Refining Storage Management

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By the time McDonald's went public in 1965, French fries had become a staple American fast food. It is interesting to note, that coincidentally, forty years ago, during the middle Sixties, frozen French fries from processing plants became a standard for the fast food industry.

Since frozen French fries from processing plants are a major reason for potato storage, it is interesting to consider the progression of storage management during this forty-year period and the detail refinements in storage management that affect storage performance. Of course this progression of storage management refinement affects the bottom line: The all-important net return from product out of storage.

Forty years ago, a supply air temperature controlled to plus or minus three degrees was considered acceptable. It wasn't long before the research community determined that tighter temperature control during storage could assist sugar conversion. Consequently, the fast food industry mandated tighter temperature control. And it wasn't long before potato storage supply air temperature was controlled to plus or minus 1½°F. When systems with three-mode temperature control were introduced in the early Seventies, supply air temperature controlled to plus or minus ½°F became possible. And today, systems are expected to control supply air to plus or minus a tenth or two. So, what additional refinements in storage management can possibly be expected? What refinements in storage management could even be possible? Plus or minus a few hundredths of a degree Fahrenheit?

THE BASIC TASK

The Basic Task of storage is to preserve both the **quantity** and **quality** of the raw product placed in storage at harvest. Preservation of the *quantity* and *quality* simply means minimizing losses: weight loss, quality losses, and loss due to spoilage. Research has shown that for every percent of weight loss during storage there is an additional percent of quality loss.

So, if one percent of raw product **quality** is lost for each percent of **weight** lost, for a total raw product loss out of storage of two percent for each percent of weight loss, this business of preserving both quality and quantity is based on absolutely minimizing weight loss. And, although refining storage management may not include controlling supply air temperature to plus or minus a few hundredths of a degree Fahrenheit, the temperatures you deal with at harvest: all the various temperatures that are part of the picture at harvest, as you will see, have everything to do with the subject of refining storage management.

REFINING STORAGE MANAGEMENT: Controlling Weight Loss

So, if controlling weight loss is the heart of refining storage management, a refined appreciation of temperature is at the heart of truly controlling weight loss. Certainly the importance for controlling weight loss is not a new idea. And, that the stage is set during the first few weeks potatoes are in storage for the amount of weight loss that takes place, is also not a new idea. However, a truly complete appreciation for all the temperatures that are part of the picture at harvest, and what those temperatures have to do with weight loss may have flown-along under the radar, so to speak, for three simple reasons:

1. First, you just don't see weight loss at harvest, . . . You don't realize the weight loss that takes place until potatoes come out of storage. So, it's easy to minimize a serious focus on the efect temperatures at harvest might have on weight loss.
2. Second, It takes a complete appreciation of supply air properties; and, specifically supply air properties relative to pile temperature, during the first few weeks potatoes are in storage. And, although a solid understanding of supply air properties, the relationship between water vapor and dry air, is not rocket science, the only way to assemble an accurate, meaningful picture for refining storage management brings us to reason Number Three:
3. The third reason why an appreciation for all the temperatures at harvest may have flown along under the radar will be a primary focus in this presentation for refining storage management, because to assemble an accurate, meaningful picture of supply air properties requires using the Psych Chart, the psychrometric chart. Examples, using realistic possible situations at harvest, will show the importance of temperature for refining storage management.

ELEMENTS TO CONSIDER AT HARVEST

Let's step back for a moment to review the importance of suberization. Minimizing weight loss requires excellent suberization. Since wound healing and suberization take place during the first few weeks spuds are in storage let's begin with a quick look at suberization. This process sets the stage for successful storage. If the suberization process is optimized, weight loss will be dramatically minimized, and quality losses can be even more significantly minimized. In addition, good suberization has a direct positive effect on the disease resistance of potatoes in storage. This brings us to the subject of Supply Air Properties, which is one of the most easily overlooked details that affect good suberization.

However, before we wade into a discussion of Supply Air properties, though, a look at what's going on with the spuds in storage during harvest will help to appreciate the business of refining storage management. It simply makes good sense that the more thoroughly we understand what's going on in storage, the more successful storage will be. Since a potato is a living, breathing organism during storage, let's begin by taking a look at the **Respiration Rate** during storage. Webster's dictionary defines respiration as "the sum total of the physical and chemical processes in an organism by which oxygen is conveyed to tissues and cells, and the oxidation products: heat, carbon dioxide and water, are given off."

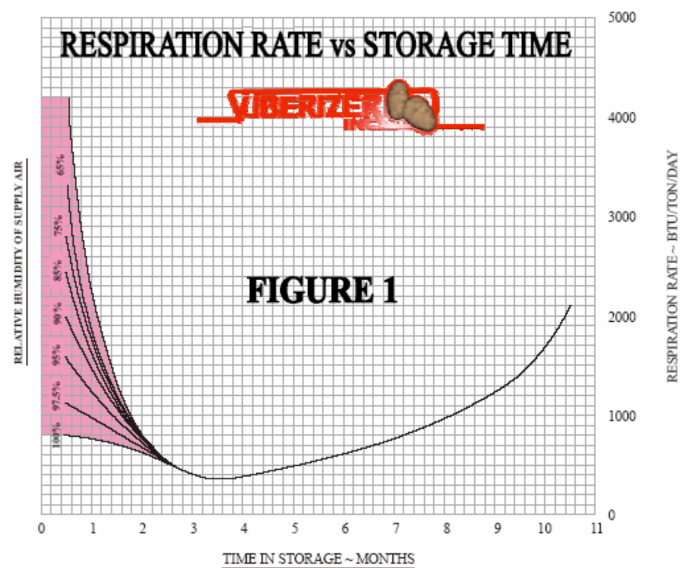
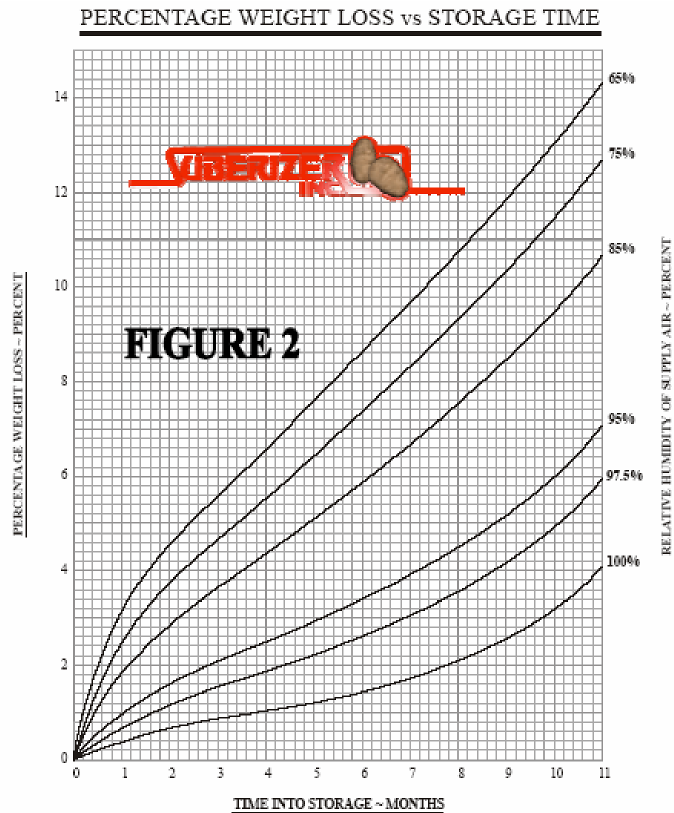


FIGURE 1

Respiration is actually a combustion process. Living, breathing organisms need oxygen. The oxygen that potatoes need in storage supports this combustion process, and the products of combustion are heat, CO_2 and water. Note that the right ordinate in **FIGURE 1** presents the heat associated with the respiration process in BTUs per ton of potatoes per day. This heat and CO_2 associated with respiration must be exhausted to control temperature and provide a proper environment for wound healing and maturation of the potatoes. How well the storage manages this heat has everything to do with successful storage.

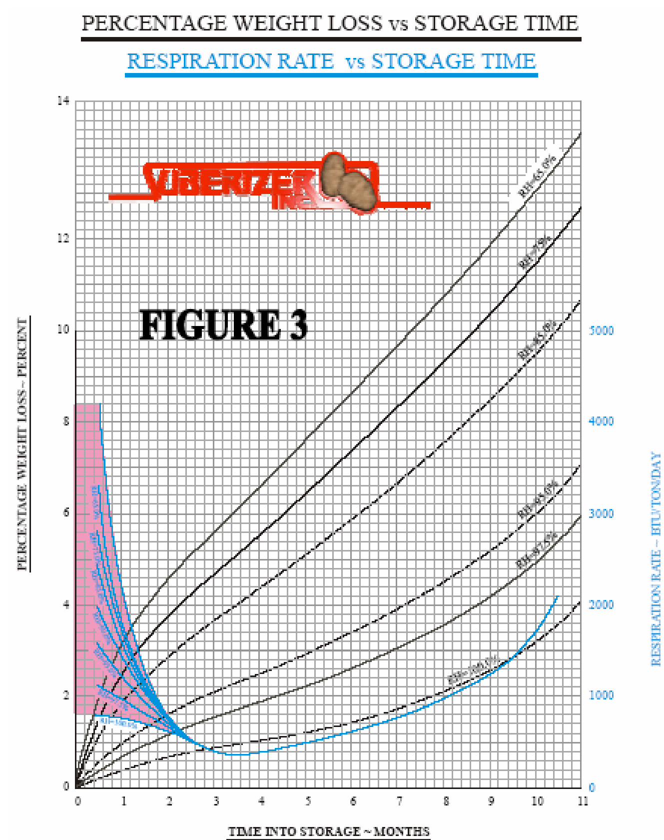
Right off the bat, when spuds are placed in storage, the plot suggests that the respiration rate can vary from an extremely high rate to a relatively low rate. Several things actually determine the respiration rate during early storage. We do know that healthy, disease-free spuds have a lower respiration rate. Furthermore, respiration rate is a function of temperature. The respiration rate is higher in a warmer pile. The left ordinate suggests that the respiration rate during the first few weeks potatoes are in storage might be a function of supply air relative humidity: that a low respiration rate is associated with high relative humidity supply air. This correlation is based on weight loss studies with various supply air relative humidities.

FIGURE 2, presents weight loss as a function of time for various supply air relative humidities. For example, with a supply air relative humidity of 95% and a storage period of 7 months, note that you should expect a total weight loss of about 4%. Actual weight loss in storage for a seven month storage period is often much greater. Note that after the first month and a half, or so, in storage, the slope of the 75% RH weight loss curve is not that different from the 95% RH curve. But, look at the difference between the slopes of the same two curves in the first month of storage!



After the first month or so in storage, weight loss potential is not so drastically affected by supply air relative humidity. Sure, the 75% RH curve is somewhat steeper after two months of storage than the 95% curve. But, during the first month and a half of storage the rate of weight loss is highly dependent on supply air relative humidity. The stage is clearly set during suberization for weight loss that will take place. Both tuber temperature and supply air relative humidity affect the process of suberization; and supply air temperature relative to tuber temperature has a huge impact on supply air relative humidity in the pile.

FIGURE 3 demonstrates an interesting thing that happens when we superimpose the two previous figures. The period of "initial high respiration rate" coincides directly with the period of time that sets the stage for the initial "rate of weight loss". Since research has shown that a portion of the cause for a high initial respiration rate is low supply air relative humidity, it's not surprising that the first month in storage is critical for weight loss.



During the first month, weight loss for 100% RH supply air is 0.4%. For 65% RH supply air: weight loss is 3.0% ! Assuring 100% RH supply air is crucial.

Although supplying saturated air to the pile is crucial, A complete appreciation for minimizing weight loss in potato storage must focus on temperature. The relation between supply air temperature, tuber temperature, and relative humidity has everything to do with minimizing weight loss by Refining Storage Management.

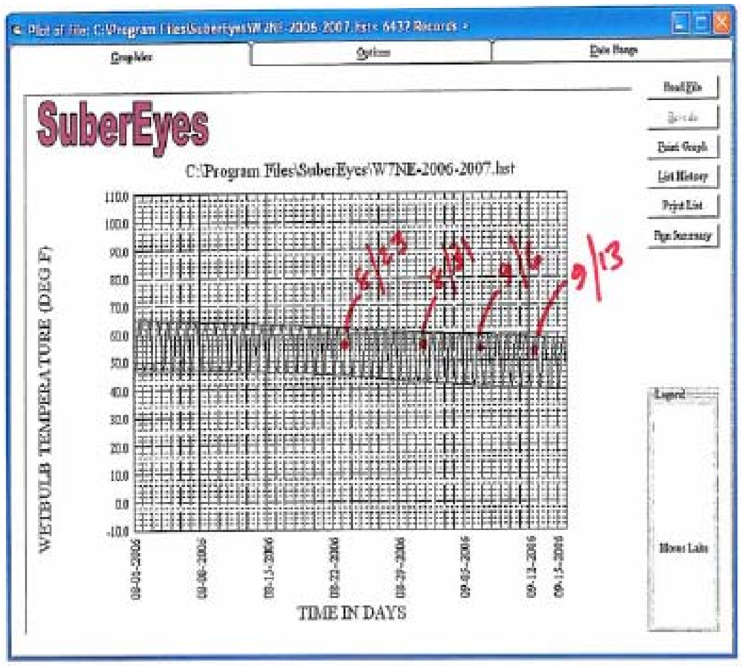
Control of virtually every storage concern, problem, and factor is related to a complete understanding of temperatures in storage and the relation between temperature and humidity. This brings us close to our primary focus on **Refining Storage Management**.

First, excellent storage management at harvest requires taking enough action to know what you've got coming into storage. A very simple six-step procedure is worth considering:

Let's briefly consider each step:

STEP ONE: KNOW PULP TEMPERATURES IN THE FIELD

Take a little booklet, or a simple spiral notebook you can carry in your pocket, along with an accurate pulp thermometer, and start a daily log of pulp temperatures in the field for a couple weeks before harvest begins.



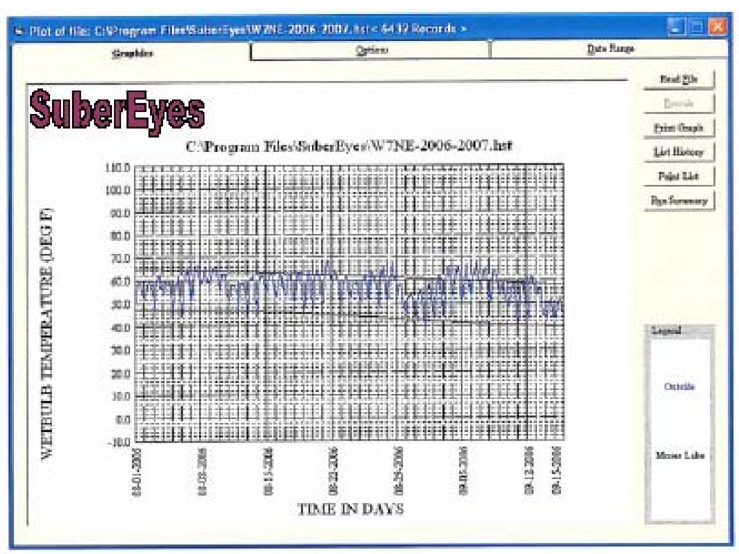
Better yet, if your control panel records storage history, you have a very helpful tool to use: Even though no potatoes are in your storage before harvest, connect to your panel, and take advantage of the fact that the panel has Average High and Average Low temperature data for your neighborhood, and generate a plot for a few-week period prior to harvest.

Make several copies of this temperature plot so you can note pulp temperatures right on the plots, for fields to be harvested into storage.

Pulp Temperature, along with Wet Bulb temperature at harvest is fundamental information.

STEP TWO: PLAN YOUR HARVEST

Make a conscious effort to plan your harvest so that you bring spuds into storage with a manageable pulp temperature range. An ideal pulp temperature range for all spuds into storage would be maybe between 55°F and 70° F. Using your knowledge of pulp temperatures, along with Average High and Low Wet Bulb temperature, will be helpful in planning the most optimum harvest schedule.



Use your control panel features to superimpose actual Wet Bulb Temperature on a plot of Average High and Low Wet Bulb Temperature so that you have actual weather temperatures as an additional assist in planning.

STEP THREE: RECORD PULP TEMPERATURES INTO STORAGE
When harvest begins, the piler operator is the perfect person to continue the task of logging pulp temperatures from each load of spuds coming into storage. He should record two or three sample temperatures from each truckload during each day of harvest in a logbook maintained during harvest. Date the top of each page.

This pulp temperature information is the basis for establishing an initial setpoint for system supply air temperature, and is the basis for lowering setpoint as harvest continues.

STEP FOUR: ESTABLISH AN INITIAL SUPPLY AIR SETPOINT
Normal conditions at harvest here in the Columbia Basin require cooling potatoes coming into storage. An initial setpoint for saturated supply air should be no warmer than the coolest pulp in storage. Pulp temperatures on the first day of harvest may be quite warm. Let's assume 56°F was logged for the coolest pulp temperature arriving in the morning, and 65°F is the highest logged temperature during the day. By the end of the first day of harvest the spuds associated with the coolest temperatures in your logbook will have warmed a few degrees. The 56°F pulp may have warmed to 60°F.

Two considerations must be observed when establishing an initial setpoint for cooling:
1. Moisture from saturated supply air which is warmer than the pulp will condense on cooler tubers. So, supply air should be the same temperature, or cooler than the coolest pulp in storage; However,
2. Minimize the spread between Supply air temperature and the warmest potatoes in storage.

The temperatures logged for this example suggest using 60°F as an initial supply air setpoint, assuming weather and your system can supply saturated 60°F air to the pile, when the storage doors are closed at the end of the first day. A 60°F setpoint will continue to be appropriate so long as no pulp is brought into storage that is cooler than 60°F by the end of the day when the system is turned on.

STEP FIVE: CHECK TOP OF PILE PULP TEMPERATURE EACH MORNING
Each morning during harvest, pulp temperature on the top of the pile at several identical locations must be checked and recorded in your Storage Record Booklet when the system is turned off, after running all night. This STEP is most important! The key here is to make certain that the pulp temperature on top of the pile does not increase during harvest. If pile temperatures increase:

1. Supply air temperature must be lowered; or,
2. More system run time must be realized; or,
3. Both a lower setpoint and additional runtime must take place.

STEP SIX: SUBERIZE, SUBERIZE, SUBERIZE
For the sake of wound-healing and suberization, ideal pulp temperature at harvest is between 50°F and 69°F. Tuber temperature below 50°F adversely affects suberization. In fact, suberization comes to a screeching halt as pulp temperature drops below 50°F. Although research suggests that the pulp temperature for an optimum suberin deposit is in the high 70-80°F range, due to the potential for accelerated microbial activity, most authorities suggest harvesting potatoes into storage with a pulp temperature below 70°F.

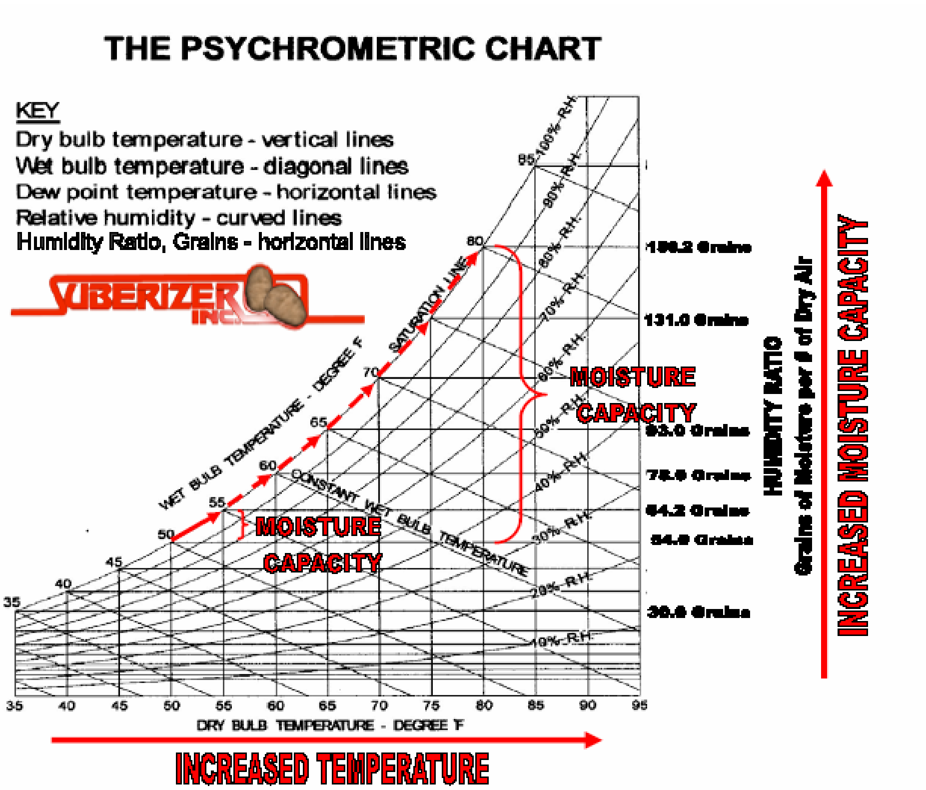
Suberization begins about the third day after harvest, and suberization is complete about two weeks after harvest. Since the suberization process is completed faster at temperatures in the sixties, the first spuds into storage are usually suberized by the time the storage is full and the doors are closed. When the deposit of suberin is complete, since the skin is less permeable, weight loss is minimized, quality losses are minimized, rot is minimized, and disease resistance is maximized.

Since the normal, or usual, temperature during harvest often includes very warm weather, this presentation is directed especially at healthy potatoes harvested into storage with pulp temperatures warmer than the desired steady-state long-term storage temperature:
With potato temperature information available, let's turn to the business of **Air, Potatoes and Water at Harvest.** An appreciation of information the Psychrometric Chart can provide is fundamental.

WHAT TEMPERATURE INFORMATION HAS FLOWN-ALONG UNDER THE RADAR?

The relation between *water vapor* and *dry air*, in the supply airflow, is quite possibly the least appreciated aspect of storage management. Consequently, the business of Refining Storage Management must include attention to the properties of saturated air as it enters a warmer potato pile. As mentioned earlier, a few examples, using realistic possible situations at harvest, with the help of the Psych Chart, the psychrometric chart, will show the importance of temperature for refining storage management.

The subject of psychrometrics in potato storage is the relationship between *water vapor* and *dry air*. An understanding of the psychrometric conditions in potato storage provides valuable insight to storage management that will provide a more complete picture of humidification, condensation, and the all-important effect **Supply Air properties** have on potatoes in storage. In fact, **Supply Air** psychrometrics is fundamental to the effective storage of potatoes.



This simplified **psychrometric chart** shows the following properties of moist air: 1. **Dry Bulb Temperature** (Vertical Lines); 2. **Wet Bulb Temperature** (Diagonal Lines); 3. **Dew Point Temperature** (Horizontal Lines); and 4. **Relative Humidity** (Curved Lines). If any two of these properties are known, the other two properties can be determined from the psych chart.

Supply Air Properties:
We will use this chart to determine the effect saturated supply air (100% RH) is warmed as it flows through the pile. A look at the Psych Chart shows that as supply air warms, the relative humidity stays at 100% if moisture is available, and the air properties follow the Saturation Line. Since moisture is readily available from the potatoes, airflow through the pile tends to stay saturated. The moisture capacity for air at any air temperature can be determined by following a horizontal line from the air temperature at the saturation line to the vertical axis on the right. The amount of moisture air can hold is presented as a Humidity Ratio: "Grains of H2O per # of Dry Air", for any air temperature on the Saturation Line. The change in moisture content the supply air can absorb is directly related to the difference in the Humidity Ratio from one air temperature to another.

Recognizing that 7,000 Grains = one Pound of water, here's what the Psych Chart suggests 50°F/10°C supply air has the capacity to absorb (from the potatoes, or the air surrounding the potatoes), as it warms, without addressing the total airflow rate:

Supply Air Temperature °F/°C	Pulp Temperature °F/°C (assumed air temperature)	Supply Air Temperature Change (ΔT) °F/°C	Grains H_2O per # Dry Air Absorbed In Pile	Pounds H_2O per # Dry Air Absorbed In Pile	Pounds H_2O Absorbed per Day per CFM/Ton of Potatoes
50°F/10°C	55°F/12.8°C	5°F/2.8°C	10.2	0.00146	0.15768 # per day/CFM/Ton of Potatoes
50°F/10°C	60°F/15.5°C	10°F/5.5°C	24.0	0.00343	0.37044 # per day/CFM/Ton of Potatoes
50°F/10°C	65°F/18.3°C	15°F/8.3°C	39.0	0.00557	0.60156 # per day/CFM/Ton of Potatoes
50°F/10°C	70°F/21.1°C	20°F/11.1°C	57.0	0.00814	0.87912 # per day/CFM/Ton of Potatoes
50°F/10°C	75°F/23.9°C	25°F/13.9°C	77.0	0.01100	1.18800 # per day/CFM/Ton of Potatoes
50°F/10°C	80°F/26.7°C	30°F/16.7°C	102.2	0.01460	1.57680 # per day/CFM/Ton of Potatoes

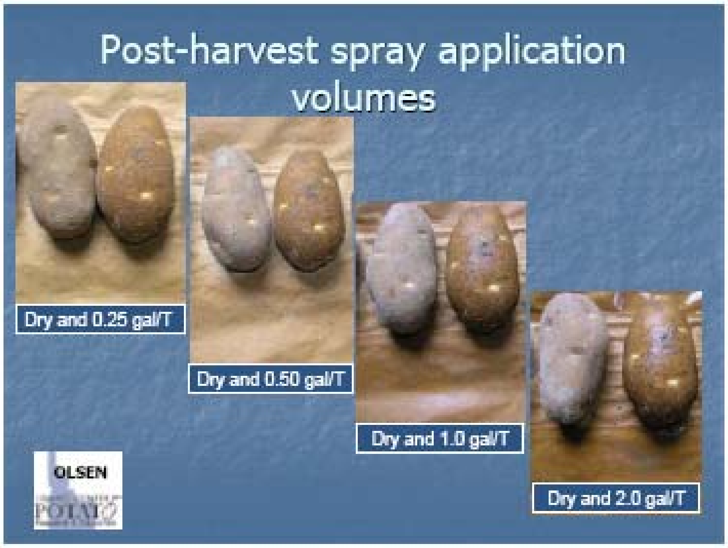
These fractional (and small) pounds of water absorbed per Day per CFM per Ton of potatoes may not seem significant until supply airflow rates are introduced for a specified quantity of potatoes. The following table presents the amount of moisture saturated supply air can absorb, assuming a saturated air supply of 20 CFM/Ton at 50°F is heated by warmer pulp, for various storage sizes:

SUPPLY AIR: @ 20 CFM per Ton of Potatoes

Supply Air Temperature °F/°C	Return Air Temperature (due to pulp) °F/°C	Supply Air Temperature Change (ΔT) °F/°C	Pounds H_2O Absorbed by Supply Air Per Day (TRANSLATES TO HUGE FINANCIAL LOSSES)			
			1,000 Ton Storage	2,000 Ton Storage	5,000 Ton Storage	10,000 Ton Storage
50°F/10°C	55°F/12.8°C	5°F/2.8°C	3,153.6	6,307.2	15,768.0	31,536.0
50°F/10°C	60°F/15.5°C	10°F/5.5°C	7,408.8	14,817.6	37,044.0	74,088.0
50°F/10°C	65°F/18.3°C	15°F/8.3°C	12,031.2	24,062.4	60,156.0	120,312.0
50°F/10°C	70°F/21.1°C	20°F/11.1°C	17,582.4	35,164.8	87,912.0	175,824.0
50°F/10°C	75°F/23.9°C	25°F/13.9°C	23,760.0	47,520.0	118,800.0	237,600.0
50°F/10°C	80°F/26.7°C	30°F/16.7°C	31,536.0	63,072.0	157,680.0	315,360.0

WET POTATOES AT HARVEST
At harvest, potatoes come to storage with varying amounts of surface moisture. When wet potatoes arrive at storage, normal concern suggests that supply air must not be saturated, so the tubers will dry. In order to gain insight regarding this issue, Nora Olsen, Ph.D. Potato Specialist, College of Agricultural and Life Sciences, The University of Idaho, conducted a study to relate the amount of surface water on potatoes to tuber appearance.

GALLONS OF WATER CONVERTED TO POUNDS
Water weighs 8.33 pounds per gallon. With reference to Nora Olsen's photograph, let's assume that 1,000 tons are harvested each day into storage. And, even though the first day of storage could provide significantly more than 20 CFM per ton of supply air, let's limit the rate of supply air to only 20,000 CFM for the first 1,000 tons of potatoes placed in storage



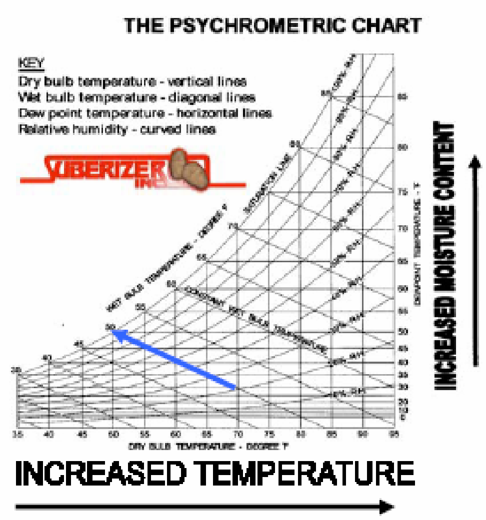
SATURATED AIR SUPPLIED at 20 CFM/Ton

POTATO APPEARANCE	POUNDS OF SURFACE MOISTURE	TEMPERATURE INCREASE of SATURATED 50°F SUPPLY AIR REQUIRED TO REMOVE SURFACE MOISTURE FROM 1,000 TONS in 24 HOURS
0.25 gal/Ton	2,082.5 #	3.2°F
0.50 gal/Ton	4,165.0 #	6.0°F
1.00 gal/Ton	8,330.0 #	10.7°F
2.00 gal/Ton	16,660.0 #	18.6°F

SATURATED AIR SUPPLIED at 50 CFM/Ton

POTATO APPEARANCE	POUNDS OF SURFACE MOISTURE	TEMPERATURE INCREASE of SATURATED 50°F SUPPLY AIR REQUIRED TO REMOVE SURFACE MOISTURE FROM 1,000 TONS in 24 HOURS
0.25 gal/Ton	2,082.5 #	1.4°F
0.50 gal/Ton	4,165.0 #	2.5°F
1.00 gal/Ton	8,330.0 #	4.9°F
2.00 gal/Ton	16,660.0 #	9.0°F

That supplying saturated air to warmer potatoes has the ability to remove massive moisture from a newly-harvested crop in storage is possibly the least understood, and least appreciated aspect of storage management. Use any reasonably-expected dollar value for potatoes, and calculate the financial loss that can take place if the pile is cooled too rapidly. Even saturated air supplied to a new crop in storage that warms the air 10°F is a major financial mistake if the crop is healthy.



COOLING WITH OUTSIDE AIR

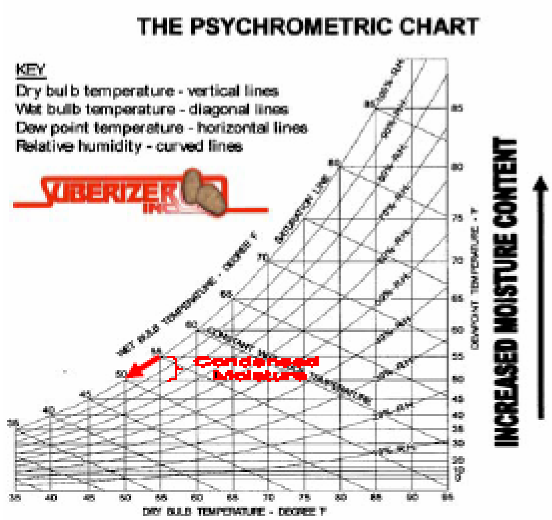
Air properties at harvest often allow significant cooling without refrigeration. The chart allows us to see just how much cooling is available when using outside air. Let's assume outside air temperature is 70°F, and the relative humidity is 20% RH. A well-designed blowthrough humidification system will bring the air to saturation. Find the intersection of 70°F on the abscissa (dry bulb temperature) and the 20% RH line. As outside air passes through the humidification system, water vapor is added to the air, and the air follows a constant wet bulb (diagonal) line to saturation (100% RH). Supply air in the plenum will be at about 50°F. That's a 20°F reduction in outside air temperature!

However, the storage management detail that will significantly minimize weight loss is the recognition that regardless of the supply air condition (the relative humidity of the supply air), air leaving the pile will be virtually saturated due to moisture present in the pile. The real message here is that if we're not careful during early storage, if the spuds are quite warm relative to the supply air temperature, we will actually be subjecting the pile to relatively low humidity air, even if the supply air in the plenum is close to saturation!

FIVE FACTORS HINDER GETTING SATURATED AIR TO THE PILE:

1. Relative humidity of the outside air must be brought to saturation by the system. When outside air is very dry it takes a surprising amount of water to get the air to saturation. When the fresh air dampers are fully open, a high-performance humidification system is necessary to actually achieve saturation.
2. Mechanical heat from the fans and other equipment is a significant portion of the total heat load. Air moving across the fans will warm the air about 1°F. This 1°F increase in temperature results in a loss of about 5% RH. Therefore, it is most important that the humidification system is downstream from the fans.
3. Impingement of the air on its way to the pile. Air in a plenum and in the ducts is turbulent. As air is redirected by structure, and by corrugations in the air pipe, the impingement during this redirection causes a change in state of moisture in the air. Air does not want to stay saturated, anyway, and this impingement simply wrings moisture out of the supply air. To help make up the vapor pressure deficit caused by this impingement it is important for the air supply to carry along some micron-sized droplets.
4. Heat of product is the heat associated with warm harvested spuds. Our example of cooler air going into a warmer pile presents this very important issue.
5. Respiration adds additional heat. The respiration rate is significant during suberization, especially if the spuds have been bruised or damaged during harvest. This combustion process is a big contributor to pile heat, and consequently respiration lowers relative humidity. Furthermore, another look at the weight loss curve presented earlier suggests that supplying saturated air can even reduce the respiration rate. So attention to temperature and supply air relative humidity, especially during suberization is a must.

But, what happens when the weather turns cold, and potatoes are brought into a warmer storage? The psych chart shows us what happens when saturated supply air in the storage is blown on colder spuds coming into storage during harvest. Suppose the storage setpoint during harvest is 55°F, and all of a sudden a cold snap drops the pulp in the field to 50°F: Condensation will form on the cooler pulp if the 55°F storage environment is more moist than ≈82% RH, so just count on those cooler spuds getting wet, unless you take some action. What can you do (if you don't have another storage to go into with this cooler pulp)? The best bet is to close the duct gates to the warmer potatoes, turn off the humidification, keep the same 55°F setpoint, and warm those cooler spuds. It's not perfect, because the supply air returning from the pile will be moist. In order to provide warmer supply air effectively, air drier than the return must be "made" available, possible by heating drier outside air.



A calculation made by following a horizontal line from 55°F on the saturation line to the right, suggests that saturated 55°F air has a Humidity Ratio of 64.2 grains of water per pound of dry air. And, following a horizontal line from 50°F on the saturation line to the right, suggests that saturated 50°F air has a Humidity Ratio of 54 grains of water per pound of dry air, a difference of 10.2 grains of water per pound of dry air. (7,000 grains = 1 pound)

Making the calculation, at an air flow rate of 20 CFM/Ton of spuds: (10.2 grains)(.0778#/ft3)(20 CFM/ Ton of Spuds)= 15.8 # of water will form in the pile each minute, for each Ton of spuds. The primary message is do everything possible to plan harvest so that you always need to cool potatoes at harvest.

Think about this for a moment: the average spud at harvest is only about halfway to the table: It is up to the storage and the storage manager to maintain both the ***quantity*** and the ***quality*** of the potatoes placed in storage for as long as necessary.