Bulletin No. 543
August 1975

Drying and Humidification of Hops

Larry G. Williams
Richard R. Romanko

Agricultural Experiment Station
UNIVERSITY OF IDAHO
College of Agriculture

The Authors

Larry G. Williams is associate profession, Department of Agricultural Engineering, University of Idaho, Moscow, and Richard R. Romanko is associate research professor, Parma Research and Extension Center.

Acknowledgement: The authors acknowledge Robert Batt for his cooperation during the 1970 tests, Wilder Farms, Inc., for its cooperation during the 1972 tests, and the Hop Administration Committee for providing humidification equipment.

Published and distributed by the
Idaho Agricultural Experiment Station
R.J. Miller, Director

University of Idaho College of Agriculture
Moscow 83843

Drying and Humidification of Hops

Larry G. Williams and R. R. Romanko

Hops grown in the United States suffer from excessive cone shatter, caused largely by the type of drying system used. Hops must be dried from approximately 75% moisture to about 8½% moisture before baling. Underdried hops will have a short storage life and will be susceptible to rapid deterioration. Overdried hops will have excessive cone shatter and a more rapid loss of alpha-acid during storage, resulting in lower market value.

Hops in Idaho are dried in conventional batch kilns at depths from 24 to 36 inches. High air-flow rates up to 50 cfm/ft^2 at temperatures up to 150°F are used to obtain rapid drying, although this results in non-uniform hops excessively dry on the bottom and wet on top. Continuous dryers are popular in Europe and may eventually replace most of the batch type kilns in the U.S. since they are capable of more uniform drying. But the cost of conversion is so high that few producers can justify the change.

Conditioning the hops by humidification after drying or during the final drying is one solution to overdrying. Since the investment for humidification equipment again is high, requirements for humidification equipment should be determined accurately.

1970 Tests

Pilot hop conditioning tests were run to study humidification and to monitor commercial kilns at the Robert Batt farm in Wilder. Performance of a continuous belt-dryer was observed at Sardis, B.C.

Two small 5 x 5 foot kilns were constructed to study the overdrying problem with conventional kilns. Heated air — supplied by an oil-fired crop dryer at a rate of approximately 40 cfm/ft^2 — was delivered through separate ducts to each kiln. A centrifugal type humidifier, which was capable of increasing the humidity to approximately 55% at 100°F, was installed in one of the ducts. Manual adjustment of the water pressure to the humidifiers controlled humidity.

From hop samples taken from 4 layers in each bin after drying, the moisture content and tendency for cone shatter were determined. Additional samples were taken following the humidification treatment on one of the bins. Cone shatter was measured using a conventional rock tumbler operated 4 minutes with 4 spherical lead weights inside.

During the first runs, hops were dried to an average moisture content of about 8% before humidification began, then the hops were humidified from 1 to 2 hours. Since getting undisturbed samples was difficult for moisture and shatter tests, only limited information was obtained. The shatter test proved too severe compared to typical losses in handling.

Performance tests were run on conventional 32 x 32 foot 2000 pound capacity kilns at the Batt farm over a 4-day period. Air was supplied at 50 cfm/ft^2 at temperatures from 140° to 150°F. After drying 7 hours, the average drying efficiency[1] was 50% (Fig. 1).

A German-built, continuous belt dryer was observed at Sardis, B.C. The dryer was approximately 20 feet tall, 10 feet wide and 80 feet long. Five 8 foot wide conveyor belts, each about 75 feet long operating in a series, carried the hops from the top of

[1]Efficiency was defined as the amount of moisture removed, divided by the amount of moisture which could be removed if the discharge air had been saturated.

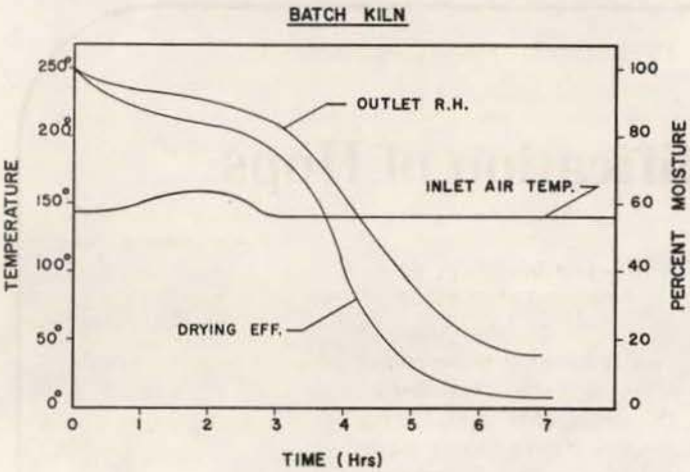

Fig. 1. Typical performance data for the commercial batch kiln.

the dryer at one end to the bottom of the dryer at the other end. The belts operated at slightly different speeds so the depth could be different on each conveyor. Design depths from top to bottom are 10, 7½, 12, 14 and 16 inches. After reaching the end of one conveyor, the hops were guided down to the next conveyor without disturbing the layer, so the hops on top of one conveyor would be on the bottom of the next conveyor.

Air, entering along the side of the dryer below each belt, was fed to the bottom 3 belts at the rate of 40,000 cfm at 120°F, and air at the same rate except 150°F was supplied to the top 2 belts. All air was discharged from the top of the dryer through 8 exhaust fans. The rated capacity of the dryer is 5000 pounds per hour of green hops, with the hops remaining in the dryer 4½ hours. Since hops were fed into the dryer at an 8 inch depth instead of the rated 10 inches, actual capacity was nearer 4000 pounds per hour.

Although the continuous dryer is capable of delivering a uniform product with closely controlled moisture content, the drying efficiency is approximately the same as for the conventional kiln (Fig. 2). Cones still tend to shatter with the belt dryer, but not nearly so severely as with conventional kilns. Losses are lower with the belt dryer because of easier unloading.

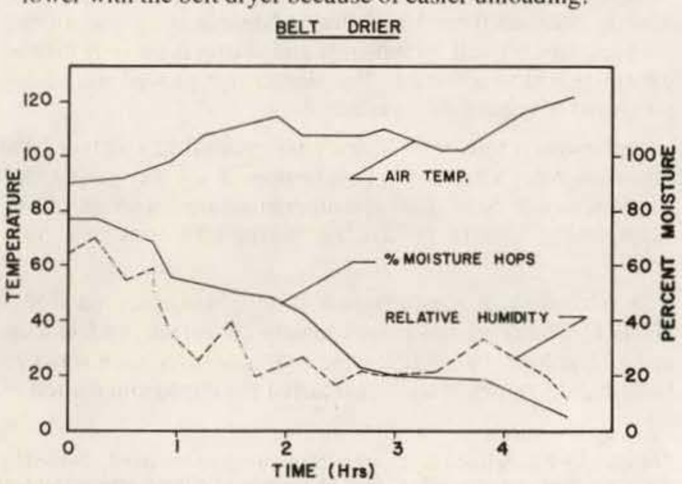

Fig. 2. Performance data for the continuous belt-type dryer.

1971 Laboratory Humidification Tests

Two model tray dryers equipped with humidification equipment were built for the 1971 tests (Fig. 3). Each dryer had 13-10 x 14 inch trays, each capable of holding 2 inches of hops, or a total depth of 26 inches. This represents the lower half of an actual kiln. Electrical resistance heaters were installed in the air supply duct between the fan and the tray dryer. An evaporated cooler was installed ahead of the fan to provide moist air for the humidification treatment.

Fig. 3. Model tray dryer used to simulate a conventional hop kiln.

Rheostats controlled temperature and air-flow rates and air temperatures were monitored throughout the dryers using thermocouples. Relative humidity measurements were also made at the inlet and exhaust air ports. Both dryers were made of sheet metal and insulated on all sides to minimize heat loss through the walls.

The model dryers were used for 2 drying and humidity tests at the Parma Research and Extension Center (Table 1). For test 1, both dryers were filled with 200 grams of green hops per tray and the air-flow rate was adjusted to 65 cfm. The air temperature was maintained at 155°F for the first hour, then reduced to 140°F. After drying, one of the treatments was humidified 2 hours using 75°F air at 65% relative humidity at an air-flow rate of 34 cfm.

A crush test was performed to determine relative shatter losses which normally occur when the hops are removed from the large batch kilns and during any subsequent handling and baling. About 10 grams of hops placed between 2 plywood plates were compressed under about 50 pounds force for 10 seconds. The whole hops were hand sorted from the badly broken hops and weighed.

Since drying time was not equal in the 2 dryers in the first test, treatments are not comparable. The "dried only" treatment was dried excessively because the elimination of moisture content could not be visually monitored.

For test 2, the procedure was altered to insure uniform treatment. Alternate trays in both dryers were used as one treatment and the remaining trays for the second treatment. Other procedures and conditions were the same as the first test.

Test 2 demonstrated how humidification can reduce shatter loss and attain a more uniform moisture content. Figure 4 compared the final moisture content for humidified and unhumidified hops from test 2 and figure 5 compared shatter losses for test 2.

Positive results are difficult to consistently obtain, especially for a commercial kiln because moisture content varies and knowing when to cease drying and begin humidification is difficult to measure.

Two additional tests were conducted at the University of Idaho using hops shipped from Parma. The procedures were the same for test 2 and test 3 except air-flow rate for both drying and humidification was 75 cfm. Test 3 was most successful for moisture control.

Hops that had been frozen were compared with conventionally dried hops in test 4, using the same test conditions. The test tried to prove that freezing would rupture the cell walls in the strig, resulting in more rapid moisture removal. The results:

	Frozen Dried	Frozen Humidified	Dried	Dried Humidified
% Moisture content	8.3	8.3	7.7	8.9
% Crush test loss	76	72	51	40

Frozen and unfrozen hops were allowed to naturally air dry at 75°F before being crushed. Shatter loss was 50% for the frozen hops and only 7.7% for the unfrozen hops. While the drying time was decreased for the frozen hops, shatter loss was excessive.

1972 Hop Humidification Tests

Research during the 1972 season was directed toward finding an economical and practical method for humidifying hops in commercial kilns. Important criteria considered in the design were:

1. The humidification system should be capable of raising the relative humidity to about 70% when ambient conditions are around 90°F. This will allow a significant amount of moisture to be added to the hops.
2. Humidification treatment time should be short to not interfere with present management practices.
3. The system should be relatively simple, requiring neither a lot of time nor special technical skills from the operator.

Preliminary calculations indicated that up to 150 gph of water would be required to raise the relative humidity of the plenum air to 70% in a typical air-flow rate of 50,000 cfm at 90°F. Residual heat from the kiln would increase this figure. Since reducing the air-flow rate of the main fan was impractical, an auxiliary air supply system of about 5000 cfm was used for humidification.

Three types of humidification equipment were installed and tested in a commercial kiln at Wilder Farms Inc. — centrifugal humidifier in the supply duct, air atomizer nozzles in the plenum and furnace nozzles both in the supply duct and plenum. For 10 tests the main fan was run for half an hour after the heat was off to cool the kiln. A 1-to 2-hour humidification treatment followed, using approximately 5000 cfm from the auxiliary fan. Measurements were taken of the following:

1. Air-flow rate.
2. Ambient air temperature and relative humidity.
3. Temperature and relative humidity of the plenum and discharge air.

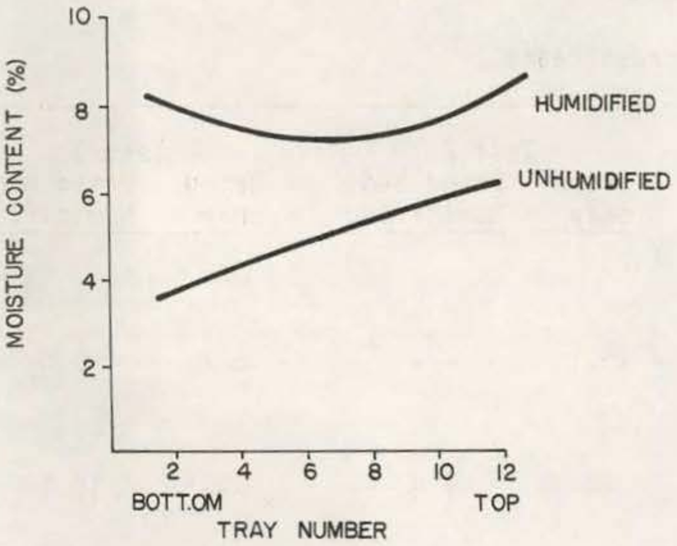

Fig. 4. Comparison of final moisture content variation for humidified and unhumidified hops from test 2.

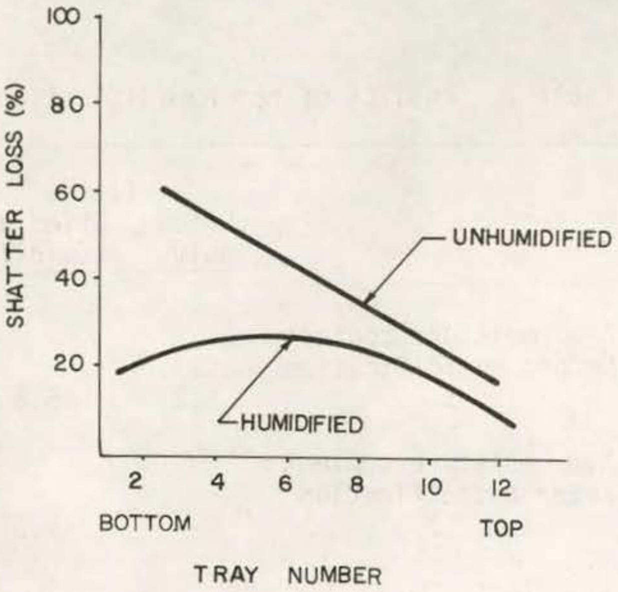

Fig. 5. Comparison of shatter loss variation for humidified and unhimidified hops for test 2.

4. Limited number of hop samples for shatter loss and moisture gain.
5. Moisture content of the baled hops.

Amounts of water supplied to and absorbed by the hops were calculated from psychrometric relationships (Table 2).

Centrifugal Humidifier

A Bahnson Type L centrifugal humidifier rated at 12 gph supplied moisture for tests 1 and 2. This unit was installed in a 4 x 4 x 8 foot duct located between the auxiliary 5000 cfm fan and the kiln. Air entering the kiln was near saturation. However, residual heat from the kiln lowered the relative humidity to 35-50% by the time it entered the kiln. Moisture had to be added directly in the kiln.

Pneumatic Atomizers

Six Bahnson Type ESC pneumatic atomizers were installed on opposite walls of the kiln to supplement the moisture from the centrifugal fan. The atomizer had a rating of 12 pounds per hour each at 28 psi water pressure and 1.5 cfm of air at 52 psi. Atomization was very poor, and since time was critical, the use of the air atomizers was abandoned.

Furnace Nozzles

In a preliminary test 4 old furnace nozzles supplied moisture at the intake of the auxiliary centrifugal fan. Satisfactory atomization was obtained even at 50 psi,however, larger droplets formed because of the interference of the spray patterns. Since the nozzles were satisfactory, simple and inexpensive, 16 of them were mounted in the plenum to supply 15 gpm at 100 psi.

Tests 4 – 10 used the furnace nozzles or a combination of the centrifugal humidifier and furnace nozzles. Air came from the auxiliary fan for all but test 6, which used the main fan.

The old furnace nozzles used for the test were mounted vertically about 4 feet above the plenum floor and distributed uniformly around the plenum. Nozzle ratings ranged from 0.85 to 2 gph. Their performances were satisfactory using pressures of 40 psi and over. Some of the larger nozzles leaked water on the kiln floor but not enough to be a problem.

Nozzle Rating

Flow rate from the nozzles was controlled by varying the water pressure. Later calibrated, the nozzles were found to

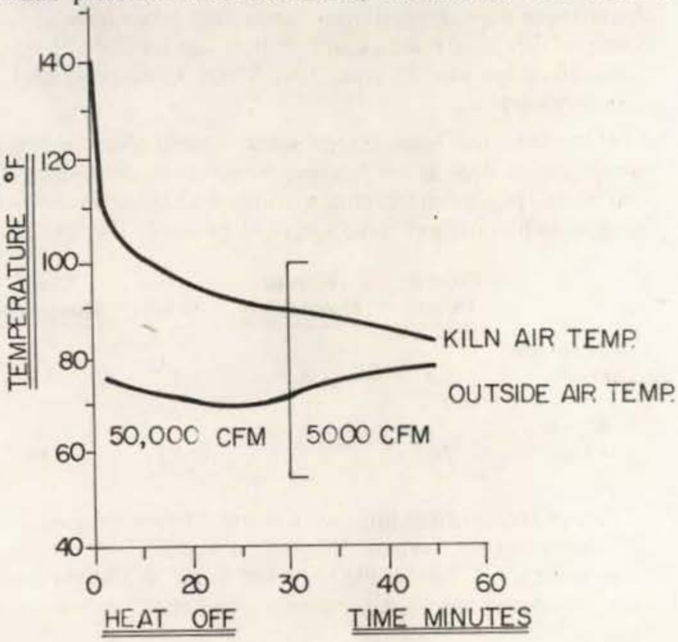

Fig. 6. Cooling rate of a kiln for test 6.

Table 1. Results of hop humidification and crush tests.

	Test 1		Test 2		Test 3	
	Dried only	Dried and humidified	Dried only	Dried and humidified	Dried only	Dried and humidified
Ave. moisture content before humidification %	5.2	5.6	5.1	---	8.7	8.5
Ave. moisture content after humidification %	---	9.3	---	7.8	---	10.1
Ave. loss from crush test %	61	27	37	22	63	37

deliver their rated flow at about 200 psi. The flow rate at other pressures varied directly with the square root of the pressure. Rating for a 1 gph nozzle was:

psi	gph
50	.5
100	.7
150	.9
200	1.0
300	1.2
400	1.4

Kiln Residual Heat

The residual heat from the kiln influenced the water requirement for humidification (Fig. 6). In test 7 the main fan was on the first 30 minutes and water was added at the rate of 15 gph immediately after the heat was off. Water had negligible effect on the kiln cooling time. Later the auxiliary fan pumped 5000 cfm of air and water was added at a rate of 24 gph. There was a 20°F difference between the ambient air and the kiln air temperatures after 30 minutes of cooling. Other test temperatures ranged from 11° to 20°F.

Table 2. Summary of the 1972 humidification tests.

Test	Ambient Temp (°F)	Ambient RH (%)	Humidification method	Water (gph)	Time (hr)	Plenum RH (%)	Plenum Temp (F)	Bale M.C. (%)	Comments
1	55	35	centrifugal	7	1.25	50	68	6-7	Although the centrifugal humidifier could raise the duct RH to nearly 100%, the maximum humidity in the kiln was only 35-50% due to residual kiln heat.
2	66	35	centrifugal	9	2	35	73	8.5	
3			air nozzles centrifugal	no data taken					Air nozzles could not be adjusted to obtain a fine mist
4	85	38	centrifugal furnace nozzles	6 13	2	65-70	85	9.0	Water was turned on when heat turned off. Bales had uniform moisture content. Operators and owners felt shatter was reduced.
5	75	46	centrifugal furnace nozzles	8 15	1.5	70	80	8.5-9.0	
6	85	32	furnace nozzles	15	2	35	92	7.5	Main fan used at about 40,000 cfm. Negligible humidification effect.
7	72	30	centrifugal furnace nozzles	9 15	1	65-90	78	7.5-8.0	Attempt to use a high humidity for a short treatment time.
8	80	30	centrifugal furnace nozzles	10 15	1.25	70-90	90	8.0	High humidity treatment showed some discoloration upon later examination.
9	80	30	centrifugal furnace nozzles	10 15	1.25	70	87	---	
10	60	75	furnace nozzles	11	1.5	75	70	---	Humidification treatment followed rain. Non-uniform drying due to blow holes.

Water Requirement

Water requirement depends on amount of water in the ambient air, residual kiln heat, humidification air-flow and desired relative humidity. Water requirements calculated from the test data for an air-flow rate of 5000 cfm are:

1. Water to overcome residual kiln heat — 10 to 15 gph.
2. Additional water to reach 70% RH for the following ambient conditions:

Temp (°F)	RH (%)	gph
90	25	11.0
90	30	9.1
80	30	8.0
70	30	7.2
70	40	4.1
70	50	3.4
60	50	3.0
60	60	1.7
50	60	1.5
50	70	0.0

Total water required - Maximum 26 gph @ 5000 cfm
Minimum 10 gph @ 5000 cfm

Rate of Moisture Pick-Up

To determine the rate of moisture pick-up by the hops, subtract the difference between the water content of air leaving and of air entering the hops. Moisture pick-up was from 5 to 6% per hour in test 5, 8 and 9. Samples taken above and below the hops indicated the rate of moisture pick-up was 1 to 2% per hour. Readings above the hops probably were in error because the outside air mixed with the discharge air.

Hop Quality

Humidified and unhumidified hops had few differences. Cone shatter was reduced about 10% and moisture content of the bales was more uniform for the humidified hops. When humidities were above 70%, some discoloration was observed.

Conclusions and Recommendations

1. Humidification can reduce shatter loss, resulting in more uniform and controlled moisture content. Since the moisture content is better controlled, the hops can generally be marketed at a higher moisture content without exceeding the maximum allowable moisture content.
2. Humidification takes 1 to 2 hours more time in the kiln.
3. An auxiliary air flow-rate of 5000 cfm is the most practical method of humidification.

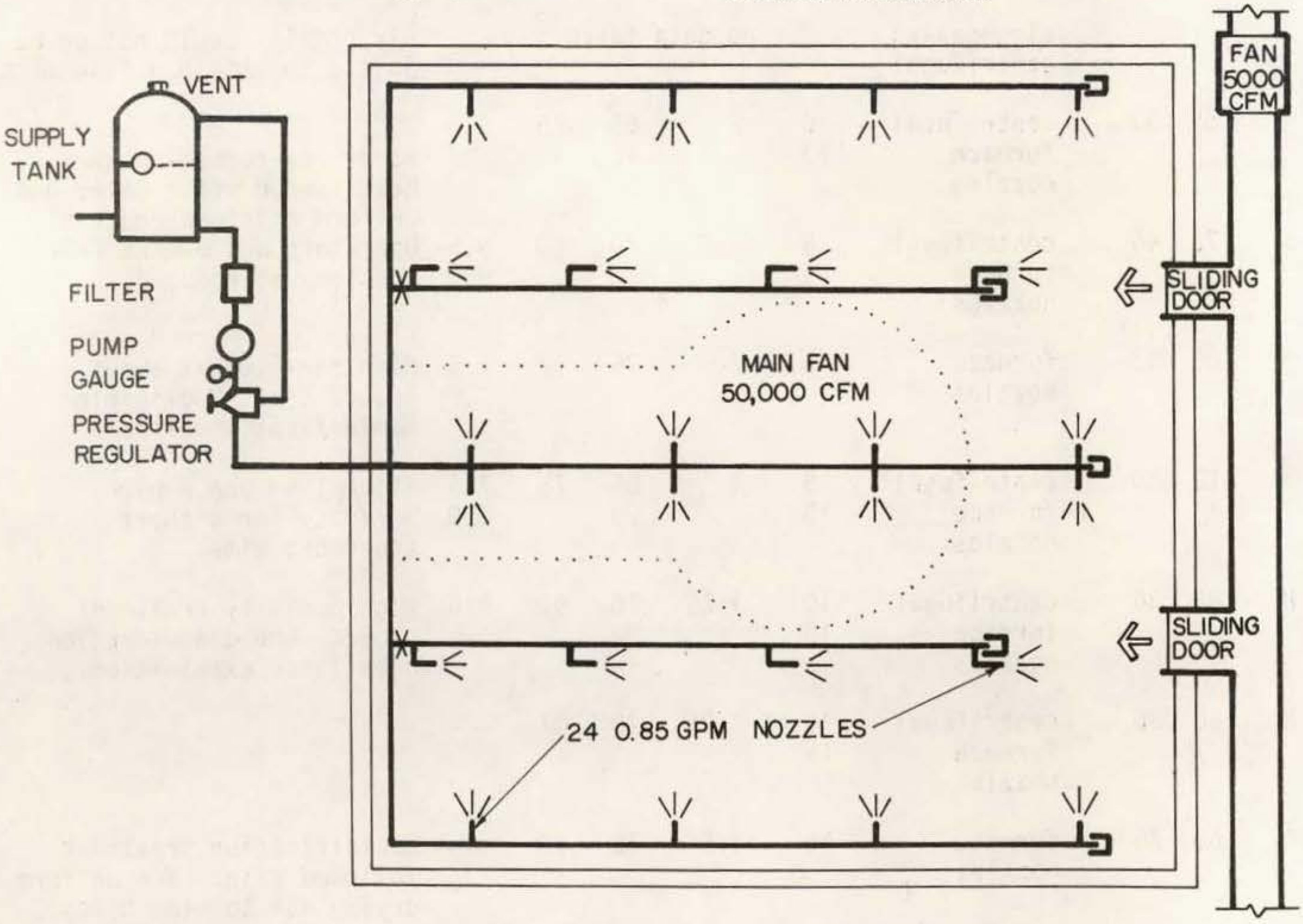

Fig. 7. Hop humidification system.

4. Moisture content above allowable levels is possible without careful management when humidifying above 60% RH.

Suggested Humidification System

A humidification system using furnace nozzles allows the water to be added inside the kiln to raise the relative humidity to 70% even during hot, dry weather. One air and 1 water system can supply 4 kilns.

By opening the 2 sliding doors, an auxiliary fan brings in air for humidification through a control duct. Water comes from 24 furnace nozzles mounted horizontally about 2 feet below the drying floor. The nozzles are pointed upward to allow the mist to be in contact with the air as long as possible. A high pressure pump supplies the water. Required for the system are:

Nozzles: 24 with screen filters and adapters for standard pipe with 0.85 gph rated flow. The total system will deliver from 10 gph at 50 psi to 28 gph at 400 psi.

Piping: ⅜-inch pipe is recommended.

Pump: Piston pump capable of delivering 1 gph at 500 psi.

Gage: 0 — 500 psi.

Pressure regulator: Equipped with by-pass value capable of manual pressure regulation from 50 to 400 psi.

Filter: Capable of removing any foreign material that could plug the system.

Tank: Any small storage tank which can be equipped with a float valve. The storage tank can be omitted if the by-pass water is wasted.

Fan: Capable of delivering 5000 cfm at ½ inch static pressure.

Supply duct: 2 x 2 foot galvanized metal duct with slidegates.

Humidity indicator: A dial-type relative humidity indicator inserted through the kiln wall and read from the outside. Since most indicators will not withstand extremely hot, dry air, they should be used only after the heat is off.

Humidity control: Control the rate of water application manually using the pressure regulator valve as dictated by the relative humidity indicator. Automatic control systems can operate a control valve with a modulating motor similar to the furnace temperature control. Protect the sensor from high temperatures.

Operation

Although the water can be turned on immediately, the main fan should be operated ½ hour after the heat is off. After the large fan is off and the sliding doors open, start the humidification treatment using the auxiliary fan. The humidity indicator also can be inserted a few minutes after the heat is off. Adjust the pressure regulator for the desired humidity and, since the water requirements will vary during the treatment, adjust the regulator occasionally.

Cost

Estimated cost of materials for the manually controlled humidification system to equip 4 kilns is $1000 to $1500, or about $300 per kiln.

REFERENCES

Henderson, S. M. 1958. Some Hop Drying Studies. Univ. of California Agr. Exp. Sta. Bull. 762.

Henderson, S. M. 1971. Hop Drying, The Unique Problems and Some Solutions. Paper presented at the ASAE National Meeting. Washington State University, Pullman.