 1000 cfm (ft^3/min) of outside air introduced use the following procedure. Dry air at these conditions weighs approximately 0.075 lb/ft^3. Therefore the pounds of dry air per minute introduced are

$$1000 \frac{ft^3}{min} \times 0.075 \frac{lb}{ft^2} = 75 \frac{lb}{min} \text{ of air.}$$

The amount of water which must be added is

$$(51-22) \frac{\text{gr water}}{\text{lb air}} \times 75 \frac{\text{lb air}}{\text{min}} = 2175 \frac{\text{gr water}}{\text{min}}$$

Converting this to gallons of water per hour yields

$$2175 \frac{\text{gr water}}{\text{min}} \times 60 \frac{\text{min}}{\text{hr}} \times \frac{1}{7000} \frac{\text{lb}}{\text{gr}} \times \frac{1}{8.33} \frac{\text{gal}}{\text{lb}} = 2.24 \text{ gal/hr/1000 cfm}$$

The above example shows that about 2 1/4 gallons of water per hour (GPH) are required to humidify 1000 cfm of air if all of the water introduced is evaporated by the air. For the types of spray water systems under discussion it is very unlikely that all the water introduced will be evaporated. A more realistic value might be 50 to 60 percent. Using 60 percent as an average figure the amount of water that must be put through the spray system is

$$2.24 \frac{\text{gal}}{\text{hr}} \times \frac{1}{0.6} = 3.73 \text{ gal/hr/1000 cfm.}$$

Water requirements based on various conditions of incoming outside air were calculated and are tabulated in Table 1. During the middle part of September in the Columbia Basin region it is quite possible that some cooling of the potato pile can be accomplished with 60°F for even 70°F outside air. With this possibility in mind the data from Table 1 indicates that about 60 GPH of water per 1000 tons of potatoes should be available through the humidification system. The humidification system should have provisions for adjusting the amount of water applied as the conditions change during the storage period. It is also readily apparent that provisions must be made to handle large quantities of excess free water either by wasting or by recirculating through the humidification system. If the humidification is done in the plenum it is important that several inches of freeboard be available between the floor of plenum and the entrances to the air distribution ducts under the potato pile. Another point to remember is that the force of the high velocity air in the plenum will cause the free water on the plenum floor to move away from the fan. If the collection point for excess free water is near the fan discharge point considerable slope in the plenum floor toward this point is required.

The previous calculations of water requirements were based on early fall conditions when 100 percent outside air is introduced in order to reduce the temperature of the potato pile. Later in the storage period some outside air may be introduced and mixed with return air in order to maintain the proper temperature and temperature uniformity of the potato pile. Less water will be required during this period. The amount depends upon the percentage of outside air in the mixture and the conditions of the outside air. The psychrometric chart can again be used to make calculations involving mixing air streams. This might be a good topic of discussion at another time.

TABLE 1. Water requirements for humidifying incoming outside air to 90% relative humidity.

Outside Air			Humidified Air		Water Required			
					100% Efficiency		60% Efficiency	
Dry Bulb °F	Wet Bulb °F	RH %	Dry Bulb °F	RH %	GPH/1000cfm	GPH/1000Ton*	GPH/1000cfm	GPH/1000Ton*
50	35	10	36	90	1.8	30.1	3.0	50.2
50	37	20	38	90	1.5	25.8	2.5	43.1
50	40.5	40	41.5	90	1.0	17.7	1.7	29.5
50	47	60	45	90	0.6	10.9	1.1	18.1
60	41	10	42.5	90	2.2	37.2	3.7	62.1
60	43.5	20	45	90	1.9	31.8	3.1	53.0
60	48	40	49.5	90	1.3	22.6	2.2	37.7
60	52.5	60	54	90	0.8	13.3	1.3	22.1
70	47	10	48.5	90	2.7	45.9	4.5	76.5
70	50	20	51.5	90	2.2	37.4	3.7	62.3
70	56	40	58	90	1.6	27.2	2.6	45.3
70	61	60	63	90	0.8	13.6	1.4	22.6
80	52.5	10	54.5	90	3.1	52.5	5.2	87.6
80	56.5	20	58.5	90	2.6	44.7	4.4	74.5
80	63.5	40	66	90	1.7	29.2	2.9	48.7
80	69.5	60	72	90	1.0	17.7	1.7	29.5

* Gallons per hour of water calculated on an air requirement of 17cfm per ton of potatoes.

DISCUSSION

High relative humidity levels are important in potato storages if potato quality is to be maintained. This may be particularly important during the first two months of the storage period. If any benefit is to be obtained from evaporative cooling, an adequate supply of water must be available. Humidification with spray or atomized water and evaporative cooling are one and the same process. Therefore, a system designed with this in mind can provide both benefits. In using such a system, expect considerable excess free water. The quantity may be 40% to 50% of total water put into the system. Facilities for wasting or recirculating this free water must be provided.

Understand the principles of operation of your particular system and learn to calculate the water requirements for various times during the storage period. A few simple calculations can prove very helpful in adjusting and in evaluating the performance of your system. Don't expect optimum results under all conditions from your system which do the humidification in the air plenum chamber. These systems are inexpensive and can be quite beneficial, but do have limitations. Learn to operate them in such a way to obtain the benefits that they are able to provide.

Literature Cited

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