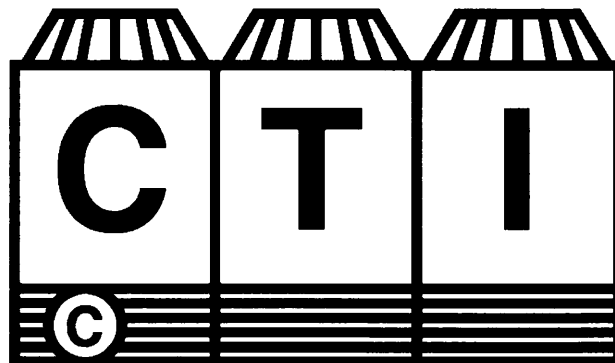


COOLING TOWER INSTITUTE

RECIRCULATION



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RECIRCULATION

Introduction

Recirculation in water-cooling towers has been defined as "an adulteration of the atmosphere entering the tower by a portion of the atmosphere leaving the tower." (2)* This adulteration by the exhaust air raises the wet bulb temperature of the entering air above that of the ambient air, reducing the tower over-all performance.

The recirculation phenomenon arises primarily because of the negative pressure produced on the leeward side of the cooling tower by the wind blowing across the structure. Thus, any factors which enhance this lee-side negative pressure will increase recirculation. At the same time, those elements of tower design or meteorological phenomena which increase the amount of ambient air which mixes with the exhaust air before entering the lee-side air inlets will reduce the magnitude of recirculation. Recirculation is therefore a complex result of factors which affect the lee-side negative pressure and the amount of exhaust air dilution.

The purpose of the work reported herein was to determine which factors of tower design and meteorological conditions influence the amount of recirculation that occurs, and to determine the effect of recirculation upon tower performance. As corollary results of the work, a simplified method of allowing for recirculation in the selection of design wet bulb temperature is presented, and recommendations concerning tower orientation to minimize recirculation are given.

History

The earliest reference in the literature to the problem of recirculation appears to be by Lichtenstein (1) in 1943. He stated: "Recirculation occurs under unfavorable wind conditions when part of the hot discharge air of the tower is sucked back by the forced draft fans into the tower, uniting with the fresh air,

raising the air entering wet bulb temperature, and so reducing the tower performance." He further indicated that the recirculation is less in induced draft towers than in the forced draft arrangements because of the greater discharge air velocity in the induced draft designs.

In 1951, Lichtenstein published a paper (2) outlining the recirculation problem mathematically and pointing to the need for quantitative measurement on actual installations in order to obtain the data necessary to permit the design of installations to allow for recirculation.

The Cooling Tower Institute activated Technical Sub-Committee #2 in 1951 and the committee began the selection, design, modification and preliminary trial runs of instruments and test procedures to obtain these data on operating industrial water-cooling towers. Actual field testing was begun in the spring of 1954.

Meanwhile, cooling tower development work which included a wind tunnel study of the recirculation problem was being conducted in England. The conclusions reported in the British literature (3) in 1956 were that recirculation is a function of the ratio of wind velocity to tower discharge velocity; that fan stacks 30 ft high had no appreciable beneficial effect; that raising the tower on stilts 30 ft did not show any improvement; and that cross winds of 8 to 10 mph represented the worst condition for recirculation, a condition at which a very long tower could be expected to recirculate a maximum of 8 per cent.

Procedure

Thirty cooling towers of various manufacture were tested in the TSC#2 study. Physical dimensions and descriptive information on these towers are given in Table 1.

Included were 2 forced draft towers, 7 cross-flow towers, 4 coilshed towers, and 17 counter-flow towers. Of these, 14 towers were of back-to-back cell ar-

rangement and 16 of straight-line cell arrangement. Tower lengths varied from 36 ft to 361 ft; tower widths from 13 to 68 ft; tower frame heights from 19 to 55 ft; fan diameters from 8 to 22 ft; fan stacks heights from 4 to 17 ft. Eleven of the towers had fan stacks taller than the standard 4 to 6 ft height. Measured exhaust air velocities varied from 165 fpm (for one of the forced draft designs) to 2005 fpm.

A description of the instruments and methods has been published (4) and will not be repeated here. A list of the items reported for each test is included in the Appendix. Each tower study consisted of 6 tests of 75 or 80 minutes each over a 3- to 5-day period. Water and air temperatures and wind direction and velocity were recorded at 5-minute intervals, giving a total of 15 or 16 readings per test for each variable.

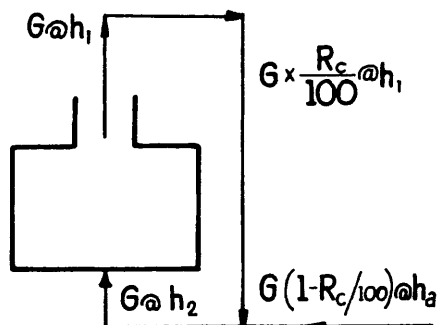
For each test, a plot was prepared with reading number or time as the abscissa and water temperatures, wet bulb temperatures, wind velocity and direction as ordinates. Examination of this plot gave a visual indication of whether the test period represented steady-state or nearly steady-state conditions. If any sudden change or erratic character was noted in the heat load, ambient wet bulb temperature or wind velocity or direction, the erratic portion of that test, or (rarely) the entire test, was omitted in arriving at test averages. A wind shift across the long axis of a tower was allowed where it occurred only momentarily and did not appreciably affect the windward-leeward relationships of inlet wet bulb temperature readings. In the majority of cases, the entire series of test readings was considered usable. Two plots illustrating edited tests are shown in Figure 1.

For purposes of evaluating the tests for recirculation, a summary sheet (see Figure 6) was prepared for each tower, showing the arithmetic average of data taken for each test, test averages and calculations. Psychrometric data for the calculations were taken from charts and tables in the ASHAE Guide.

*Numbers in parentheses refer to literature listed in "References."

Calculations

From the mathematical standpoint, recirculation can be expressed as the per cent of the exhaust air which re-enters the tower at the air inlets. Thus, considering a heat balance on the air around the tower:



$$Gh_2 = G(1 - R_c/100)h_a + G(R_c/100)h_1$$

Solving for R_c :

$$R_c = \frac{h_2 - h_a}{h_1 - h_a} \times 100 \quad \dots (1)$$

In applying Equation (1) to the test data, the average *windward* wet bulb temperature was considered to be more representative of the ambient air state than the single ambient station readings. The former represented the average reading of 5 psychrometers spaced along the windward side of the structure, and the latter a single psychrometer which gave readings that were sometimes slightly higher and sometimes slightly lower than the average windward readings, but the differences were in all cases small and would have little effect on the final correlation. In those few cases where the wind direction made it difficult to distinguish between leeward and windward sides of the structure, the side having the lower average wet bulb temperature was considered the windward side.

Strictly speaking, h_2 in Equation (1) should be the *weighted* average inlet air enthalpy, taking into account the air flow and the wet bulb temperature at each inlet measuring station, with the stations located to completely traverse the air inlet area. However, due to the variable nature of the atmosphere and other outside influences, the simultaneous measurement of inlet air velocity and wet bulb temperature at each location was found to be impossible in field tests on large cooling towers. The *arithmetic* average of the wet bulb tempera-

tures read on both sides of the structure at the air inlets was therefore used to determine the enthalpy of the entering air.

Correlation

For correlation purposes, only that test which gave the maximum recirculation percentage for each tower was used. Because only 6 tests were run on each tower, it is recognized that the maximum recirculation reported for a given tower may not represent the true maximum which could be obtained under more adverse conditions of wind direction and velocity. On the final correlation, therefore, those test points which fall sub-

stantially below the curve drawn can be given less consideration on the basis that they do not represent a maximum recirculating condition.

Table 2 lists the average values of all principal variables from the test giving maximum recirculation on each tower. These average data, together with the tower physical characteristics given in Table 1, comprise the entire data used in the correlations.

As a starting point for determining possible correlating variables, the maximum per cent recirculation for each tower was plotted against a number of suspect variables including tower length,

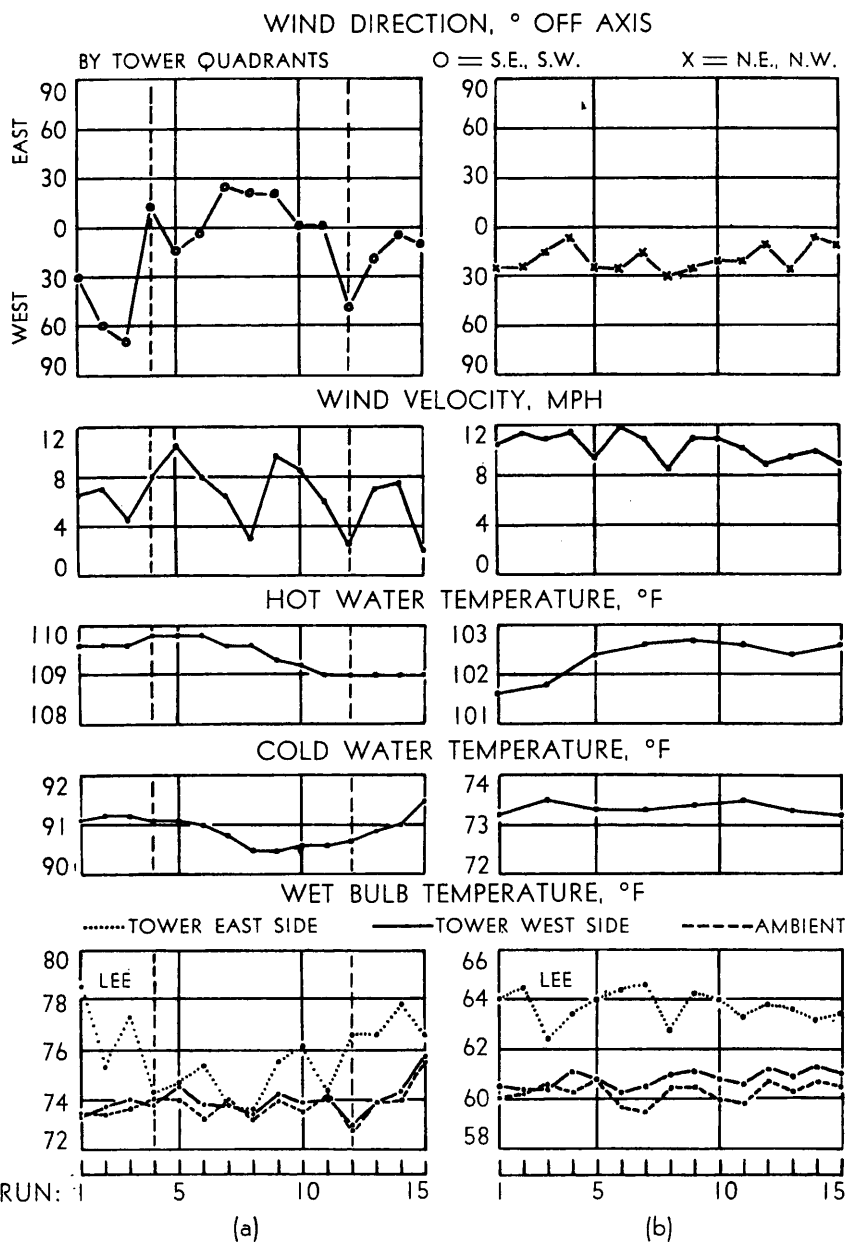


Figure 1. Typical plots of test variables. (a) Runs 4 through 12 used in test averages; shifting wind direction was reason for omitting other runs. (b) All runs used in test averages.