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7 NOV 1972

Water Droplet Dispersions from Spinning Disks For Evaporative Cooling

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ACCEPTABLE environment control in plant and animal structures requires control of solar and biologically produce heat. Ventilation alone often is not sufficient to maintain the desired temperatures during hot days, so some form of cooling is advantageous. Due to the magnitude of the cooling loads in such structures and the problems encountered with dirt collection on the cooling coils of mechanical cooling units, evaporative type cooling has proven to be a practical form of environmental modification.

Three methods of evaporative cooling have been used: namely, exhaust fans with wetted pads in the opposite wall, pressure fans pulling air through wetted pads and discharging the cooled air into the building, and high pressure mist nozzles within pressure or exhaust ventilated spaces. Well designed wetted pad systems normally can cool the air only 85 percent of the difference between the wet bulb and dry bulb air temperatures. The spray nozzle systems have a higher potential efficiency, and in high humidity areas where maximum cooling would be important, such a high efficiency would be desirable.

The high pressure mist nozzles have the disadvantage, however, in that it is difficult to vary the flow rate to correspond to environmental changes and still maintain fineness of drop size. These systems also have the difficulty that small orifices are used which are subject to plugging unless fine particle filtration is provided.

REVIEW OF LITERATURE

With most atomization systems, droplets are formed with a variation in size which is assumed to be normally distributed (Fraser et al, 1957; Nelson and Stevens, 1961; Tate and Janssen, 1965 and Turner and Moulton, 1953). Walton and Walker (1970), in a study of the trajectory of evaporating water droplets in a horizontal air stream, reported that droplets 100 microns in diameter will theoretically fall approximately 5 ft in an ambient environment of 90 F and 40 percent relative humidity before they evaporate. The literature suggest the total distance of vertical fall is highly dependent on the initial droplet size, and small increases in the diameter will significantly increase the distance of fall.

If complete evaporation is desired, the larger droplets in a normal dispersion would be the critical drops since they would fall the greatest distance before evaporating. From a practical viewpoint, total evaporation would not be essential as long as the floor or occupants of the building were not wetted to the extent that the surfaces were actually dampened.

Relationships defining droplet diameter as a function of disk speed, disk radius, surface tension of the liquid, and density of the liquid were proposed by Pattison and Aldridge (1957) and Walton and Prewett (1949). Neither of these investigators considered water flow rate to be an influencing variable.

A more complex relationship was proposed by Friedman, et al (1952), which included flow rate as a variable;

$$\frac{D}{r} = 1.2 \, {\frac{\Gamma}{\rho n r^3}}^{0.6} \, {\frac{u}{\Gamma}}^{0.2} \, {\frac{\sigma \rho L}{\Gamma^2}}^{0.1} \quad \ldots\ldots\ldots [1]$$

where

Γ = the feed rate per length of wetted periphery in lb per min-ft,

u = the viscosity of the fluid in lb per ft-min,

D = the droplet diameter in ft,

r = the disk radius in ft

n = the disk rotation rate in rpm,

ρ = the fluid density in lb per cu ft,

σ = the surface tension of the liquid in lb force per min-min

L = the wetted periphery of the disk in ft.

If standard values of 62.14 lb per cu ft for ρ, 574 lb force per min-min for σ and 0.0404 lb per ft-min for μ are subtiituted in the above expression and if w/L, where w is the total disk flow rate in lb per min, is substituted for Γ the following expression is obtained:

$$D = 0.1256 \, \frac{w^{0.2}}{r^{0.3} \, n^{0.6}} \quad \ldots\ldots \ [2]$$

In developing their relationship, Friedman et al (1952) utilized experimental data from a number of different disk configurations. In particular, the data they report when discussing the determination of the effect of flow rate were predominately with grooved or serrated edge disks. Their data points for smooth plane disks were erratic and neither supported nor contridicted the proposed exponent of 0.2. In discussing their test results, they also indicate that the effect of disk radius was not fully evaluated and primarily proposed the exponent shown because of dimensional analysis considerations.

In the above-mentioned relationship, it is assumed that there is no circumferential slip between the disk and the water. Pattison and Aldridge (1957) in discussing plane disks indicates that slippage does occur and is most noticeable as flow rates are increased. Since the relationship proposed by Friedman et al (1952) was developed primarily from data on vaned disks where slippage would not occur, it would be of questionable value for plane-smooth disks, particularly, as the flow rates were increased.

EXPERIMENTAL INVESTIGATIONS

Determination of Droplet Size Relationship

Since plane-smooth disks are simple to fabricate and provide small droplet dispersions, it was decided to restrict the investigation to such disks. Specifically, the experimental investigations were conducted to determine the usefulness of the equations proposed by Friedman et al (1952) to describe the maximum droplet size and to determine how the exponents in the equation

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Article was submitted for publication on November 5, 1971; reviewed and approved for publication by the Soil and Water Division of ASAE on March 6, 1972.

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The investigation reported in this paper (No. 71-2-130) is in connection with a joint project of the Kentucky Agricultural Experiment Station, University of Kentucky and the Agricultural Engineering Research Division, ARS, USDA, and is published with the approval of the Director of the Station and the Division.

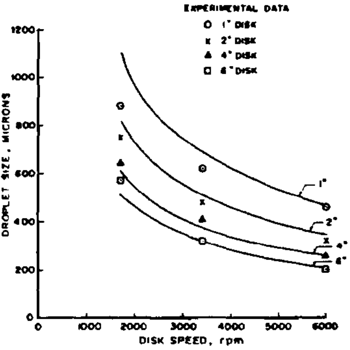

FIG. 1 The effect of disk speed on maximum droplet size for 1, 2, 4 and 6-in. radius disks at a 1.5 lb per min flow rate.

needed to be changed, if at all, to obtain valid predictions.

The investigations conducted consisted of operating four disk sizes (2, 4, 8, and 12 in. in idameter), at three speeds (1,700, 3,400 6,000 rpm), at four flow rates (0.75, 1.5, 3.0 and 4.5 lb per min), and measuring the droplets as they leave the edge of the disk. The disks were fabricated from stainless steel. The edge of the disk was a sharp edge with the face sloping away from the top edge at a 45 deg angle. Water was metered through a nozzle which was positioned over the center of the disk.

Droplet size was determined by the procedures outlined by Turner and Huntington (1970). This consisted of coating Kodak bromide paper with bromophenol blue dye and, after drying, exposing these papers to the mist leaving the disk edge. Upon exposure the mist droplets impacting on the paper left a clearly discernible circular dot on the paper. The three largest dots in each paper were measured and, by use of a conversion coefficient, the droplet diameter was determined. The three values so obtained were averaged to obtain the maximum droplet size.

The theoretical droplet size was also determined by use of equation [2]. Theoretical values ranged from 1,256 to 241 microns. The relationship tended to overestimate droplet size for the experimental conditions which resulted in small droplets and tended to underestimate droplet size when large droplets were generated.

Using the same equation form as suggested by Friedman et al. (1952), a multiple regression analysis was performed on the data, which resulted in the following equation:

$$D = 0.1797\ \frac{w^{0.158}}{r^{0.431}\ n^{0.678}} \quad \cdot\cdot \quad [3]$$

The standard deviation of predicted values using equation [3] was determined and found to be 123.6 microns.

The exponents for the terms in equation [3] differ from those in equation [2] to some extent. Most notably the regression expression indicated that the effect of both flow rate and disk radius upon droplet size was less than that proposed by Friedman et al (1952). It should be recalled that in the study conducted by these investigators, much of the data were obtained from vaned disks where slippage and method of droplet formation would be different from what it would be for smooth disks such as were used in this study. The results of this study are more consistent with the results reported by earlier investigators who reported little effect of flow rate upon droplet size until flow rates became large and who reported droplet size to vary with the 0.5 power of the disk radius.

When a goodness of fit is determined for this experiment using equation [2], the standard deviation increased to 141.8 microns. To obtain the visual representation of the effects of disk radius and disk speed, the data for the 1.5 lb per min flow rate were plotted as shown in Fig. 1. The theoretical prediction curves as computed from equation [3] for each disk size is also shown. To illustrate the effect of flow rate upon droplet size, the data for the 4-in. radius disk were plotted as shown in Fig. 2. The small effect of flow rate upon droplet size is apparent by the small separation of the curves for the various flow rates. Similar curves could have been plotted for the other treatment combinations. In both curves, the accuracy of prediction increased as the disk speed increased.

Based upon the results of this investigation, it was the conclusion of the authors that equation [3] can be used to predict the maximum size droplets which are generated by the size of smooth plane disks used in this study and which are operated at the higher disk speeds and at the flow conditions which were evaluated.

Evaluation of Water Fallout

To determine the maximum droplet size which would not result in significant wetting, a series of experiments were conducted with 1 1/2 in., 2 1/2 in. and 4 in. radius disks rotating at 3,400 and 6,000 rpm. In these studies, the disks were enclosed in a housing so water could only leave from a 20 deg arc of the disk. This was necessary to reduce the total amount of water misted into the air stream below that necessary to saturate the air. The air stream velocity passing the disk was measured and found to vary from 85 to 109 ft per min. The air temperature and relative humidity were controlled to 90 F and 37 percent respectively. Four levels of water flow to the disks were used; 0.75, 1.5, 3.0 and 6.0 lb per min.

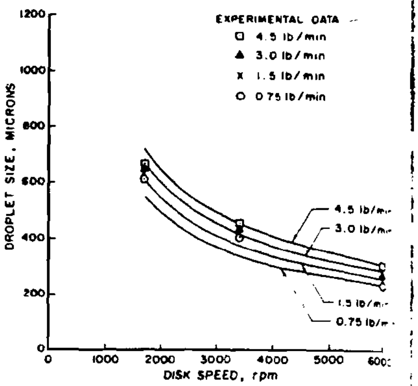

FIG. 2 Effect of disk speed on maximum droplet size for flow rates of 4.5, 3.0, 1.5 and 0.75 lb per min for a 4-in. radius disk.

The disks were positioned 5 ft above the floor. Square pieces of blotter paper, 6 x 6 in., were placed radially 1 ft apart from a point directly below the disk outward in a direction parallel to the air stream direction. The disks were then operated until a total of 20 lb of water was sprayed with the 1.5, 3.0 and 6.0 lb per min flow rate, and 10 lb of water was sprayed with the 0.75 lb per min flow rate. The pieces of blotter paper were weighed prior to initiation of a test run and weighed again immediately after the desired total water flow had been sprayed. The weight gain for all pieces of blotter paper was added to obtain a relative measure of the total fallout. Three replications of each test condition were conducted. The averages of each test treatment are shown in Table 1. For the 0.75 lb per min flow rate, the measured fallout was multiplied by 2 to obtain a fallout value comparable to the other tests in which twice as much water was sprayed. As shown in the table, the amount of fallout varied considerably with only the 4 in. radius disk operating at 6,000 rpm showing relatively low fallout. Using equation [3], the theoretical droplet size for each test condition was determined, and the values obtained are shown in Table 1. For the environmental test conditions, a theoretical maximum droplet size of 257 microns or less would appear desirable if water fallout is to be minimized.

TABLE 1. WATER FALLOUT IN GRAMS AND THEORETICAL MAXIMUM DROPLET SIZE FROM VARIOUS SIZE ROTATING DISKS

Radius, in.	Flow rate, lb per min	Observed water fallout, grams		Theoretical droplet size, microns	
		3400 rpm	6000 rpm	3400 rpm	6000 rpm
4 in.	0.75	88.73	3.66	399	231
	1.5	79.48	4.90	378	257
	3.0	72.33	24.54	422	287
	6.0	89.18	62.19	471	320
2¼ in.	0.75	152.64	61.04	415	282
	1.5	103.93	41.68	463	315
	3.0	144.6	62.88	517	352
	6.0	147.82	82.24	577	392
1½ in.	0.75	71.15	65.91	518	352
	1.5	125.19	83.72	578	393
	3.0	178.90	133.73	644	438
	6.0	182.90	119.70	719	489

SUMMARY

An analysis of the potential methods for evaporative cooling plant and animal enviroments indicated that a high-speed spinning disk which generated fine water droplet dispersions should have several inherent advantages. Such a system would theoretically maintain fine droplet size over a wide range of water flow to the disk and would not require filtered water.

The first phase of the investigations reported were directed towards determining the validity of a theoretical relationship proposed by Friedman et al (1952). For this purpose, a series of tests were conducted with different size smooth disks. It was concluded that the proposed equation was not applicable and regression techniques were used to obtain a revised relationship. The revised relationship gave reasonably accurate prediction of droplet sizes for the higher speeds investigated.

A study of the water fallout indicated that droplet sizes of 257 microns or smaller were necessary if fallout was to be kept minimal. For the range of disk sizes and speeds evaluated in this study, a disk speed of 6,000 rpm or greater was generally required to obtain droplets of this size. At these speeds, the revised regression relationship gave good accuracy.

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Deep Plowing and Chemical Amendment

(Continued from page 684)

SUMMARY AND CONCLUSIONS

Deep plowing and chemical amendments (sulfur or gypsum) improved a Solonetzic soil, slightly increased barley yields, and substantially increased wheat yields under the dryland conditions of western North Dakota. The Rhoades silty clay loam, which had a shallow dense sodic claypan, was plowed initially to 6, 12, and 24-in. depths with and without soil amendments. Split plots were alternately fallowed and cropped for 5 years. Barley was grown 4 years and wheat on the 5th year. Crop yield increases attributed to deep plowing appeared to be associated with greater soil water availability for crop use and for soil leaching. Soil improvement was evidenced by the reduction of bulk densities and lessened saline-sodic soil conditions. Hardness of the soil crust was reduced by deep plowing, and amendments further increased soil friability. The 5th year after deep tillage and amendment treatments, spring wheat yields were 1,170, 1,570, and 1,885 pounds per acre (19, 27, and 34 bushels) for the 6, 12, and 24-in. plowing depths, respectively.

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