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PRELIMINARY STUDIES ON COOLING PAD EFFICIENCY

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At the request of the CFGA Research Committee, we began evaluation of evaporative pads this summer. After devising a method to calculate pad efficiency, our studies show two main advantages with the newer impregnated paper pads such as Kool-Cel and Cel-Dek: 1) High air velocities can be achieved through the new pads with less difficulty while still maintaining efficiency. 2) There is no problem with pad uniformity as commonly occurs with aspen pads. Efficiency of all pads varies with the volume of air moved through them. In general, the 4-inch thick Kool-Cel was about 5% less efficient than the 6-inch Cel-Dek — if the latter was properly installed. The 4-inch Cel-Dek's efficiency dropped off rapidly to about 70% at air flows in excess of 350 CFM/sq.ft. A compressed aspen pad was usually more efficient than a 2-inch aspen, and permitted an air flow of about 330 CFM/sq.ft. at 0.1-inch suction, as contrasted to 260 CFM/sq.ft. at the same suction for the 2-inch aspen. A 6-inch Cel-Dek mounted backwards compared favorably with a 4-inch Kool-Cel. However, a Kool-Cel pad can be mounted without regard to sides, whereas care must be taken to mount the Cel-Dek properly for maximum efficiency.

Materials and methods

Samples of 4-inch Kool-Cel and 6-inch Cel-Dek were obtained through the courtesy of Acme Manufacturing Company and Munter's Corporation. Four-inch Cel-Dek was obtained by cutting 2-inches from a 6-inch sample. New samples of aspen pad were mounted to provide a 2-inch thick test section, or compressed to approximately one-inch thickness.

These samples were attached to a three-foot long wind tunnel so that one square foot of pad area was exposed for testing. A variable speed suction fan was mounted at the opposite end of the tunnel, and the apparatus placed inside a room to reduce vagrant wind movements that could effect readings inside the tunnel at low velocities.

Temperature measurements employed thermistor units that were matched. Trials with a sensing unit inside the tunnel showed no significant effect of position on temperature measurement until the bulb was within one inch of the downstream side of the pad. Measurements with any given pad material were generally restricted to mid-day and early afternoon. The fan speed was set to provide a given air flow, and after the air velocity had stabilized, a series of instrument readings were taken in succession to provide 4 sets of data for that wind speed providing: 1) inside dry bulb temperature, 2) outside dry bulb temperature, 3) inside wet bulb temperature, 4) outside wet bulb temperature, 5) inside dew point temperature 6) outside dew point temperature, 7) wind velocity inside the tunnel, and 8) pressure differential between inside and outside the wind tunnel. Outside wet bulb temperatures were checked with an Assman psychrometer, using matched thermometers mounted in an aspirated, double-shielded cover.

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Calculating pad efficiency

The purpose of a cooling pad is to evaporate water. There may be some cooling of a warm air stream by conduction to cold water in a pad, but this is minor. Evaporation of one ounce of water, however, will cool 1000 cubic feet of air approximately 3.4°F. It requires about 61.9 BTU to evaporate one ounce of water, and the heat to do so is extracted from the air which has a heat capacity of 0.018 BTU per cubic foot per degree Farhenheit.

Therefore, water is added to the incoming air and there will be higher humidity on the downstream side of the pad. The outside wet bulb temperature, which has been commonly used to determine pad efficiency can never be achieved no matter how well the pad does its job. Secondly, if a pad cools the air to within one degree of the inside wet bulb temperature, that one degree difference results in higher efficiency if the air is cooled 20 degrees as compared to 10 degrees. So determination of cooling efficiency must take into account inside wet and dry bulb temperatures as well as outside wet and dry bulb temperatures. Outside wet and dry bulb temperatures show potential cooling, and a measurement of inside wet and dry bulb indicate how well that potential was achieved.

To arrive at pad efficiency, calculated as a percentage, for this study, we employed the following formula:

$$\left(1-\frac{\text{Inside dry bulb temperature} - \text{Inside wet bulb temperature}}{\text{Outside dry bulb temperature} - \text{Outside wet bulb temperature}}\right)$$

100 = percent pad efficiency.

If at any time the numerator is zero, pad efficiency is 100%. As the denominator becomes larger, however, for any given value in the numerator, efficiency rises. This method compensated for variations in conditions at which each pad was tested. Outside dew points varied from 60°F to 43°F, and outside dry bulbs varied from 80°F to 92°F.

In our calculations, we were able to compare efficiencies calculated from psychrometric measurements versus dew point measurements. On the average, efficiency obtained from dew points was one to two percent higher than those obtained by wet and dry bulb readings. As dew point is a basic measurement of absolute vapor concentration, and is subject to less error, we had more confidence in dew point. We have employed dew points in place of wet bulb temperatures in presenting the results.

Results

The most striking differences between the various pad materials were obtained when we compared air flow through cooling pads and the suction necessary to achieve that air flow (Fig. 1). Two-inch aspen had the highest resistance to air movement above wind speeds of 75 CFM/sq.ft., followed by compressed aspen. All other materials allowed much higher air volumes at lower suctions. As greenhouse exhaust fans are generally rated for capacity at 0.1-inch suction, the significance of these differences is readily apparent. From the curves we calculated theoretical air movement at suctions of 0.01, 0.05 and 0.1 inches, and these are shown in Table 1. At low suctions, the newer pad materials usually provided double the air per square foot of pad area of the aspen pads. The recommendation of 150 CFM/sq.ft. of aspen in sizing cooling pads for a greenhouse is a safe design as either type readily permits that volume with safety. Kool-Cel and Cel-Dek requirements as to area can be reduced by at least one-third. We suggest, on the basis of this preliminary data, that area can be based upon a maximum air volume of 300 CFM/sq.ft. This is not the recommendation of the manufacturers.

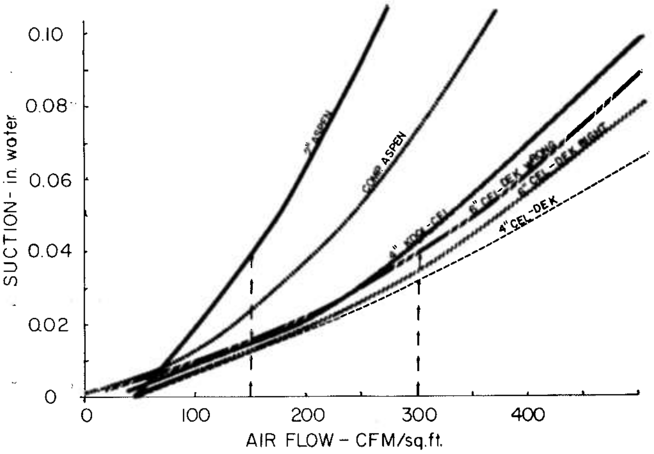

Fig. 1: Relationship between air velocity through different evaporative pads and suction. These are calculated curves with correlations exceeding 0.95, where 1.0 is perfect. The vertical arrows indicate 150 CFM/sq.ft. recommended for aspen pads, and the 300 CFM/sq.ft. that may be suggested for the newer paper pads.

Table 1: Calculated cubic feet per minute per square foot of pad area delivered at different fan suctions.

Pad	Suction (in water)		
	0.01	0.05	0.10
Kool-Cel, 4-in. thick	112	334	457
Cel-Dek, 4-in. thick	134	413	578
Cel-Dek, 6-in. thick, right side in	133	384	471
Cel-Dek, 6-in. thick, wrong side out	106	357	458
Aspen pad, 2-in. thick	74	172	260
Aspen pad, compressed to 1-in.	79	253	334

Note that these values were calculated from curves similar to those shown in Fig. 1.

Table 2 presents the actual average efficiencies measured for each pad material at the three stated wind velocities. For some reason, for which we have no definite explanation, aspen pads showed peak efficiencies of 96% at air flows of around 100 CFM/sq.ft., and dropped off on either side of that condition (Fig. 2). In contrast, all the paper pads showed steadily declining efficiency as wind speed increased (Fig. 2). This latter behavior was logical. It may be that non-uniformity of the aspen could be considered as a reasonable cause for the differences.

Calculated efficiencies are provided in Table 3 for the air volumes of 150 and 300 CFM/sq.ft. One can note that at 150 CFM, aspen pads should provide greater efficiencies than the paper pads at 300 CFM. Against this lower rating, one must balance the fact that fewer square-feet of pad should be required; the new pads, if maintained, should not deteriorate; and the new pads should last considerably longer than aspen.

Table 2: Average percent pad efficiencies at three air flow rates. Each value in the body of the table is an average of 4 measurements.

Pad Type	Air flow (CFM/sq.ft.)			Mean
	44	88	176	(All air flows)
Kool-Cel, 4-in. thick	96.5	90.2	87.1	92.3
Cel-Dek, 4-in. thick	99.8	91.3	82.2	91.1
Cel-Dek, 6-in. thick, right side in	99.5	98.5	94.9	97.6
Cel-Dek, 6-in. thick, wrong side out	98.5	94.1	89.2	93.9
Aspen pad, 2-in. thick	93.0	96.0	88.5	92.5
Aspen pad, compressed to 1 inch	92.5	96.0	89.2	93.6
Mean (all pads combined)	96.6	94.9	89.2	93.6

NOTE: For individual comparisons in the table, there must be a 5% difference between any two comparisons for statistical significance. For comparisons between pad types, regardless of wind speed, there must be a 2.2% difference between values. For comparisons between flow rates, all pads combined, there must be a 1.3% difference for statistical significance.

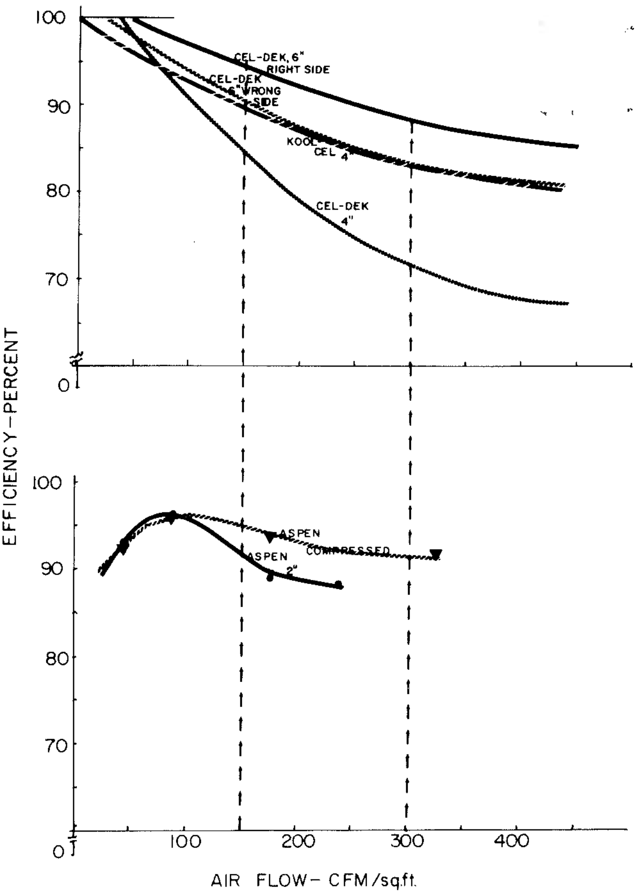

Fig. 2: Effect of air velocity through one square foot of different evaporative pads on percent efficiency. Note: The curves for aspen pads were drawn in contrast to the others which were calculated statistically. The actual mean values are shown for the aspen. The vertical arrows show air flows of 150 and 300 CFM/sq.ft. Note that suctions required to achieve those air flows are about the same for both aspen and the new paper pads.

This study employed small samples of evaporative pads under an ideal situation. One cannot expect as high efficiencies under actual greenhouse conditions where infiltration may significantly reduce the amount of air pulled through pads. A ten percent loss may not be uncommon in the usual commercial greenhouse. This has not been tested, but the grower should take it into account when deciding pad installation.

Table 3: Calculated evaporative-pad efficiency when air flow is 150 and 300 cubic feet per minute per square-foot of pad area.

Pad Type	Air flow (CFM/sq.ft.)	
	150	300
Kool-Cel, 4-in. thick	89.5	83.1
Cel-Dek, 4-in. thick	84.4	71.5
Cel-Dek, 6-in. thick, right side in	94.3	88.3
Cel-Dek, 6-in. thick, wrong side out	90.2	83.0
Aspen pad, 2-in. thick	91.0	(86.0)*
Aspen pad, compressed to 1 inch	94.9	(91.0)*

*Note that these are calculated values derived from Fig. 2. It is doubtful that 300 CFM/sq.ft. air flow can be achieved through aspen pad unless suctions are 0.1 inches or higher.