COOLING TOWER WINDAGE: A NEW ASPECT TO ENVIRONMENTAL ASSESSMENT¹

F. G. Taylor and S. H. Park²

Environmental Sciences Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

MASTER

ABSTRACT

DISCLAIMER

This work was prepared as part of work sponsored by an agency of the United States Government. The Government is authorized to reproduce and distribute reprints for government purposes, not withstanding any copyright notation that may appear hereon. It is understood that any copyright, trademark, or other right in any article, product, or process disclosed herein shall inure to the benefit of the United States Government. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

During the past decade the environmental impact of cooling tower drift on terrestrial environments has been a major consideration. Recent studies at the Paducah, Kentucky, Gaseous Diffusion Plant suggest that there is also a significant potential for aquatic impacts. Blow-down at the Kentucky and Oak Ridge Gaseous Diffusion Plants (ORGDP) is engineered for zero chromate discharges to receiving streams by either chromate reduction or chromate recovery procedures. Past operating experiences at the Paducah facility without chromated discharges resulted in violations of National Pollutant Discharge Elimination Systems (NPDES) permit standards for hexavalent chromium for which remedial action has since been taken. These episodes of noncompliance have been associated with high winds, cold weather, and tower operation without fan-induced draft. Under these circumstances, cooling water is lost from the sides of the tower instead of from the top as with drift, and transported to streams as runoff. This loss of cooling water, termed

¹Research sponsored by the Office of Health and Environmental Research, U.S. Department of Energy, under contract W-7405-eng-26 with Union Carbide Corporation. Publication No. ____, Environmental Sciences Division, ORNL.

²Thermal Systems Development Section, Oak Ridge Gaseous Diffusion Plant, Oak Ridge, Tennessee 37830.

By acceptance of this article, the publisher or recipient acknowledges the U.S. Government's right to retain a non-exclusive, royalty-free license in and to any copyright covering the article.

"windage," may impact the water quality of the regulated streams. Operating experiences at Paducah provided the impetus to quantify windage losses from the ORGDP cooling towers. Data are presented for the K-861 and K-892J towers under varying meteorological conditions, and the potential for NPDES noncompliance is discussed. Windage was measured volumetrically (effective windage) and calculated (true windage) from the total chromium residue present in each sample and the measured chromium concentration in the recirculating water system. A comparison between the two methods indicates that effective windage may introduce a significant bias due to evaporation (up to 30%) in assessing the chemical mass deposited. In a worst case example (wind gusting from 4 to 7 meters/second) windage losses from the new 78,000 gpm "J" tower ranged from 108.4 liters/m²/hr at 0.5 meters distance to 0.9 liters/m²/hr at 4 meters. This represents approximately 4500 gallons per hour. Estimates of true windage are derived from measured windage by correction for evaporation and thus is the more appropriate parameter for estimating total chemical release and for determining possible noncompliance with NPDES standards. Results of the research also have implications for power utilities since a common practice to prevent cooling tower icing is to operate without fan-induced draft.

INTRODUCTION

Recirculating cooling water (RCW) systems at Department of Energy (DOE) contractor-operated gaseous diffusion plants in Kentucky, Ohio, and Tennessee require the addition of a chromate, zinc-phosphate corrosion inhibitor for protection of copper in cooling condensers. For

optimum protection a 20 ppm chromate concentration is maintained. During evaporative cooling cycles dissolved solids concentrate in the recirculating cooling water and must be removed to prevent scaling and deposition on heat exchangers. This is typically accomplished by periodic blowdown to receiving streams. Since the blowdown stream contains the same chemical concentrations as the recirculating cooling water system, cooling tower effluent constitutes a potential for impacts on water quality and stream biota.

In 1974 plant liquid effluents from DOE facilities were regulated to meet the National Pollutant Discharge Elimination System (NPDES) permit limits for hexavalent chromium by 1977. Before July of 1977 blowdown from the several cooling towers at the Paducah facility was discharged to Big Bayou and Little Bayou Creeks, and to the Clinch River at Oak Ridge. At that time (1977) blowdown treatment was engineered for zero chromate discharges through a recovery-recycle softener procedure at Oak Ridge and a chromate reduction procedure at Paducah (C-616 Plant Liquid Effluent Pollution Control Facility). The recovery-recycle system uses lime and soda ash (softening) to reduce calcium hardness and ionic polymers for clarification. Chromate concentration is unaffected by the softening with the resultant sludge returned to make-up clarifiers for recycle (Koteski and Vaughn, 1979). At Paducah hexavalent chromium is reduced to trivalent chromium by addition of ferric sulfate to the blowdown effluent and subsequently precipitated in a clarifier using lime. The clarified water is discharged to a settling lagoon before releasing to Big Bayou Creek.

In September of 1977 chromium concentrations in Little Bayou Creek occasionally exceeded permit limits (0.05 ppm Cr^{+6}), even though there were no discernable chromate discharges to the creek (Conrad, 1979). These episodes of non-compliance with NPDES standards were associated with high winds, cold weather, and tower operation without fan-induced draft. Operation of the cooling towers without fans is sometimes effected to maintain a minimum required temperature for the enrichment cascade. Under those conditions, it was noted that the loss of cooling water from the sides of the towers was detectably greater than during operation with fans on. Water lost in this manner, termed "windage" (Conrad, 1979), was found to be greater from newly constructed towers (counterflow) designed for high performance fill, than from the older, cross-flow towers. Windage water was subsequently transported to streams as runoff where water quality was adversely impacted. As an abatement strategy, wind screens were placed in the new towers and concrete aprons were constructed to reduce windage losses.

The results of the field studies at Paducah provided the impetus to determine if windage was also a problem at Oak Ridge and to assess the potential for compliance with NPDES standards. A series of field studies were conducted at the Oak Ridge K-25 plant's new 78,000 gpm K-892J tower and the new cell added to the K-861 tower during varying meteorological conditions. Aside from being site-specific, the data have generic application for power utilities since a common practice to prevent cooling tower icing is to operate without fan-induced draft.

METHODS

In studies conducted at the Paducah site, windage water was collected as wetfall along a distance gradient from the tower base and the results were expressed as precipitation (cm depth per hour). Sample collections were made at Oak Ridge by placing 50 ml of distilled water in glass collectors (12 cm dia. x 6 cm deep) at distances of 0.5, 2, 4, and 10 meters from the K-892J tower (Fig. 1) and at 0.5, 2, 4 and 8 meters from the K-861 tower. In a test of cell 17 only (add-on to K-861) sampling stations were arranged to 10 meters distance. The blank solution was added to each collector to prevent adherence of the chromium residue to the collector surfaces and possible error in subsequent chemical analyses. Depth (height of the water column) was calculated from the relationship of the volume, less than 50 ml blank, to the diameter of the collector, and termed effective wetfall windage. Pilot studies indicated that evaporation might be an important consideration in volumetric determinations. Since evaporative processes would not affect the total chemical residue in the samples, true windage volume was calculated from the total chromium present in each sample, and the measured chromium concentration of the recirculating water system. Each water aliquot was analyzed by atomic absorption spectrophotometry with graphite furnace attachment for microdeterminations. Results were expressed as true wetfall windage (cm depth/hr) and windage flux ($\text{liters/m}^2/\text{hr}$).

ORNL-DWG 80-11386

Figure 1. Windage sampling locations adjacent to the K-892J cooling tower. Drawing is not to scale.

RESULTS

The initial windage study was conducted in December 1979 at the newly constructed K-892J tower, which is of a counter-flow design, and consists of eleven cells utilizing high performance fill packing. The long axis of the tower is oriented east and west. The tower is 100 meters long, 12.8 meters wide, and 7.6 meters high. Diameter of the air exits is 7.3 meters. On the day samples were collected, three cells were operated without fans while three additional cells operated normally (fans on). Five cells were not in operation. The wind was from the south, southwest with gusts from 4 to 7 meters per second (10 to 16 mph). After nearly four hours exposure, it was noted that collectors adjacent to cells operating with fans on contained less water than the initial volume (50 ml blank). This suggested that evaporation was a significant consideration. The collected volume was measured, depth (wetfall) calculated and the results tabulated as effective windage volume. Samplers adjacent to cells operating without fans collected water very rapidly. In addition to the volumetric measurements, windage was also calculated from the total chromium residue present in each sample and the measured chromium concentration of the recirculating water system. Since evaporative processes would not affect the chemical residue in the samples, windage determined chemically was considered representative of true windage. A comparison of results from the two methods (Table 1) indicates that estimates of effective windage contain a significant negative bias (30%) in assessing the magnitude of the wetfall. Maximum effective windage (10 cm/hr)

Table 1. Comparison Between Effective and True Windage Volume and Wetfall from the K-892J Tower and with Fans Off.

Station	Distance (meters)	Exposure (hrs)	Effective Windage Volume (ml)	True Windage Volume (ml)*	Evaporation (%)	Effective Wetfall (cm/hr)	True Wetfall (cm/hr)
16	0.5	0.57	395	420	5.95	6.13	6.52
17	0.5	0.37	430	576	25.35	10.28	13.77
18	2.0	2.67	195	201	2.99	0.65	0.67
19	4.0	3.28	5	22	77.27	0.01	0.06
20	10.0	3.33	—**	—	—	—	—
21	0.5	0.38	375	482	22.20	8.73	11.21
22	0.5	0.38	465	515	9.71	10.82	11.98
23	2.0	2.72	335	445	24.72	1.09	1.45
24	4.0	3.32	23	38	42.11	0.06	0.10
25	10.0	3.35	—	—	—	—	—
26	0.5	0.42	470	624	24.68	9.89	13.14
27	0.5	0.43	335	423	20.80	6.89	8.71
28	2.0	2.77	320	288	—	1.02	0.92
29	4.0	3.37	30	36	16.67	0.08	0.09
30	10.0	3.38	—	—	—	—	—

*Calculated from the total chromium content of the sample and the known concentration in RCW system.

**Indicates no windage water collected.

measured adjacent to the tower (0.5 meters) was comparable to wetfall measured at the Paducah facility (Conrad, 1979), whereas true windage indicated a maximum of 14 cm/hr. Effective windage during operation with fans on was not measurable. However, windage calculated from the chemical residue indicated that a small quantity of water was falling. This small fraction was likely in the form of drift droplets of large diameters (500 to 2500 μm).

The data were further summarized as windage flux to the ground (liters/ m^2/hr) and best fit curves plotted (Integrated Software Systems Corporation, 1970) using spline functions described by Reinsch (1967). Results from the K-892J tower during operation with fans on and fans off are depicted in Fig. 2. Wind was from the south, southwest from 4 to 7 meters/second ($\bar{X} = 5 \text{ m/s}$). The majority (>95%) of the windage water was deposited (fans off) within 5 meters from the tower base. Losses from cells operating with fan-induced draft depict water entrained in the exit air flow and deposited as drift. The point of intersection of the two curves (8 meters) represents the maximum distance windage was transported from the tower. At the K-892J tower the windage water drains to an open ditch and is transported to Poplar Creek. The windage runoff contains 9 ppm hexavalent chromium and therefore constitutes a violation of the National Pollutant Discharge and Elimination System as an unpermitted discharge. In order to estimate the total chromium deposited as windage (fans off), the areas under the curves were integrated over the distance from the tower (10 meters) and along the length (100 meters) of the tower, assuming no end effects. This represents a worse case example since all 11 cells would be in operation

Figure 2. Windage from the K-892J cooling tower on December 7, 1979.

Wind was from the SSW at 4 to 7 meters/second ($\bar{X} = 5$ m/s).

without utilizing the fans. Total hexavalent chromium discharged through the windage was calculated by assuming a 9 ppm water concentration. Under the meteorological conditions of the first study (December) it is estimated that 1.7×10^4 liters of chromium laden water was lost per hour of operation. This represents approximately 153 grams of hexavalent chromium that may eventually impact water quality of Poplar Creek. The windage phenomena is primarily restricted to cold season months (November through March). After the chromium reaches Poplar Creek it is diluted well below EPA standards (0.05 ppm).

A second study was conducted on the K-892J tower in January during slightly different meteorological conditions. Winds were from the west, southwest at 2 to 6 meters per second ($\bar{X} = 3.5$ m/s). The data were resolved as best fit curves by spline interpolation and yielded curves similar to the previous example. Average wetfall was calculated to be 12.24 ± 2.04 cm/hr at 0.5 meters. The greatest distance windage water was observed to be transported was 7 meters. Beyond that distance drift (fans on) was considered to be the major source of cooling water deposition (Fig. 3). Total windage water was estimated to be 1.5×10^4 liters/hour. This represents approximately 132 grams of hexavalent chromium which was transported to Poplar Creek as runoff.

In addition to studies at the newly constructed K-892J tower, similar investigations were conducted at the existing K-861 cooling tower and a newly constructed add-on cell (cell 17). The K-861 tower has been in operation for nearly three decades. It is 117 meters long, 7.4 meters high, and 19 meters wide. There are 16 cells with an

Figure 3. Windage from the K-892J cooling tower on January 25, 1980.

Wind was from the WSW at 2 to 6 meters/second ($\bar{X} = 3.5$ m/s).

air exit diameter of 6.8 meters. The cell 17 add-on tower has similar dimensions to individual cells of the K-892J tower. The add-on cell contains high performance fill material, whereas the older K-861 tower contains conventional splash bar (wooden) fill. Windage estimates during fans off operation (wind 2.4 m/s) depict the cell 17 add-on, whereas fans on data represent the older tower. Average wetfall was calculated to be 5.12 ± 1.37 cm/hr at 0.5 meters distance. Maximum distance of windage impact (4.7 meters) is indicated at the point where windage (fans off) and drift (fans on) loss curves intersect (Fig. 4). Total windage was estimated to be 1.33×10^3 liters/hr from the add-on cell.

A final test was conducted on January 16, 1980, at the cell 17 add-on tower during operation with fan-induced draft and without fans. Wind was from the southwest at 0.2 to 4 meters/second ($\bar{X} = 0.8$ m/s) during operation with fans off. Data with fans on operation depict drift losses whereas losses without fans represent windage. The maximum distance of windage transport was 2.5 meters (Fig. 5). Wetfall was < 0.5 cm/hr at 0.5 meters distance and total windage was estimated to be < 45 liters/hour.

CONCLUSIONS

Results of the several investigations presented herein have provided quantitative estimates of windage from Oak Ridge Gaseous Diffusion Plant cooling towers. Windage water deposited on the ground has the potential to reach nearby streams through runoff. Windage deposited on moisture depleted soils would not be significant. During winter

Figure 4. Windage from the K-861 cooling tower on January 8, 1980.

Wind was from the NE at 1 to 3.5 meters/second ($\bar{X} = 2.4$ m/s).

Fans off operation is for the cell 17 add-on tower, whereas
fans on operation represent the older tower.

Figure 5. Windage from the cell 17 add-on tower (K-861) on January 16, 1980. Wind ranged from 0.2 to 4 meters/second ($\bar{X} = 0.8$ m/s) from the SW during fans off operation, and from 0.2 to 3.3 meters/second ($\bar{X} = 0.4$ m/s) from the West and the South during fans on operation.

months at Oak Ridge soils generally have a high moisture content such that windage deposition could be quickly transported as runoff. It is during this time that cooling towers are sometimes operated without fan-induced draft. Since windage water contains the same hexavalent chromium concentration (9 ppm) as the recirculating cooling water system, the runoff stream from the K-892J tower constitutes a NPDES violation as an unpermitted discharge. As a long-term abatement strategy, concrete aprons were constructed along each side of new cooling towers at the Paducah, Kentucky Gaseous Diffusion Plant. The maximum distance of windage impact is wind dependent. If apron construction is envisioned as an abatement strategy at Oak Ridge, the maximum distance of impact can be inferred graphically from the several points where windage (fans off) and drift (fans on) loss curves intersect under the different meteorological conditions. Once the hexavalent chromium laden runoff stream reaches Poplar Creek, it is diluted well below the standards for drinking water and poses little potential for biological effects to aquatic systems.

ACKNOWLEDGEMENTS

The authors wish to acknowledge P. D. Parr (Environmental Sciences Division, Oak Ridge National Laboratory), K. P. Brown and R. P. Miller (Enrichment Technology Division, Oak Ridge Gaseous Diffusion Plant) for sample collection and analyses. T. Bard (Environmental Management Group, Oak Ridge Gaseous Diffusion Plant) provided the spline interpolations and graphics.

LITERATURE CITED

- Conrad, M. C. 1979. Chromium transport to surface streams from cooling tower windage. IN Compilation of papers presented at the 1979 UCC-ND Waste Management Seminar. Report Number K/C-1347, pp. 107-114.
- Integrated Software Systems Corporation. 1970. *DISSEPLA*: Display Integrated Software System and Plotting Language. Vol. 1, Beginners and Intermediate Manual. Vol. 2, Advanced Manual, San Diego, California.
- Koteski, R. A. and Vaughn, B. E. 1979. Recirculating cooling water blow-down treatment at the Oak Ridge Gaseous Diffusion Plant. IN Compilation of papers presented at the 1979 UCC-ND Waste Management Seminar. Report Number K/C-1347, pp. 65-78.
- Reinsch, C. H. 1967. Smoothing by spline function. *Numerische Mathematik* 10: 177-183.