6-45-11

THE THERMAL PERFORMANCE CHARACTERISTICS OF LARGE SPRAY COOLING PONDS

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ABSTRACT

In recent years, there has been a renewed interest in determining the performance characteristics of large spray cooling ponds, since the verification of the adequacy of pond design is difficult because of the limited amounts of performance data for large ponds. The results of previous well instrumented tests on a large pond at a nuclear power installation have been published and analyzed over the limited ranges of data for critical parameters. The findings of these tests are briefly discussed.

Testing has recently been performed on a large conventional spray cooling pond presently operating in southern Florida. This spray pond is similar in design to ponds used in nuclear power plants, and its performance characteristics are representative of those ponds. The paper describes the facility and testing procedures, and reports the results of preliminary testing. The new data reported broadens the data base that can be used by engineers to design large fixed piping spray pond systems.

INTRODUCTION

Spray cooling ponds have been used for many years as an efficient and economical means of dissipating waste heat. Past experience has shown that an 8 to 11° C (15 to 20° F) approach to wet bulb temperature for large ponds can be achieved with a straightforward system design which compares quite favorably to alternative waste heat rejection systems when operating costs and maintenance are considered. In applications where a closer approach is required, design modifications result in acceptable system performance, albeit at greater capital and operating costs.

In recent years, spray cooling ponds have been used in the nuclear power industry in safety related cooling water systems (Ultimate Heat Sinks) because of their reliability and adequate performance. However, considerable difficulties have plagued the design effort for spray cooling ponds for two reasons. First, the performance of spray cooling ponds is complex and strongly influenced by numerous variables whose effect on performance can only be described over the full range of variables by computer analyses. Secondly, a limited data base for the performance of large spray ponds makes very difficult the verification of design adequacy, through any means but actual pond performance testing.

It is precisely this lack of adequate performance data for large ponds which promted the investigation reported herein. Tests have been performed on a large spray cooling pond, and the data taken compares well with results of tests performed earlier at Rancho Seco.[1] The objectives of this paper are to briefly discuss factors significant in spray pond operation, to describe the facility tested and the test procedures used, to report test results, to compare the results to those of earlier tests, and to evaluate the needs for further testing.

GENERAL CONSIDERATIONS

There are many design parameters for spray cooling ponds which have significant effects on pond performance. Most important among these are the following; meteorology (including, but not limited to wet bulb temperature and wind velocity), hot water temperature, pond geometry (size, spray unit spacing, and nozzle elevation) and nozzle operating pressure.

Meteorology

Two uncontrollable variables which are dominant in determining spray cooling pond performance are the wet bulb temperature and the wind velocity.

Wet Bulb Temperature

The wet bulb temperature represents the minimum temperature to which a droplet could be cooled if it were allowed to come to equilibrium with its surroundings. However, in a spray cooling pond, the droplet flight time is such that equilibrium is not achieved and the actual temperature of the droplet as it enters the pond is significantly greater than local wet bulb temperature. A frequent practice is to relate the cooling achieved to the ambient wet bulb temperature as an expression of the pond performance.

Wind Velocity

Ambient wind speeds and directions markedly influence pond performance. At zero wind speed, the draft induced by the increased specific volume in and above the spray region over the ambient specific volume results in a supply of fresh air to interior zones of the spray region. As the winds increase, the plume is shifted downwind and the supply of fresh air to upwind portions of the spray region is enhanced. In general, the greater the wind speed, the greater is the availability of fresh air to all zones of the spray region, and the greater is the pond heat dissipation capability.

The wind direction has an important influence on pond performance if the spray region presentation changes with wind direction. For example, if a pond is designed so that the spray region is 91 m. (300 ft) long by 40 m. (130 ft) deep, pond performance will change with wind direction. The cooling will be greatest when the wind is perpendicular to the pond major axis and reduced when the wind is parallel to the major axis. In any case, however, the degree of cooling achieved will not be less than that for low wind speeds.

Hot Water Temperature

The slope of the water vapor pressure versus temperature curve increases monotonically with increasing temperature. Therefore, the potential for evaporation, with a given difference between hot water and wet bulb temperatures, is markedly greater when the hot water temperature is higher. Since the cooling resulting from spray cooling systems is dominated by that resulting from evaporation, performance in spray cooling ponds is more effective at higher hot water temperatures. Also, the higher hot water temperature and evaporation rate lead to increased induced air flow under low wind conditions.

Pond Geometry

Geometry factors which influence pond performance include pond size, spray unit spacing and nozzle elevation.

Pond Size

As the size of the spray region increases, the ratio of spray region perimeter to spray region area decreases. Since availability of fresh air is determined largely by the perimeter, the cooling which can be achieved per unit of sprayed mass decreases as the pond size increases. The practical effect of increased pond size is that droplets from the spray units located in the interior zones of the spray region are exposed to a degraded environment (with increased moisture content). The cooling of the droplets in interior zones is less than the cooling of droplets from spray units in exterior zones of the spray region where the moisture content of the air is nearer the ambient moisture content. The overall effect is that the average cooling achieved per unit mass sprayed decreases with pond size, even though the total cooling increases.

Spray Unit Spacing

As the spray unit spacing is increased, the availability of fresh air to each spray unit is increased such that each spray unit behaves more nearly like an isolated spray unit with an unlimited availability of fresh air. Thus, pond performance improves with increased spray unit spacing.

Nozzle Elevation

Increasing the nozzle elevation above the water level increases the droplet flight time and therefore increases the cooling of the droplets, though this effect is less significant than the previously mentioned geometric factors.

Nozzle Pressure

The pressure at which the nozzle operates influences droplet cooling because of two effects; the shift of droplet size distribution and a change of droplet flight time.

Droplet Size Distribution

As the nozzle pressure is increased, the droplet size distribution is generally shifted to smaller sizes. The energy in a droplet is proportional to its volume. However, heat transfer is governed by droplet surface area and since the ratio of area to volume increases as the droplet decreases in size, the cooling potential is greater for smaller droplets.

Droplet Flight Time

As the nozzle pressure is increased, the droplet exit velocities increase resulting in longer flight times and, as previously discussed, produces greater droplet cooling.

TESTING PROGRAM FOR THIS INVESTIGATION

This section will discuss the facility at which these tests were performed, the variables which were monitored, the testing procedure and results.

Test Facility

The facility at which these tests were performed is located in southern Florida where wet bulb temperatures are generally high. However, during the time when the testing was performed, unusually cool temperatures existed so performance data at higher wet bulb temperatures were not obtained.

The spray region is 101 m. (330 ft) long by 49 m. (160 ft) wide with the pond major axis oriented perpendicular to prevailing winds. The spray units consisted of 4 nozzles on 1.5 m. (5 ft) spray arms and a fifth nozzle on the junction box, except for spray units on the two exterior rows, which lacked the fifth nozzle. The spray units were spaced 4.0 m. (13 ft) apart on the rows which were separated by 7.6 m. (25 ft).

The spray flow rate varied from 2,780 l/sec (44,000 gpm) to 3,030 l/sec (48,000 gpm) at pressures of 69,000 Pa (10.0 psi) and 82,000 Pa (11.9 psi), respectively. The heat load was approximately 73.3×10^6 watts (250×10^6 BTU/hr).

The pond is oriented so that prevailing winds are perpendicular to the pond major axis.

Variables Monitored

In order to establish the performance characteristics of the spray cooling pond the following ambient variables were monitored; wind speed, wind direction, wet bulb temperature, and dry bulb temperature. In addition, the hot water temperature, the cooled water temperature, and the pond water temperature were recorded at appropriate times.

Testing Procedures

In the present tests, batch samples of cooled water were collected just as the droplets were about to enter the pond water, at several points within the spray region. The batches were collected in covered insulated containers which were located appropriately before the cover was removed for the collection time. The ambient conditions of wind speed and direction and dry bulb and wet bulb temperatures were recorded during the collection time and the batch temperatures, hot water temperature and pond water temperatures were measured and recorded immediately after each batch was collected. The hot water temperature changed slowly enough that no significant error was induced by not measuring this temperature simultaneously with batch collection.

During much of the testing, rather high winds dominated, which improved droplet cooling. Although it had been an objective to examine the degradation of pond performance as a function of depth into the spray region parallel to both the major and minor axes, these higher winds made edge effects much more significant, i.e., cooling around the perimeter perpendicular to the wind direction was markedly enhanced by the winds. Therefore, the degradation of cooling performance was examined only through the center of the spray region parallel to the pond minor axis.

The degradation data obtained are presented graphically in Figure 1. The edge effects are clearly visible from curves A and B. Intuition suggests that as the edge of the spray region is approached from interior zones, the rate of change of cooling achieved decreases due to a reduced rate of moisture addition to ambient air.

As winds increase, improved performance is observed deeper into the spray region from the upwind edge, and then cooling falls off rapidly. As the wind speed decreases to low values and the induced draft becomes the dominant air flow mechanism, the cooling at the downwind edge of the spray region increases relative to the cooling in the interior zones. This effect is shown in curves B and E of Figure 1.

As a matter of interest, several temperatures have been shown in Figure 2. An approach of approximately 10° C (18° F) was achieved, with a cooling range of about 7° C (13° F).

RESULTS OF PREVIOUS TESTING

Numerous spray pond tests have been performed to determine design performance. However, most of those tests were not instrumented well enough to provide data that can be used to gain significant insight into the effect of various parameters on performance. The only well instrumented testing that has been performed is that at the Rancho Seco Nuclear Power Plant of Sacramento Municipal Utility District in California. The results of that testing were presented in a report by the University of California, Berkeley, California. [1]

The tests done at Rancho Seco were instrumented comprehensively but were limited to a maximum hot water temperature of about 38° C (100° F). The results of the Rancho Seco tests [1] are presented in Figure 1 showing spray efficiency as a function of position in the spray region. The dependence of spray efficiency on wet bulb temperature is not indicated explicitly in the results, but the results do indicate the magnitude of efficiencies that can be expected at various depths into the spray region.

Although the spacing of the spray units was the same in both designs, the Florida pond had nearly twice the sprayed area, and almost twice the depth of spray region in the direction of the wind. The increased depth of spray region in the direction of the wind provides a better base for degradation data. Spray efficiency in the Florida testing was measured at six locations through the spray volume to quantify degradation, while the Rancho Seco tests apparently included three measurement points to describe degradation.

The results of the Florida testing indicate that a large spray pond may be expected to have spray efficiencies varying between 60% and 35% depending on position in the spray region and on the wet bulb temperatures and wind conditions.

CONCLUSIONS

The Florida tests significantly expanded the data base by providing data at higher nozzle pressure and for a higher water loading than those characterizing Rancho Seco. Even though these tests did not significantly expand the range of performance data with respect to hot water and wet bulb temperatures, the results of these tests reinforce the validity of the Rancho Seco tests. However, further testing needs to be performed with hot water temperatures in the range of 49° C (120° F) to 54° C (130° F) and with wet bulb temperatures in the range of 21° C (70° F) to 27° C (80° F) in order to provide actual operating data in design ranges similar to those encountered in conventional and nuclear Ultimate Heat Sink applications.

Since numerous mathematical models have been developed to predict spray pond performance outside the ranges where data exist, additional testing should be performed in order to demonstrate the credibility of these models.

REFERENCES

1. Schrock, Virgil E. and Trezek, George J., Rancho Seco Nuclear Service Spray Ponds Performance Evaluation, University of California, July 1, 1973.

TABLE 1. COMPARISON OF VARIABLES CHARACTERIZING TEST FACILITIES

		Florida	Rancho Seco
Spray Flow Rate	(l/sec)	2,780	1,010
	(gpm)	44,000	16,000
Sprayed Area	(m^2)	4,910	2,920
	(ft^2)	52,800	31,400
Nozzle Pressure	(Pa)	69,000	48,300
	(psi)	10	7
Nozzle Elevation	(m)	2.1	1.5
	(ft)	7	5
Nozzles per Spray Unit		5*	4

*See sub-section "Test Facility"

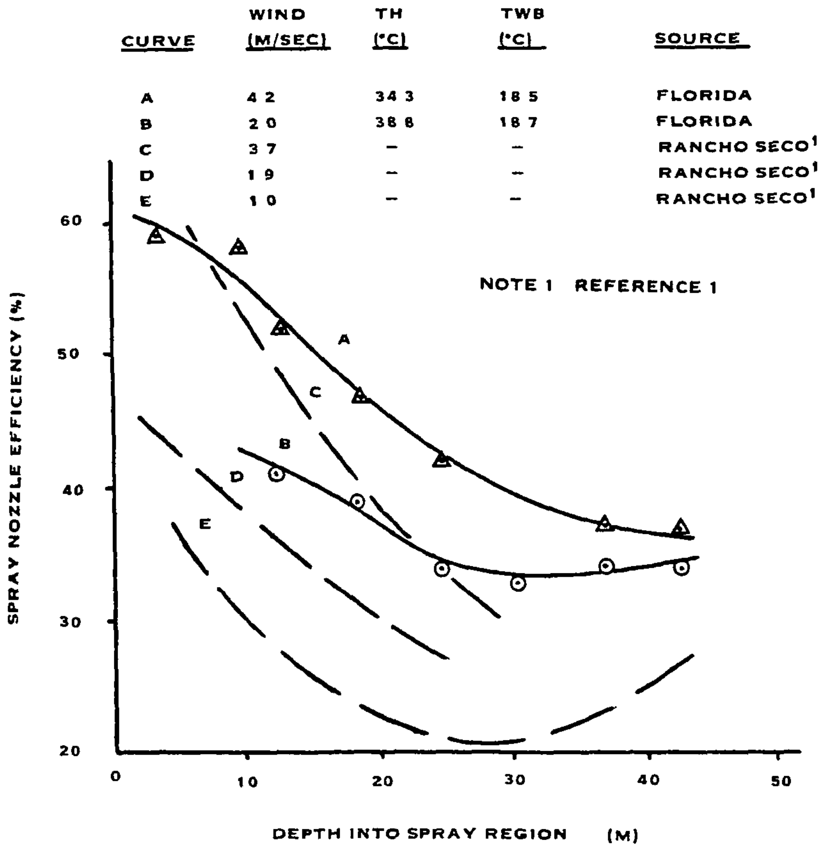

FIGURE 1 DEGRADATION OF PERFORMANCE WITH DEPTH INTO SPRAY REGION

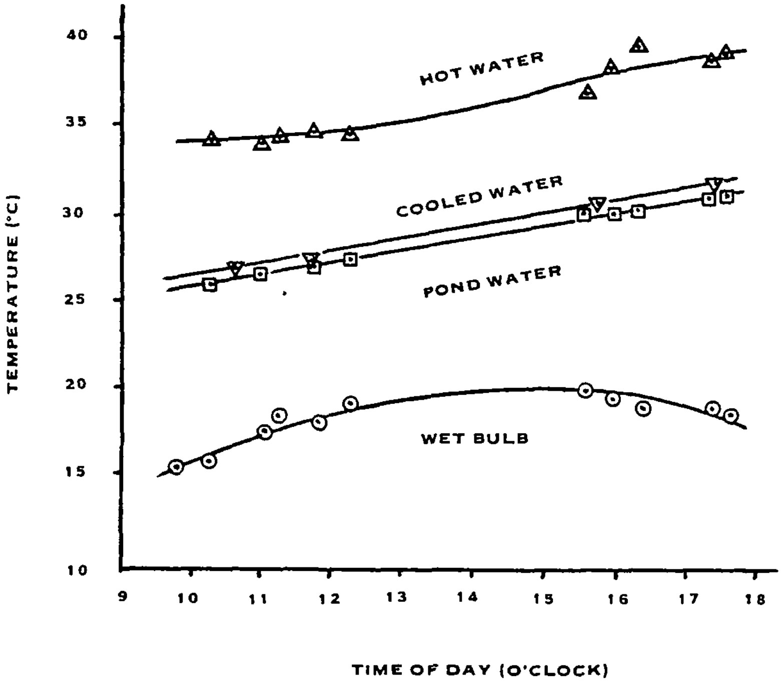

FIGURE 2 TEMPERATURES AS A FUNCTION OF TIME OF DAY