

HUMIDITY CONTROL IN FRUIT COOLING AND STORAGE

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Humidity balance

Humidity in a cooler or storage depends on a balance of losses and gains of moisture. The chief loss is commonly from condensation on cooling surfaces, though absorption by containers, packing materials, walls, floors and ceilings may be important at times. Moisture is gained by evaporation from the produce and by water sprays if they are used. There is evaporation from wet ice only if the return air is either quite dry or is within a degree or two of the ice temperature.

Moisture contained in the room air at any one time is usually not more than may be gained or lost in a few minutes. If gains and losses do not balance, the air humidity soon changes until they do. It is possible to provide large cooling surfaces which operate at a temperature close enough to that of the return air so that condensation is eliminated, or water may be sprayed into the air to offset condensation.

Condensation is proportional to cooling load, other things being equal, and is calculated in the following table, for return air at 35F. The figures would be a little different for return air warmer or colder than 35F, and the calculations are for cooling surfaces at uniform temperature. Actually, the different parts of a cooling unit are not all at the same temperature and the temperatures vary as the compressors cycle. However, the table gives an idea of what to expect.

Return air relative humidity	Temperature difference (F), return air to surfaces						
	20	10	5	4	3	2	1
Condensation (gal per hr per ton refrigeration)							
60	.23	0	0	0	0	0	0
70	.30	.14	0	0	0	0	0
80	.37	.33	0	0	0	0	0
90	.44	.46	.36	.32	.17	0	0
95	.46	.49	.48	.45	.42	.32	.17

Fruit storages in California have commonly been designed for a difference of 10F or more between return air and cooling surfaces at full load. The table shows that, to stop condensation from 90 percent relative humidity return air, this temperature difference must be reduced to about 2F, requiring about five times as much cooling surface and five times as much air circulation. It should be noted that even entire elimination of condensation on cooling surfaces does nothing to supply moisture that may be absorbed by containers, walls and ceilings.

High humidity may usually be maintained at less expense by spraying water into the air to offset condensation and absorption. The table shows that up

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to about half a gallon of water per hour per ton of refrigeration may condense on the cooling surfaces. The spray system should be able to supply this much water, plus a margin for absorption by containers, and by walls, ceilings and floors if the plant has been out of use in dry weather. A system capable of supplying one gallon of water per hour per ton of refrigeration should be able to maintain 95 percent relative humidity under any reasonable conditions, and when the demand is less the water can be throttled down.

Air and water nozzles

One way of spraying water into the air is with nozzles in which compressed air is used to produce a fine fog which will not settle, though it will wet anything against which it impinges.

Two types of air-and-water nozzles are available. The internal-mixing type mixes air and water inside the nozzle and then discharges the mixture through an orifice. This requires that water pressure be not more than 10 to 20 pounds per square inch less than air pressure, or air will stop the spray and blow back into the water lines. Public health regulations prohibit direct connection of such nozzles to a potable water supply because of the possibility that such a blow-back will introduce contamination. Check valves are not a legal safeguard. Water should be pumped to internal-mixing nozzles from a tank in which the level is maintained by a float valve. This adds considerably to the complication and cost of the system. Trouble may also be experienced from water pressure being above the air pressure, which produces a coarse spray or even complete stoppage of the air, with a solid stream of water from the nozzle.

In external-mixing nozzles the air and water are discharged through separate orifices and are mixed outside of the nozzle. This eliminates blow-backs and allows the nozzle to operate through a wide range of air and water pressures. These nozzles are designed, however, to syphon water from a tank below the nozzles or to be supplied at water pressures of a pound or two per square inch. Friction in the water piping, or even air bubbles, can effect these low pressures enough to cause uneven discharge from different nozzles. Water lines to such nozzles should be large enough to make friction negligible, and should be carefully leveled or given a slight uniform slope to eliminate bubbles or air lock. Nozzles can be purchased with individual needle valves, which can be used to adjust out any uneven discharge.

The water supply to external-mixing nozzles is easily increased to produce a heavy, coarse spray when the air humidity is low, or the water supply may be decreased to produce a light, fine spray when the humidity is high, full air supply being used at all times. This adjustment is more difficult with internal-mixing nozzles.

Piping and water supply

Nozzles can conveniently be supported by tees turned upward in a three-quarter inch galvanized water line. The line should be leveled or slightly sloped to avoid bubbles and air locks, as noted above. Electrically heated tape or cable can be wrapped around the water pipes and the nozzle risers to prevent freezing. Expansion of air as it leaves the nozzles may cool them several degrees and freeze them even when the room is above freezing. Copper tubing of the same size as the air compressor discharge, with flare fittings, is convenient for supplying air.

Air supply

Air may be supplied by a compressor sized to operate continuously while supplying the air for one set of nozzles. No tank or pressure regulator is needed, though a relief valve should be installed in the air line for safety.

Alternatively, air for several sets of nozzles may be supplied by one large compressor. A storage tank and a pressure regulator are then needed to permit shutting down some of the nozzles. Pressure will run up and down as the compressor cuts in and out. This is allowable with external-mixing nozzles but an additional pressure regulating valve is needed to provide close control for internal-mixing nozzles. Usually, the single large compressor with its accessories will cost more to buy than several small ones, and will cost more to run if some of the nozzles are out of use for any length of time.

Size of nozzles

A fine spray, well distributed, is desirable for quick evaporation, especially if there is limited space in which to install the nozzles. Finer spray is produced by higher pressure air and by more air in proportion to the water discharged. Better distribution is obtained with many small nozzles rather than a few large ones. Unfortunately, higher pressure, more air, and more nozzles all add to the cost of an installation. Three typical nozzles may be characterized as follows, all using 1 cubic foot of air per minute at 40 pounds per square inch.

Best atomization and distribution, highest cost

1/2 gallon water per hour, spray evaporates about 6 feet from nozzle.

Good atomization and distribution, moderate cost

1 gallon water per hour, spray evaporates about 9 feet from nozzle.

Fair atomization and distribution, lowest cost

1-1/2 gallons water per hour, spray evaporates about 12 feet from nozzle.

Maintenance

A strainer should be provided in the water line to prevent plugging of the nozzles with scale or dirt. When starting a new system and at the start of each season it is well to screw off all the nozzle tips and flush and blow out the water and air systems. It is not usually necessary to provide a strainer in the air line.

Corrosion of brass nozzles from sulfuring in a grape storage can be reduced by removing the tips at the end of the season; cleaning, washing and drying them; and storing them in a dry place; or corrosion-resistant steel nozzles may be used.

High pressure water nozzles

A recent development aimed at simplifying and reducing installation costs is the use of small high pressure water pumps. These pumps are capable of

maintaining continuous water pressure of 700 to 800 P.S.I., pump capacity being designed to fit the capacities of nozzles installed. The nozzle orifice is constructed of carbide to minimize excessive wear at the high operating water pressures. Nozzles are obtainable in a range of sizes to fit different room and pump design capacities. Although use of this type of equipment installation is still somewhat experimental, results show promise.

Very small orifices are needed to limit the discharge from each nozzle at these high pressures and extreme care is necessary to avoid plugging. Each nozzle must be operated at full pressure to obtain fine atomization, or else shut off entirely. Spray is somewhat coarser than with pneumatic nozzles and it may give trouble by impingement on solid surfaces unless it is allowed plenty of space in which to evaporate.

Mechanical atomizers

Mechanical types of atomization are being tried. One such unit is made up of a double-shafted high-speed motor upon which is mounted a fan and a disc. Water is fed to the center of the disc under a constant pressure. This water spreading out by centrifugal force forms a thin film which strikes a set of teeth which surround the whirling disc. Impact with these teeth breaks the water into a fine mist, the mist then being picked up by the air stream generated by the fan blades and evaporated into the moving room air.

Mechanical atomizers appear the best adapted to situations where a few atomizers with relatively large discharges may be used without trouble from impingement of the spray before it has evaporated. The water supply may be increased to produce a heavy, coarse spray when the humidity is low, or the supply may be reduced to produce a light, fine spray when the humidity is high. Mechanical atomizers are well suited to use in portable units, which are convenient in some operations.

Steam humidification

Water added in the form of steam eventually condenses on the cooling surfaces as either liquid water or ice, releasing heat which adds as much as 50 percent to the refrigeration load. Steam seldom offers any advantages sufficient to justify the cost of installing and operating this additional refrigeration.

Location of nozzles or atomizers

The ideal position for spray nozzles is in the air supply to the room, at a point where the air has picked up any heat from the ceiling and fans and before it reaches the produce. The spray will not settle, but troublesome drip will result if the spray plume blows against any surfaces, posts, braces, pipes, or even wires, before it evaporates.

Sometimes sprays must be placed near the air returns, or even in the returns, because there is no other place for them. This produces higher humidity around the cooling surfaces than in the room, which increases condensation on the cooling surfaces, which in turn requires more spray. The effect is not important if the temperature of the air return is within a degree or two of the blast. It can be calculated that with a three-degree difference between blast and return, nozzles in the return instead of in the blast must supply about a half more water, while with an eight-degree difference nozzles in the return must supply twice as much water. Condensation on the cooling surfaces is

correspondingly increased. Any droplets that impinge on the cooling surfaces add to the condensation or frosting without doing anything to improve the humidity.

There is also another consideration in adding spray to the return air. Air leaving surfaces sprayed with brine cannot be raised to 100 percent relative humidity by any addition of spray in the return, due to condensation in the brine. The air may then be warmed a degree by friction in a powerful fan and in high-velocity ducts, and perhaps another degree by heat leakage through ceiling and walls in hot weather. Each degree that the air is warmed reduces its relative humidity by about four percent. The final result may be that it is not possible to obtain satisfactory humidity in the room, no matter how much spray is added to the return air.

Controls

Manual adjustment of the water supply allows an operator to take account of conditions everywhere in a room, reducing or stopping the spray if excessive moisture appears anywhere. With external-mixing pneumatic nozzles, or with mechanical atomizers, manual control allows use of a coarse, heavy spray or a light, fine spray, depending on what is needed. A fine needle valve is needed for this purpose, remembering that full flow is usually only a few gallons an hour.

Automatic control eliminates the attention of an operator, but it senses conditions only at one point, which may not be representative in a large room containing various lots of fruit. Automatic controls are sometimes troublesome at the very high humidities used in fruit storage and cooling, particularly if changes in temperature result in the sensing element being temporarily warmer or colder than the air, which will make the element either drier or wetter than it should be. Most automatic controls turn the spray either on or off and are not able to adjust the volume, though controls to do this may be had at a higher cost.

Best atomization may be assured in a pneumatic system by leaving the air full on and controlling only the water. More information on controls may be obtained from sources listed at the end of this paper.

Air cooling with water spray

In some plants the air is cooled by sprays of cold water, either in spray chambers, or by spraying the water over special heat-exchange surfaces, or by spraying the water over ice in bunkers. The finer drops of spray are carried in the air until removed by eliminators, allowing the air to come practically to the droplet temperature and to 100 percent relative humidity. This system has the advantage of automatic maintenance of ideal humidity in the air supply, with no attention and no equipment other than that used to cool the air.

However, as the air travels on in its circuit it picks up heat and its relative humidity goes down by about four percentage points for each degree rise in temperature. Some of the advantages of a high-humidity air supply may be lost by warming of the air before it reaches the fruit, a two-degree rise lowering the relative humidity from 100 to 92 percent, for example.

Systems in which air is cooled by water, which in turn is cooled by ice, must operate with the water a little warmer than the ice and the air a little

warmer than the water. Consequently: it is not possible to have air temperatures below about 34F so long as plain water is used. Lower temperatures can be attained by salting the water, with some lowering of humidity also, as shown in the following table.

<u>Sodium chloride</u> <u>(percent in water)</u>	<u>Baumé</u> <u>density</u>	<u>Ice freezes</u> <u>or melts (F)</u>	<u>Relative humidity</u> <u>(air at water temperature)</u>
0	0	32.0	100
2	2.2	30.0	98.7
4	4.4	27.8	97.4
6	6.6	25.5	96.1
8	9.0	23.0	94.7
10	11.3	20.3	93.3
12	13.4	17.3	91.8
14	15.7	14.0	90.4

For example:

The temperature of the entire system may be lowered about 4 degrees by addition of 4 percent of salt to the water, and the relative humidity of the air supply will be lowered from 100 to 97.4.

In such a system the water is in contact with ice that is just melting or freezing. In conventional brine-spray systems, where the coils must be kept free of ice, the freezing point of the brine must be below the lowest coil temperature, requiring a considerably stronger brine, with a correspondingly greater reduction in humidity.

Summary

A system capable of adding one gallon of water per hour for each ton of refrigeration, or for each ton of ice melted per day, should be able to maintain up to 95 percent relative humidity under any reasonable conditions.

External-mixing pneumatic nozzles, directly connected to the regular water system, and to an air compressor chosen to maintain suitable pressure while operating continuously, are a standard system. High-pressure water systems need no air compressor but have some disadvantages. Mechanical atomizers are self-contained and are good where the layout allows use of a few rather large units. Cooling the air with cold water provides an automatic high-humidity air supply, but to obtain air below about 34F requires use of weak brine.

Manual control is good if good supervision is available. Automatic controls are better than poor supervision and can operate without any supervision.

Fog-spray nozzles and accessories are known to be available from the following firms. Other names will be added as we learn of them.

Nozzles, strainers and accessories

Delavan Manufacturing Company
Grand Avenue and 4th Street
West Des Moines, Iowa

Harang Engineering Company
Tanforan and Montgomery Avenues
P. O. Box 396
San Bruno, California

Spraying Systems Company
3201 Randolph Street
Bellwood, Illinois

Missimers, Inc.
3737 San Fernando Road
Glendale 4, California

Small high-pressure water pumps

Harang Engineering Company
Tanforan and Montgomery Avenues
P. O. Box 396
San Bruno, California

Hypco Engineering, Inc.
700 39th Avenue, N. E.
Minneapolis 21, Minnesota

Air compressors

Atlas Copco, Inc.
930 Britten Avenue
San Carlos, California

American Brake Shoe Company
1010 Russ Building
San Francisco 4, California

Cal-State Distributors
735 East 14th Street
Oakland, California

Ingersoll-Rand Company
11 Broadway
New York, New York

Automatic humidity controls

El-Tronics, Inc.
Warren Pennsylvania

The Foxboro Company
Foxboro
Massachusetts

Hydrodynamics, Inc.
939 Selim Road
Silver Spring, Maryland

Minneapolis-Honeywell Regulator Co.
1402 "E" Street
Sacramento 14, California

Refrigeration Machinery Corporation
1024 East Anaheim
Wilmington, California

Pipe-heating cable and accessories

Electro-Trace Corporation
285 Riverside Avenue
Westport, Connecticut

General Electric
Wiring Device Department
Providence 7, Rhode Island

Centrifugal Humidifiers

The Bahnson Company
1001 South Marshall Street
Winston-Salem, North Carolina