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Suppression of ice fog from the Fort Wainwright, Alaska, cooling pond

Kerry E. Walker and Walter Brunner

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Ice fog near the Ft. Wainwright cooling pond creates a visibility hazard. Observations show a substantial reduction in visibility along both private and public roadways in the path of the cooling pond's ice fog plume. This reduction in visibility increases as the ambient air temperature decreases. Visibility was less than 215 m (700 ft) on the Richardson Highway on the average of 8 days for each of the 3 data years. Data collected during the winters of 1979-80, 1980-81 and 1981-82 statistically show that use of a monomolecular film evaporation suppressant, hexadecanol ($C_{16}H_{33}OH$), on the pond to reduce ice fog is

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ineffective. There is an immediate need for a driver warning system when visibility is affected by the ice fog.

PREFACE

This report was prepared by Kerry E. Walker, Research Civil Engineer, and Walter Brunner, Engineering Technician, both of the Alaska Projects Office, U.S. Army Cold Regions Research and Engineering Laboratory. Funding for this research was provided by the 172nd Infantry Brigade, Fort Richardson, Alaska.

The authors express gratitude for the cooperation and support that was given by the staff of the Fort Wainwright power plant. Appreciation is expressed to Charles Collins and Harold J. Coutts of CRREL for reviewing the technical content of this report, and to Robert J. Walker, Alaska Cooperative Fisheries Research Unit, for technically reviewing the statistical analysis. The authors especially acknowledge the help of the project designer and coordinator, Dr. Terry McFadden.

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SUPPRESSION OF ICE FOG FROM THE FORT WAINWRIGHT, ALASKA, COOLING POND

by

Kerry E. Walker and Walter Brunner

INTRODUCTION

Ice fog

Oftentimes, in the midst of a cold spell, inhabitants of far northern communities can watch a cloud of ice particles grow and cover their town. Because this mist is similar to fogs of more southerly climates, it is called "ice fog." Siberians call it "white fog" or "habitation fog," the latter name being particularly appropriate as it is almost always an indicator of human habitation. Ice fog differs from normal fog in that it is made of very small ice particles (8-35 μm in diameter) rather than water droplets.

Ice fogs are most common in very cold, clear, calm weather. Suitable conditions are found during the winter in Fairbanks, a place in interior Alaska with a population of approximately 50,000 people.

Ice fog conditions

Ice fog seldom occurs above -29°C (-20°F) and is almost always present below -46°C (-51°F) provided there is a water vapor source. In Fairbanks, where winter nights are more than 20 hours long, radiative heat loss from the ground to clear skies is considerable and low temperatures are common. During the winter, this radiative heat loss sometimes continues unimpeded through the day because of clear skies resulting from high pressure systems. Fairbanks also experiences one of the strongest thermal inversions in the world. Denser, colder air tends to remain at the surface, with no vertical mixing because of the almost windless conditions associated with the stable high pressure system.

Why ice fog forms

Ice fog forms when either combustion exhaust containing water vapor or water evaporated from an open water source is added to cold air that has temperatures lower than -30°C (-22°F). The water vapor cools rapidly, adsorbs to particles in the air and freezes to these nuclei. The result is a profusion of small ice particles that tend to hang in the stable air mass (Benson 1970).

Sources of ice fog

In Fairbanks the largest quantity of pure ice fog is formed over power plant cooling ponds. However, the most offensive ice fog is caused by automobiles because the ice fog they form has noxious nuclei and also markedly reduces street visibility. Furnace exhaust is a third important ice fog source.

Problems caused by ice fog

Fog occurs all over the world, so why does ice fog merit special attention? One reason is the length of time an ice fog episode lasts. In warmer climates the sun will burn off the fog; however, ice fog can last up to two weeks. It will persist until the stable pressure system breaks down and a cloud cover comes in to inhibit radiation loss from the earth, thus warming the air and dissipating the ice fog; winds associated with a frontal system may break up the stable air mass and dissipate the ice fog*.

Ice fog causes several environmental problems. Visibility is very poor in ice fog because of the dispersion characteristics of ice particles. This reduced visibility leads to unsafe driving conditions and represents a serious problem for aviation. It also compounds the psychological effect of long winter nights. In addition, some respiratory problems may arise from inhaling ice fog crystals that have toxic exhaust particles as nuclei.

Problems from cooling pond ice fog

As mentioned before, ice fog is often associated with automobile and furnace exhaust; a great deal of it also comes from power plant cooling

*Personal communication with S.A. Bowling, Geophysical Institute, College, Alaska, 1980.

Figure 1. In the foreground is ice fog formed over the cooling pond at Fort Wainwright's power plant. Above is the ice fog caused by the exhaust from the plant stack.

waters (Fig. 1). At Fort Wainwright, cooling water is circulated through the power plant to cool the condensors. The water carries the heat into a 150- by 300-m (500- by 1000-ft) cooling pond where it is dissipated into the atmosphere. During the winter, evaporation from the cooling pond produces a thick plume of ice fog that reduces visibility in the vicinity of the pond and for several kilometers around. A recent report by the Fairbanks North Star Borough (1980) cites the fog from Fort Wainwright's cooling pond as contributing to many winter accidents on the Richardson Highway. Table 1 is a list of accidents during ice fog conditions in that vicinity from January 1971 through December 1979.

The cooling pond dissipates waste heat from the power plant by three types of heat transfer: convective, radiative and evaporative. We can calculate the approximate percentage that each of these contributes to the overall heat transfer from the pond. The critical heat transfer mechanism that causes the ice fog, evaporation, accounts for a major percentage (on the order of 25%) of the total heat dissipated from the open water surface during the winter months (McFadden and Collins 1978).

The ice fog problem would be reduced or eliminated if evaporation is reduced or eliminated. However, since this particular type of heat loss accounts for a major portion of the total necessary heat loss from the

Table 1. Reported motor vehicle accidents during fog conditions on the Richardson Highway from mile marker 2 to 4 (reporting period January 1971 through December 1979). Information supplied by Alaska Department of Transportation and Public Facilities (after Fairbanks North Star Borough 1980).

Milepoint from Anchorage	Accidents	Persons killed	Persons injured	*Amount of injuries ($)	Property damage ($)	Number of vehicles	Light conditions	Road surface conditions	Location
292.74	00486	0	0	0	1,600	2	Other	Snow/ice	
293.12	06498	0	0	0	7,600	3	Street light	Snow/ice	3 Mile Gate
293.63	28604	0	5	47,450	4,000	2	Daylight	Dry	
293.64	16655	0	2	18,980	3,075	2	Dark	Dry	
293.82	28354	0	2	18,980	3,800	2	Daylight	Dry	
294.05	06060	0	0	0	2,000	2	Other	Snow/ice	
294.05	06075	0	2	18,980	2,200	0	Other	Snow/ice	
294.10	18850	0	2	18,980	1,900	5	Daylight	Dry	
294.11	02416	0	4	37,960	16,400	9	Daylight	Snow/ice	Old Rich Jct.
294.11	18661	0	0	0	4,000	3	Daylight	Other	Old Rich Jct.
294.11	84536	0	1	9,490	3,800	2	Daylight	Other	Old Rich Jct.
294.21	20578	0	1	9,490	1,500	2	Dark	Other	
294.37	06054	0	1	9,490	1,800	2	Other	Snow/ice	
294.39	06064	0	0	0	2,300	3	Other	Snow/ice	
204.40	45538	0	0	0	150	2	Daylight	Other	
294.53	31108	0	0	0	700	2	Dark	Other	
294.55	06065	0	1	9,490	2,900	3	Daylight	Snow/ice	
Totals		0	21	$199,290	$59,725	46			

* Dollar amount for injuries was calculated using cost factor supplied by Alaska Department of Transporation and Public Facilities which is $9.490 per injury.

pond, the other forms of heat loss must be maintained or increased in order for the cooling pond to serve its purpose and keep the power plant operating. If evaporation from the pond can be reduced while, at the same time, convection and radiation are maintained, the ice fog can be reduced without harm to the power plant. Therefore, the problem of cooling pond ice fog can be viewed as a problem of evaporation suppression.

Approach to solving the problem

During the last 3 years, CRREL's Alaskan Projects Office (APO) has been assessing and documenting the magnitude of the visibility hazard caused by ice fog from the Fort Wainwright cooling pond. APO has also been testing the ability of an evaporation suppressant, hexadecanol ($C_{16}H_{33}OH$) to reduce that hazard.

Literature review

Extensive work on evaporation control has been conducted by chemists, physicists, biologists and engineers from university facilities, government agencies, private research foundations and commercial enterprises. The most promising method for reducing the rate of evaporation from an open water surface is, apparently, coverage with an oily film. Because it is inexpensive and spreads spontaneously, hexadecanol ($C_{16}H_{33}OH$) has been studied extensively (LaMer 1962). Suppression efficiencies of 9 to 50% have been reported for experiments conducted with hexadecanol on lakes and ponds (Roberts 1957, Roberts 1962, Vines 1962). Various methods of application have been tested, including powder, molten liquid (Stringham and Hansen 1961), and emulsions. In general, the powdered form is considered best for use on water, in terms of both convenience and results (Timblin and Florey 1961, Roberts 1961, Barnes and LaMer 1962, Michel 1963, LaMer and Healy 1965, Slaughter 1970). Vines (1962) reported suppression efficiencies of 50% when hexadecanol was applied as a powder from a boat. Evaporation suppression has been enhanced further by use of floating grids on the water surface to prevent the breakdown of the film due to wind and wave action (Crow 1967, Nicholaichuk 1978). However, the film will still break down because of sublimation, dissolution and biological degradation (Mansfield 1962, Chang et al. 1959). Therefore, Chang et al. (1962) recommended that the hexadecanol be applied continuously.

The above review revealed that some work has been done in a situation analogous to the Fort Wainwright cooling pond; however, most of the investigations of monolayer effectiveness have been concentrated on unheated water bodies in warmer climates. Extrapolating the results of that work to a heated body of water, particularly a heated body of water in a very cold climate, is almost impossible. The literature does not reveal whether the observed suppression efficiencies of 9 to 50% could be expected on a cooling pond in a cold climate.

Some tests of hexadecanol on water bodies in cold climates are recorded. Ohtake* tested hexadecanol by placing two pans of heated water outside at -40°C (-40°F). The ice fog generated from each pan was visually assessed and determined to be the same. The experiment was repeated after one of the pans had hexadecanol crystals added to it. The pans were again set outside at -40°C (-40°F). There was no visible difference in the ice fog from each of the two pans.

The amount of water vapor in the air is not, however, directly proportional to visibility. It may be that in Ohtake's experiment a portion of the water vapor was suppressed, but the two clouds still looked the same.

*Personal communication with T. Ohtake, Geophysical Institute, College, Alaska, 1982.

McFadden (1974) reports on evaporation tests in the subarctic using two standard Colorado floating pans placed on the power plant cooling pond at Eielson Air Force Base near Fairbanks, Alaska. Hexadecanol was added to one of the pans while the other pan was left untreated. Evaporation in the treated pan immediately dropped by over 80% and continued to remain significantly lower than the control pan until the test was suspended 120 hours later. The average suppression was 84%. However, during baseline tests between two untreated pans, differences in evaporation between the two pans were measured to be as high as 17.6% over a period of 166 hours. These results show that suppression efficiencies of 60 to 70% in pans on cooling ponds in cold climates may be obtainable with the use of hexadecanol films. However, Langmuir and Shaefer (1943) showed that screening tests performed in the open, even on closely adjacent pairs of evaporation pans, frequently give inconclusive and misleading results because these pans often measure fluctuations in micrometeorology only. Therefore, we cannot extrapolate from evaporation pans to a 150- x 300-m pond.

To assess the effects of hexadecanol on a large pond, McFadden and Collins (1978) performed a test on the entire Fort Wainwright pond. In March 1975, with an ambient air temperature of -14°C (7°F), a film of hexadecanol was applied to the pond early in the morning. Later in the same morning, the fog had cleared perceptably.

The foregoing tests indicate that use of hexadecanol can be expected to reduce evaporation from cooling ponds in cold climates, but quantification of the reduction and the determination of whether it is enough remained. A field experiment to assess these concerns was designed and implemented by APO during the winters of 1979-80, 1980-81 and 1981-82.

MATERIALS AND METHODS

Objective

We attempted to measure differences in visibility in the area surrounding the Fort Wainwright cooling pond that resulted from using a hexadecanol film for evaporation suppression.

Setup

Measuring visibility is a difficult task. Visibility is defined as the distance a person can see. This varies over a wide range with subjec-

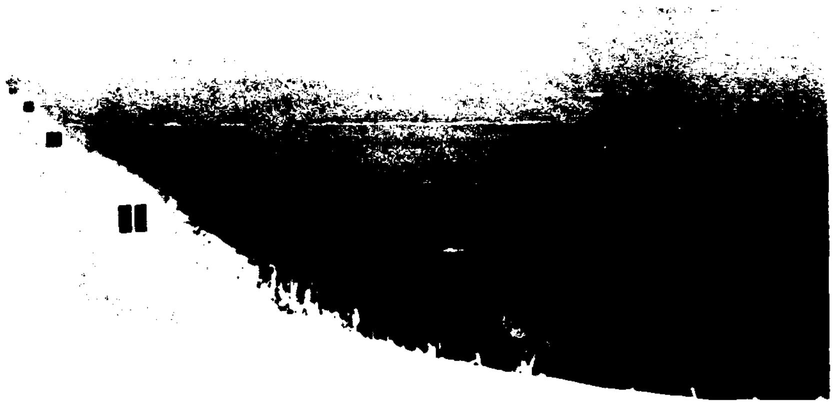


Figure 2. Orange signs set at 30 m (100 ft) intervals that were used as a measure of visibility in ice fog.

tive interpretation. In an attempt to objectively measure visibility, a row of targets that could be observed from a fixed point was set up. Each target was the size and shape of a highway directional sign and painted orange (Fig. 2). The sign shape was used to simulate a familiar object and at the same time it provided a means for a repeatable measure of visibility.

The targets were set in a line at 30-m (100-ft) intervals. One set of 14 targets was placed on the levee about 15 m (50 ft) west of and 6 m (20 ft) above the pond. A second set of 17 targets was set up in an east-west direction along Alder Avenue, about 150 m (500 ft) south of the pond. The last set of 18 targets was arranged in a east-west direction about 460 m (1500 ft) south of the cooling pond, adjacent to the Richardson Highway (Fig. 3). The visibility along the Richardson Highway was of utmost concern as it is a major traffic artery through Fairbanks.

Since the hexadecanol film is easily displaced by wind, it is necessary to protect the integrity of the film. A floating grid can reinforce the film so that it will not be broken up, blown aside by the wind, or carried away by current. We used a grid of black 1-1/4-in. polyethylene pipe that was formed into large hoops which were floated on the pond. They were fastened together in long chains, stretched across the surface of the pond, and secured on each side. It was not necessary to connect adjacent

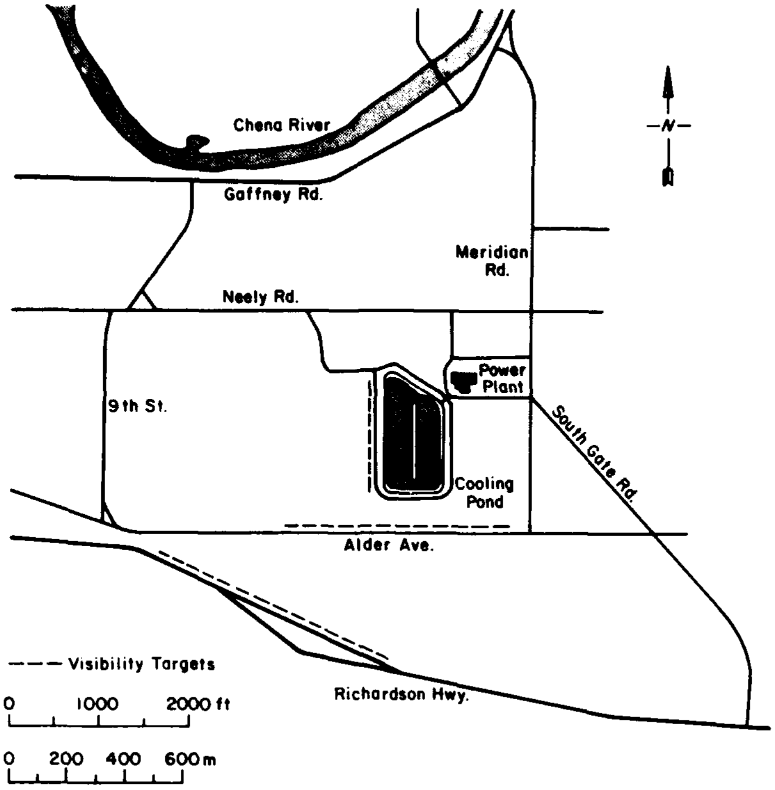


Figure 3. Map of ice fog area.

Figure 4. Viewed from the south, the west portion of the cooling pond is covered with hoops to maintain the integrity of the hexadecanol film. The east, cooler side of the pond generally freezes over in the winter with the ice cover suppressing ice fog.

Figure 5. Viewed from the northeast, this winter scene shows that the natural ice cover over most of the east portion of the pond effectively suppresses ice fog formation there. Some ice fog can be seen forming at the southern end where there is no ice cover.

chains and it was possible to leave up to 3-m (10-ft) spaces between adjacent rows of hoops (Fig. 4). The east portion of the pond was not covered because during ice fog conditions there is usually a natural ice cover on the east portion which effectively suppresses ice fog formation (see Fig. 5).

Procedure

During each of the three winters, when ice fog was present, observations were made one to eight times a day during daylight at all three sampling sites. A typical sampling run began on the levee above the pond (see Fig. 3) where date and time were recorded. Visibility readings were then taken. First, from an established observation point on the levee, the number of orange targets visible along the levee was counted and recorded. The other two observations, along Alder Avenue and the Richardson Highway, followed a somewhat different format. Rather than observing from a fixed point, technicians made observations from the target nearest to the edge of the ice fog cloud. The number of targets visible within the fog was counted. During days without ice fog, when visibility was good, the maximum

Figure 6. To apply the hexadecanol to the pond, one person rowed, one scattered the hexadecanol grains and one remained on shore.

number of discernible targets along Alder Avenue was 14 and along Richardson Highway 15 were visible. These were considered to be maximum visibility in our analysis.

Hexadecanol, in granular form, was applied to the pond by hand from a rowboat. The workers in the boat traveled from the warm to the cool side of the pond, spreading approximately 3 kg of chemical on the warm side and approximately 1 kg on the cool side so that each half received more alcohol than needed to form a monomolecular layer. The total time for application was approximately 2-1/2 hours. A team of three people was necessary for the job, one rowing, one spreading the hexadecanol and one on shore for safety (Fig. 6). The application procedure was repeated as often as necessary. When the weather remained cold enough for ice fog, the hexadecanol was applied at intervals between 3 and 11 days, depending on whether the film appeared to be stable or not.

A few days after hexadecanol application, the smooth, glossy appearance of the film disappears and small wavelets appear on the pond. This indicates that the film is no longer effective. The most probable cause of this is bacterial degradation (Chang et al. 1962). Two common water bacteria thrive on hexadecanol film; they surround and isolate the granular particles and prevent the spreading needed to repair tears in the film

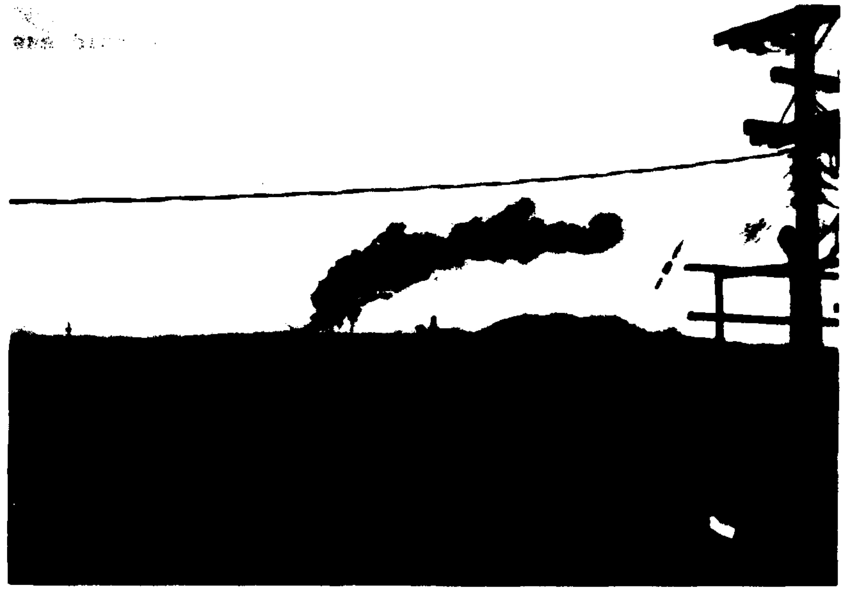


Figure 7. Beyond the building in the foreground are three types of ice fog on Fort Wainwright. Along the ground, spreading the entire width of the picture is the ambient fog covering most of the post caused by daily activities (e.g. automobile exhaust, human respiration and furnace exhaust). The high plume in the middle is ice fog from the power plant stack. The lower wide plume to the right is ice fog from the cooling pond.

caused by the wind or waves. Sometimes we observed numerous particles floating on the surface of the pond, but there was little or no film between them. This indicated that it was necessary to apply the hexadecanol again.

Ambient air temperature data for Fort Wainwright are recorded hourly at the airfield about 1 mile from the cooling pond, and the air temperature at the time of each visibility observation was recorded.

In evaluating the difference between visibility with and without the hexadecanol, ambient air temperature was chosen as the independent variable because it has been shown to have a strong correlation with visibility in ice fog (Ohtake 1970) and it was the easiest, most reliable variable to measure.

However, many other variables affect ice fog generation and visibility besides ambient air temperature, such as water input temperature, water volume flow into the cooling pond, relative humidity of the air, wind direction, particulate matter available for nucleation, solar input, whether the intake well used as an aid in cooling the condensers is on or off, and the magnitude of the ice cover that grows on the cold east side of the pond. Also, visibility observations were made by a different observer each of the three winters, adding to the variability of the data.

There are two other sources of ice fog in the area, besides the cooling pond, to complicate matters further. First, the stack on the power plant releases exhaust with a high water content. This plume sometimes does not settle to the ground for 0.8 km (0.5 miles) or so; however, sometimes it settles quicker and mixes with the cooling pond ice fog plume (Fig. 7). Second, vehicles traveling in Fort Wainwright and on the Richardson Highway produce about a gallon of water vapor per gallon of gasoline burned. These vehicles create some of the ice fog in the area. We believe the ice fog at the test sites comes from all three sources.

RESULTS

Winter 1979-80

Samples were taken on 38 days during the 1979-80 season (6 in December, 19 in January, and 13 in February). Continuous monitoring was concluded after 79 consecutive days. During the 1979-80 ice fog season, hexadecanol was applied to the pond 11 times at intervals that ranged from 3 to 11 days.

A sampling circuit took 25 minutes. Only data taken when temperatures were below -19°C (-2°F) were used in the analysis. Fog composed of cold water droplets forms at about this temperature and it is as much a visibility inhibitor as the ice particle fog that forms below approximately -30°C (-22°F). The measurements, along with all other recorded observations, are tabulated in Table A1. The table includes time, date, ambient air temperature and observed visual range at the three target sites.

Winter 1980-81

Samples were taken on 62 days during the 1980-81 season (23 in December, 20 in January, and 19 in February). Continuous monitoring was suspended after 82 consecutive days. During the 1980-81 ice fog season, hexadecanol was applied to the pond only once. The purpose of the 1980-81 season's sampling was primarily to obtain baseline visibility data to compare with the previous year's data to evaluate the effectiveness of hexadecanol applications.

The measurements, along with all other recorded observations, are tabulated in Table A2. The table includes time, date, ambient air temperature and observed visual range at the three target sites.

Winter 1981-82

Samples were taken on 28 days during the 1981-82 season (3 in December, 15 in January, 9 in February and 1 in March). Continuous monitoring was concluded after 72 consecutive days. During the 1981-82 ice fog season, hexadecanol was applied to the pond three times. The purpose of the sampling in 1981-82 was to observe the hexadecanol at very low temperatures; the winter of 1979-80, when most of the other hexadecanol observations were made, was unusually warm.

The 28 sampling days yielded 141 usable measurements of visibility in daylight with temperatures below -19°C (-2°F). The visibility measurements, along with other observations, are recorded in Table A3. The table includes time, date, observed visual range at each of the target sites and ambient air temperatures at the time of observation.

ANALYSIS

The highest temperature at which a reduction in visibility was observed at either of the test sites along the roads was -19°C (-2°F). Therefore, if an evaporation suppressant is to effectively increase visibility it must work below this temperature. To test the effectiveness of the hexadecanol, all the data for temperatures less than -19°C (-2°F) were separated into two groups. Group one was baseline data accumulated during 1980-81 when hexadecanol was not being used. These data represented naturally occurring ice fog without any type of suppressant. Group two was data obtained while using the hexadecanol. These include all the data from the winters of 1979-80 and 1981-82. Statistical tests were conducted at a 0.05 probability or significance level (i.e. the null hypothesis had 1 chance in 20 ($P \leq 0.05$) of being rejected when true).

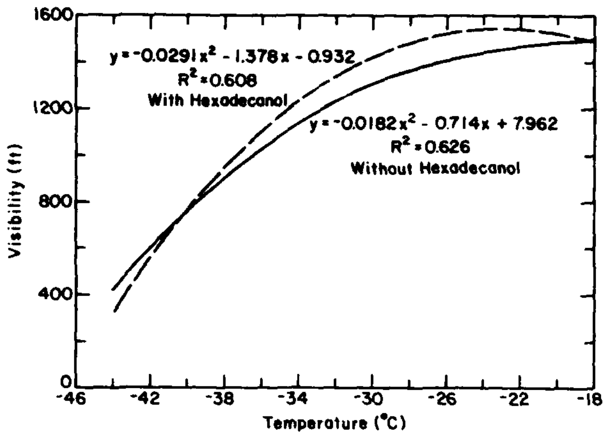
Least-squares polynominal regressions of visibility against temperature were performed for each site for each of the two groups. The order of the polynominal was determined by significant reduction of unexplained variability of the dependent variable (visibility) with the addition of a higher order term of the independent variable (temperature) or the lowest order polynominal in which the residuals do not display a systematic pattern (Draper and Smith 1980). Once the relation was empirically determined, analysis of covariance (ANCOVA) was performed to test for significant differences in slopes and intercepts between the two groups of data. In this manner the null hypothesis that hexadecanol does not effect the temperature-visibility relation for each site was statistically tested.

Richardson Highway

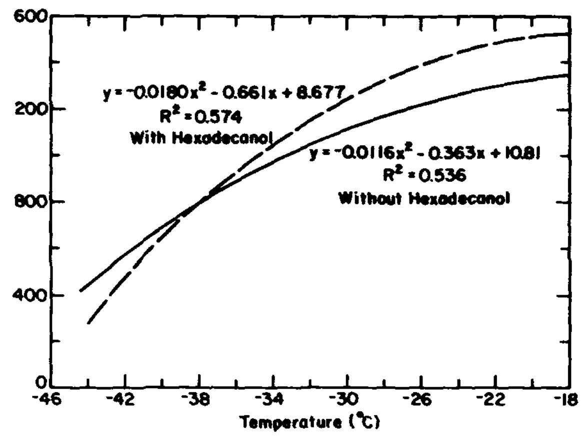
The best fit for each group of data (with and without hexadecanol) from the Richardson Highway test site was a quadratic (Table 2). For both groups, over 60% (i.e. $R^2 \geq 0.6$) of the variability in visibility can be explained by the regression (Fig. 8a). ANCOVA determined that there is no significant difference between the two groups in slopes (P = 0.393) or

Table 2. Polynomial regressions of cooling pond data. The dependent variable is visibility (y) versus the independent variable, temperature (x). N is the number of data points and R^2 is the coefficient of determination.

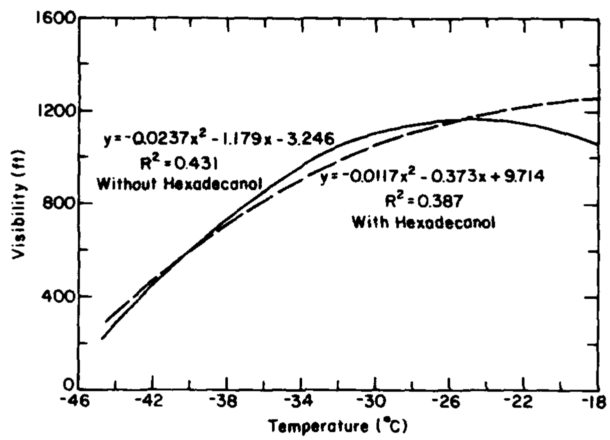
Group	Regression line	N	R^2
	Richardson Highway		
Without hexadecanol	$y = -0.0182x^2 - 0.714x + 7.962$	56	0.626
With hexadecanol	$y = -0.0291x^2 - 1.378x - 0.932$	134	0.608
Combined data	$y = -0.0252x^2 - 1.136x + 2.464$	190	0.622
	Alder Avenue		
Without hexadecanol	$y = -0.0116x^2 - 0.363x + 10.81$	56	0.536
With hexadecanol	$y = -0.0180x^2 - 0.661x + 8.677$	134	0.574
Combined data	$y = -0.0151x^2 - 0.515x + 10.165$	190	0.564
	Levee		
Without hexadecanol	$y = -0.0237x^2 - 1.179x - 3.246$	56	0.431
With hexadecanol	$y = -0.0117x^2 - 0.373x + 9.714$	134	0.387
Combined data	$y = -0.0167x^2 - 0.708x + 4.384$	190	0.407



a. Richardson Highway site.



b. Alder Avenue site.



c. Levee site.

Figure 8. Least-squares polynomial regressions of visibility vs temperature. There is no significant difference between the with- and without-hexadecanol data sets.

intercepts (P = 0.453). Therefore, use of hexadecanol does not have a significant effect on the temperature-visibility relationship at the Richardson Highway test site.

Alder Avenue

A quadratic fit was also used for visibility against temperature for the two groups of data from the Alder Avenue test site (Table 2). Over 50% of the variability in visibility can be explained by the regressions (Fig. 8b). ANCOVA again determined there is no significant difference between the two groups in slopes (P = 0.159) or intercepts (P = 0.849). Therefore, use of hexadecanol does not have an effect on the temperature-visibility relationship at the Alder Avenue test site.

Levee

Even though a quadratic fit was not significantly better than a linear fit for the with-hexadecanol data, to be able to compare the two groups quadratic fits were used for both (Table 2). The regressions (Fig. 8c) could only explain 40% of the variability in visibility, but the relationship between temperature and visibility was still significant. ANCOVA determined that there is no difference between the two groups in slopes ($P = 0.495$) or intercepts ($P = 0.883$). Therefore, use of hexadecanol does not have an effect on the temperature-visibility relationship at the levee test site.

Dispersion analysis

The last analysis performed on the visibility-temperature data concerned dispersion characteristics of the fog. We hypothesized that by reducing the total amount of fog generated it would disperse faster, even though visibility may not appear enhanced close to the pond. To test this hypothesis two dispersion variables were created. The first variable, called road-to-highway, was calculated as the difference in visibility observed on each data collection run between Alder Avenue and the Richardson Highway. Since the highway is much further from the pond than Alder Avenue, much of the fog should disperse before it gets there and visibility at the highway should always be better than at Alder Avenue. If significant suppression of ice fog is taking place, then the dispersion for the hexadecanol group should be significantly higher than for the without hexadecanol group. A variable similar to the road-to-highway variable was created to test dispersion between the levee and Alder Avenue (levee-to-road).

Initially, least-squares polynominal regressions of dispersion against temperature were fitted for each of the two dispersion variables for both the with- and without-hexadecanol groups. There was no significant reduction of unexplained variability in dispersion (i.e. road-to-highway and levee-to-road) by using the predictor variable temperature. Analysis of variance (ANOVA) was performed for each dispersion variable between the two groups. The mean and standard deviation of the road-to-highway variable for the with-hexadecanol group was 1.72 ± 3.11 and for the without-hexadecanol group 0.84 ± 2.51. ANOVA determined that there is no statistical difference between the two groups ($P = 0.114$). Therefore, use of hexadecanol does not have a significant effect on the dispersion (i.e. change in visibility) between Alder Avenue and the Richardson Highway. For the levee-to-road variable, the mean and standard deviation for the with-hexadecanol group was 1.59 ± 3.96 and the without-hexadecanol group 2.20 ± 3.40. ANOVA determined that there was no statistical difference between the two groups ($P = 0.405$). Therefore, use of hexadecanol does not have a significant effect on the dispersion between the levee and Alder Avenue.

CONCLUSIONS

Although hexadecanol has been proven to suppress evaporation, use of hexadecanol on the cooling pond makes no discernible difference in visibility at any of the three test sites. The dispersion rate of the ice fog, measured as the change in visibility from sites closer to the pond to sites further away, also does not change with the use of hexadecanol. Since visibility in the immediate vicinity of the source is an inverse exponential function of ice fog density, visibility quickly drops to near zero with only a small amount of ice fog present (McFadden and Collins 1978). So, when there is a large amount of ice fog present at the pond, as happens in extremely cold weather, reducing that amount by 50% can still mean that there is enough ice fog left to cause low visibility. Hexadecanol does not suppress enough of the evaporation to improve visibility.

RECOMMENDATIONS

Many varied alternatives for reducing or solving the ice fog problem created by Fort Wainwright's cooling pond have been proposed by scientists and laymen. To date, the only one studied extensively has been the use of hexadecanol and this approach does not solve the visibility problem. Alternate and supplemental techniques have been identified and are discussed in Appendix B. These techniques are broken down into four categories: adapting to the fog situation as it is, eliminating the open water on the pond, catching or redirecting the fog, and suppressing the evaporation from the pond.

Immediate action

There is a danger to human life where the ice fog from the Fort Wainwright cooling pond crosses the Richardson Highway. The visibility was reduced to less than 300 m (1000 ft) on 43 days out of the last 3 winters and less than 215 m (700 ft) on 25 days. The stopping sight distance along an icy level roadway (friction coefficient of 0.2)* such as the Richardson Highway at an initial velocity of 88 kph (55 mph) is about 215 m (700 ft). Therefore, on an average of 8 days each year the visibility at the test site on Richardson Highway was reduced to less than the stopping sight distance.

Fortunately, no one has been killed to date in this area, but the potential for a serious accident exists. Also, something should be done immediately to prevent additional accidents.

The Alaskan Department of Transportation should be advised that a warning device or sign should be placed in this fog area now. The options are discussed under the Adapt to Situation Section in Appendix B. They include reducing the current speed limit of 88 km/hr (55 mph) along the affected stretch of road or using a flashing light warning system which is activated when the ice fog reaches a certain density. The latter would be the most acceptable to the community as this is a highly used commuter route and during most of the year there is no justification for reduced speed in the vicinity. The flashing light system is currently being used in Wyoming to warn of impaired visibility under blowing snow conditions.

Long term action

As shown by the hexadecanol experiments, partial suppression techniques do not eliminate enough ice fog to solve the visibility problem on the Richardson Highway. Therefore, the techniques identified that may be able to solve the visibility problem are those in Appendix B under the Eliminate Open Water Section. To solve the ice fog problem, emphasis should be placed on study and analysis of those techniques.

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APPENDIX A: VISIBILITY DATA

Table A1. Winter 1979-80 visibility.

Date (day/mo/yr)	Time	Airfield temperature (°C)	Number of targets visible: Levee	Alder Ave.	Rich. Hwy.
20/12/79	1105	-33	13	14	15
20/12/79	1320	-31	13	14	15
21/12/79	1300	-29	13	14	15
26/12/79	1120	-21	13	14	15
26/12/79	1315	-20	13	14	15
27/12/79	1115	-24	13	14	15
27/12/79	1315	-23	13	14	15
28/12/79	1130	-20	13	14	15
28/12/79	1420	-21	4	14	15
30/12/79	1330	-34	13	14	15
03/01/80	1130	-42	13	4	6
03/01/80	1230	-42	3	7	6
03/01/80	1240	-42	7	5	5
04/01/80	1100	-42	6	5	4
04/01/80	1300	-42	7	3	6
07/01/80	1100	-16	13	14	15
07/01/80	1300	-16	13	14	15
08/01/80	1035	-18	13	14	15
08/01/80	1230	-18	13	14	15
09/01/80	1110	-29	13	7	8
09/01/80	1305	-28	9	14	15
10/01/80	1100	-39	4	7	6
10/01/80	1305	-37	10	2	5
11/01/80	1105	-42	6	7	5
11/01/80	1240	-42	5	4	10
14/01/80	1120	-31	13	14	14
15/01/80	1030	-32	13	14	15
15/01/80	1300	-32	13	14	15
16/01/80	1035	-38	10	14	15
16/01/80	1235	-36	13	14	15
17/01/80	1105	-30	5	14	15
17/01/80	1310	-29	7	14	15
22/01/80	1300	-8	13	14	15
23/01/80	1035	-26	13	14	15
23/01/80	1300	-23	4	14	15
24/01/80	1110	-30	13	14	15
24/01/80	1320	-28	13	14	15
25/01/80	1030	-22	13	14	15
25/01/80	1300	-13	13	14	15
28/01/80	1030	-12	13	14	15
28/01/80	1300	-12	13	14	15
29/01/80	1030	-25	13	14	15
29/01/80	1310	-22	13	14	15
30/01/80	1330	-27	13	14	15
31/01/80	1230	-37	8	11	12
01/02/80	1100	-18	13	14	15
01/02/80	1310	-18	13	14	15
04/02/80	1030	-20	13	14	15
08/02/80	1130	-16	13	14	15
14/02/80	1110	-12	13	14	15
14/02/80	1300	-9	13	14	15
15/02/80	1000	-16	13	14	15
19/02/80	1000	-14	13	14	15
19/02/80	1400	-9	13	14	15
20/02/80	1000	-19	13	14	15
20/02/80	1400	-12	13	14	15
21/02/80	1000	-18	13	14	15
21/02/80	1400	-14	13	14	15
22/02/80	1000	-15	13	14	15
22/02/80	1400	-12	13	14	15
25/02/80	1000	-9	13	14	15
26/02/80	1000	-14	13	14	15
26/02/80	1400	-11	13	14	15
27/02/80	1000	-12	13	14	15
27/02/80	1400	-7	13	14	15
29/02/80	1000	-12	13	14	15

Table A2. Winter 1980-81 visibility.

Date (day/mo/yr)	Time	Airfield temperature (°C)	Number of targets visible: Levee	Alder Ave.	Rich. Hwy.
8/12/80	1100	-33	9	4	11
8/12/80	1330	-33	8	4	8
9/12/80	1000	-37	13	9	7
9/12/80	1415	-37	6	3	2
10/12/80	1000	-39	13	9	9
10/12/80	1400	-39	4	5	3
11/12/80	930	-39	3	10	10
11/12/80	1400	-39	6	7	10
12/12/80	945	-43	2	8	8
13/12/80	1030	-38	4	9	10
14/12/80	1030	-31	6	8	11
15/12/80	930	-38	5	7	11
15/12/80	1100	-38	13	4	10
15/12/80	1245	-38	1	11	14
15/12/80	1400	-38	13	9	11
16/12/80	915	-44	2	4	2
16/12/80	1300	-44	3	4	3
16/12/80	1400	-44	3	4	5
17/12/80	1000	-45	4	4	10
17/12/80	1245	-43	2	4	3
17/12/80	1400	-43	2	3	2
18/12/80	945	-42	3	5	3
18/12/80	1400	-39	5	6	7
19/12/80	1000	-41	4	8	7
20/12/80	1330	-38	4	6	6
21/12/80	1000	-39	3	6	5
22/12/80	900	-38	13	10	12
22/12/80	1130	-38	8	5	8
22/12/80	1345	-38	13	10	9
23/12/80	915	-37	4	6	4
23/12/80	1130	-37	13	14	15
23/12/80	1400	-36	13	10	11
24/12/80	900	-37	4	7	10
26/12/80	1000	-37	2	4	5
27/12/80	1000	-45	3	4	3
28/12/80	1030	-45	2	3	2
29/12/80	915	-44	2	4	3
29/12/80	1100	-43	4	5	4
29/12/80	1400	-43	4	6	5
30/12/80	900	-38	7	8	11
30/12/80	1300	-40	13	13	9
31/12/80	930	-16	13	14	15
31/12/80	1300	-14	13	14	15
31/12/80	1400	-14	13	14	15
2/01/81	900	2	13	14	15
3/01/81	930	-19	10	9	14
4/01/81	1000	-26	13	14	15
5/01/81	930	-23	13	14	15
5/01/81	1315	-24	13	14	15
6/01/81	1000	-8	13	14	15
6/01/81	1330	-6	13	14	15
7/01/81	930	-6	13	14	15
7/01/81	1315	-2	13	14	15
8/01/81	1130	-11	7	14	15
8/01/81	1330	-13	13	14	15
9/01/81	1130	-10	13	14	15
10/01/81	1000	-14	13	14	15
11/01/81	915	-17	13	14	15
12/01/81	915	-18	13	14	15
13/01/81	930	-16	13	14	15
14/01/81	930	-5	13	14	15
14/01/81	1330	-3	13	14	15
15/01/81	1015	1	13	14	15
19/01/81	930	-6	13	14	15
20/01/81	1000	-8	13	14	15
21/01/81	900	-12	13	14	15
22/01/81	915	-13	13	14	15
26/01/81	945	-12	13	14	15

Table A2 (cont'd).

Date (day/mo/yr)	Time	Airfield temperature (°C)	Number of targets visible		
			Levee	Alder Ave.	Rich. Hwy.
27/01/81	1000	-4	13	14	15
28/01/81	1000	-7	13	14	15
2/02/81	1000	4	13	14	15
3/02/81	1015	-4	13	14	15
5/02/81	1130	-7	13	14	15
9/02/81	1230	-7	13	14	15
10/02/81	1300	-13	13	14	15
11/02/81	1030	-21	3	14	15
12/02/81	930	-21	11	14	15
12/02/81	1400	-15	13	14	15
13/02/81	1100	-20	13	14	15
14/02/81	815	-38	7	14	15
15/02/81	900	-36	9	13	13
16/02/81	830	-27	10	13	13
17/02/81	830	-42	6	3	7
17/02/81	1330	-30	13	14	15
19/02/81	815	-27	13	14	15
20/02/81	900	-27	13	14	15
21/02/81	930	-17	13	14	15
24/02/81	830	-19	13	14	15
25/02/81	830	-5	13	14	15
26/02/81	800	-15	13	14	15
28/02/81	800	-18	8	14	15

Table A3. Winter 1981-82 visibility.

Date (day/mo/yr)	Time	Airfield temperature (°C)	Number of targets visible		
			Levee	Alder Ave.	Rich. Hwy.
28/12/81	1310	-38	5	4	5
28/12/81	1340	-38	9	5	8
28/12/81	1405	-37	4	8	5
28/12/81	1455	-37	4	5	4
29/12/81	945	-41	6	5	9
29/12/81	1015	-41	6	9	10
29/12/81	1040	-41	6	5	5
29/12/81	1105	-41	3	7	9
29/12/81	1315	-41	6	9	15
29/12/81	1345	-41	6	7	10
29/12/81	1415	-41	6	7	5
29/12/81	1445	-41	6	7	5
30/12/81	935	-39	7	5	10
30/12/81	1005	-40	7	4	3
30/12/81	1035	-39	5	9	9
30/12/81	1105	-39	3	9	10
30/12/81	1133	-38	7	5	3
30/12/81	1305	-37	4	9	15
30/12/81	1340	-37	5	4	4
30/12/81	1425	-37	7	4	4
30/12/81	1455	-37	7	4	4
7/01/81	1000	-39	7	4	5
7/01/82	1250	-39	8	6	7
7/01/82	1020	-44	5	6	6
7/01/82	1100	-44	6	6	5
7/01/82	1255	-41	3	4	7
7/01/82	1325	-41	10	5	5
7/01/82	1415	-41	5	4	4
7/01/82	1450	-42	2	3	3
8/01/82	930	-41	6	5	6
8/01/82	1000	-41	6	4	3
8/01/82	1030	-41	3	7	10
8/01/82	1050	-41	2	8	7
8/01/82	1125	-41	2	7	7
8/01/82	1300	-40	6	5	5

Table A3 (cont'd). Winter 1981-82 visibility.

Date (day/mo/yr)	Time	Airfield temperature (°C)	Number of targets visible Levee	Alder Ave.	Rich. Hwy.
8/01/82	1327	-40	6	5	5
8/01/82	1355	-40	11	7	7
8/01/82	1425	-39	7	8	5
8/01/82	1455	-40	3	4	5
9/01/82	1010	-39	2	2	4
9/01/82	1040	-39	4	2	8
9/01/82	1105	-38	5	1	6
9/01/82	1135	-38	1	8	11
9/01/82	1255	-34	6	2	15
9/01/82	1320	-35	2	3	15
9/01/82	1350	-35	2	2	6
9/01/82	1415	-35	4	6	9
11/01/82	1030	-28	4	14	15
11/01/82	1400	-24	12	14	15
12/01/82	948	-25	10	14	15
12/01/82	1455	-24	13	14	15
13/01/82	950	-38	4	3	5
13/01/82	1025	-36	4	8	10
13/01/82	1050	-36	6	9	15
13/01/82	1115	-36	6	4	10
13/01/82	1145	-36	13	13	10
13/01/82	1410	-33	4	7	11
13/01/82	1448	-34	13	14	15
14/01/82	1340	-24	13	14	15
15/01/82	1320	-22	13	14	15
18/01/82	1045	-29	7	14	15
18/01/82	1305	-26	13	14	15
18/01/82	1510	-26	13	14	15
19/01/82	945	-32	13	14	15
19/01/82	1430	-27	13	14	15
20/01/82	1025	-21	13	14	15
20/01/82	1520	-18	13	14	15
21/01/82	1050	-12	13	14	15
25/01/82	1105	-33	7	6	15
25/01/82	1445	-28	8	14	15
25/01/82	1525	-30	13	14	15
26/01/82	920	-38	3	5	10
26/01/82	1005	-38	8	8	11
26/01/82	1050	-37	13	12	15
26/01/82	1140	-35	10	7	10
26/01/82	1310	-32	7	11	15
26/01/82	1420	-30	13	14	15
26/01/82	1510	-32	13	10	14
27/01/82	1015	-38	13	11	11
27/01/82	1120	-37	13	13	15
27/01/82	1315	-30	13	14	15
27/01/82	1350	-27	13	14	15
16/02/82	1440	-25	13	14	15
17/02/82	840	-33	7	14	13
17/02/82	918	-31	13	14	15
17/02/81	1140	-32	13	14	15
17/02/82	1557	-29	13	14	15
18/02/82	955	-32	13	14	15
19/02/82	840	-33	13	14	15
22/02/82	910	-40	7	14	15
22/02/82	938	-39	13	14	15
22/02/82	1557	-31	13	14	15
23/02/82	830	-40	3	7	8
24/02/82	810	-38	5	10	9
25/02/82	812	-34	4	12	9
26/02/82	820	-34	3	14	15
2/03/82	823	-25	13	14	15

APPENDIX B: PROPOSED SOLUTIONS TO THE COOLING POND ICE FOG PROBLEM

Adapt to situation

Change the speed limit

The speed limit along the section of the Richardson Highway where the ice fog plume from the cooling pond crosses the road is 88 km/hr (55 mph). A permanent change in the speed limit in this area to a cautious 48 km/hr (30 mph) would be a way to make the area safer during ice fog conditions. However, since this is a highly used commuter artery, the public would most likely resist this move. Except for times when the ice fog is bad (temperatures below about -35°C [-31°F]), and times when rain on ice makes the road slippery, this is a fairly safe road and to force drivers to slow down year-round because of the ice fog generated by the cooling pond may cause some resentment.

Flashing warning signs

Flashing warning lights that are activated when visibility is impaired could be installed on either end of the area of the Richardson Highway affected by the cooling pond ice fog plume. A device for detecting visibility (e.g. a visiometer) could be installed and used to activate the driver warning system. A visual range monitor has been developed at the Rocky Mountain Forest and Range Experiment Station for use in areas where visibility is reduced by blowing snow (Tabler 1977). These devices have been used to activate speed limit reduction signs and flashing warning lights. This system could be adapted to the ice fog situation.

Eliminate open water

Cooling towers

Dry cooling towers can completely eliminate ice fog, at a considerable investment. A direct circulation system is preferable, despite the possibility of freezeup, as it avoids the added complexity and cost of heat exchangers and glycol. An enclosed tower with controllable shutters should allow regulation of the cooling through recirculation of air and should prevent freezeup. Additional manpower for maintenance would be required. Dry cooling towers are used successfully in Alaska in the Anchorage area and at the University of Alaska power plant in Fairbanks.

Create an ice cover

Thermopiles. Cooling through thermopiles seems, at first glance, an ideal solution. Thermopiles would require little maintenance, and the costs would largely be those of procurement and installation. With an adequate number of piles an ice cover could be easily maintained, eliminating the cooling pond as a source of ice fog. However, assuming an input of water into the pond of 38,000 L/min (10,000 gal./min), which represents about half of the plant's full capacity, and a maximum ΔT of 14°C (25°F), we have a heat input of 37,000 kW (125,125,000 Btu/hr) that has to be dissipated*. A typical thermopile's capacity would be about 192 W/m (200 Btu/hr•ft) of submerged depth. The maximum submerged depth for a thermopile installed in the Fort Wainwright cooling pond would be 3 m (9 ft) (this figure could be increased, at additional cost, through use of a coiled thermopile). At 192 W/m (200 Btu/hr•ft) and a working length of 3 m (9 ft), we have a heat dissipation of 577 W (1800 Btu/hr) per thermopile; 69,514 thermopiles would be needed. At an estimated $500 per thermopile, without consideration of installation, the cost would be approximately $35 million. Clearly, both in cost and number required, thermopiles are not a feasible solution. Sizing for an average ΔT of 8°C (15°F) rather than the maximum would cut the requirement by 40% to approximately 42,000 thermopiles, still an excessive number.

Enlarge pond. The one method of ice fog suppression that promises to be both effective and low in operating costs is the establishment of a complete ice cover. Costs would be low since the low temperatures of the normal arctic winter would provide both cooling and storage of cooling capacity in the ice sheet.

*Personal communication with G. Brewster, Fort Wainwright power plant, 1982.

McFadden (1974) showed that the normal growth rate of the ice sheet on the pond was insufficient and had to be enhanced. This was done by flooding the ice. However, it proved impossible to apply water evenly over the surface or to apply a water layer of optimum thickness to ensure that the water would freeze at the optimum rate. Ideally, successive thin layers of water at 0°C (32°F) should be evenly applied and allowed to freeze fully before a following layer is applied. However, to do this on a cooling pond is not economically feasible. A heavy ice cover could be naturally grown if the pond had a larger surface area and was divided into smaller individual ponds that would be connected only by a manifold system so that the plant could be connected to any one pond at a time. With the onset of cold weather, three of the ponds would be allowed to freeze. Before ice fog starts to form, the power plant would be connected to an ice-covered pond, while the first pond would be allowed to freeze. By rotating from pond to pond every 48 hours or so, it should be possible to maintain an ice cover on all four ponds throughout the cold season.

As expected, and as shown by McFadden (1974), the ice cover will first melt at the warm water inlet, and then melt back from the inlet as well as generally melt. Since any open water would immediately generate ice fog, a system to distribute the hot water over the whole bottom of the pond is needed. This would require an extensive network of pipes on the pond bottom, with perforations spaced to release progressively more water into the pond farther from the inlet as the water cools. To dissipate 37,000 kW (125,125,000 Btu/hr) every 24 hours, a 40-cm (16-in.) ice thickness would be needed.

Stefan's equation (converted to SI units) gives the growth rate of an ice cover,

$$H = 3.41\alpha \sqrt{\theta}$$

where

H = ice thickness in cm

α = a coefficient representing local conditions (α = 0.80 - 0.70 for medium sized lakes)

θ = the number of freezing degree-days (°C-days).

This gives a natural growth rate of the ice cover of 11.5 cm (4.5 in.) at -18°C (0°F) and 17 cm (6.8 in.) at -40°C (-40°F) per day if α is assumed to equal 0.80. Accordingly, it would take from 3 to 4 days to regrow the 40 cm (16 in.) of ice melted during 24 hours of operation. With an adequate ice thickness established on three of the ponds before the ice fog season, four ponds with a total volume, and surface, twice that of the present pond should prove adequate for even prolonged ice fog periods and heavy loads. In addition, a heat exchanger to allow tempering of the cooling water may be required, as the pond water under the ice cover will initially be close to 0°C, and will tend to remain at this temperature until after the ice cover has completely melted.

Injection wells

Injection wells provide an alternate solution to the ice fog problem. If enough water can be drawn from wells (and the cooling pond, since it is in essence a shallow well), used to cool the condensor, and then reinjected into the aquifer, ice fog from the cooling pond would be eliminated.

An injection well for disposal of hot cooling water was tried at the Municipal Utilities System (MUS) power plant in Fairbanks in the early 1970's. The well, sunk into the gravel on the bank of the Chena River, immediately started to plug up and the volume of water that could be forced into it declined. The well was later abandoned as unusable.

Injection wells are widely used for recharge of restricted aquifers and of unconfined aquifers separated from the surface by restricting layers. The technique is also used in coastal zones to create freshwater barriers to protect pumped inland aquifers from saltwater intrusion. Injection wells, except at the MUS power plant in Fairbanks, have not, to our knowledge, been used for the disposal of cooling water. However, drastic reductions in the injection rates have been observed for a variety of reasons. The main difference between injection and discharge wells is the former's sensitivity to clogging of the aquifer at the borehole. This clogging is caused by suspended solids, bacteria and the accumulation of corrosion products. Air binding is another cause of clogging when the injected water is high in dissolved air and has a lower temperature than the aquifer. To alleviate this problem, water should be piped down into the well to avoid splashing.

One practice alternates injection with pumping to combat plugging. Not resolved is the legality of injecting water into the aquifer, as Alaska statutes specifically prohibit any contamination of groundwater aquifers.

The groundwater level in the Fairbanks area drops during the winter, but because the Chena River is close to the power plant adequate flow in the gravel aquifer should be maintained.

If we assume that the prospect of clogging and the legal aspects can be resolved, the high cost of drilling wells of the required size remains, as does the cost of pumps and additional maintenance requirements because the use of untreated well water will require more frequent cleaning of the condenser tubes.

Diversion

The traditional methods of discharging cooling water into lakes or streams are feasible only if no ice fog is created around inhabited areas. MUS dumps cooling water into the Chena River, creating ice fog in the center of town. If this technique is employed by Fort Wainwright, the outfall must be located downwind from inhabited areas. For the Fort Wainwright power plant, the Tanana River is suitably located. If possible environmental objections can be overcome, a pipeline to the Tanana would alleviate the ice fog problem on base and on the Richardson Highway. It is assumed that existing wells and the pond can sustain a draw of 38,000 L/min (10,000 gal./min) for the periods of ice fog. The proximity of the Chena River should prevent a lowering of the water table of the immediate area, which does not have any private wells. Since gravity air flow is to the south, the ice fog created by the open water in the Tanana River should not cause any problem at Fairbanks International Airport; no problem is caused by the outfall of the MUS sewage treatment plant, located much closer to the airport.

If sewage lines from Fort Wainwright to the MUS plant have adequate capacity to carry an additional 38,000 L/min (10,000 gal./min) and the sewage plant and outfall pipe are of adequate capacity to handle the additional load, diverting the power plant's cooling water through the sewage system at times of ice fog may represent a feasible, and economical, solution. By the time the water had gone through the plant its temperature would be reduced so that little thermal load would be imposed upon the Tanana. Yet the heat added to the sewage plant would be beneficial, as would be the added flow of heated water through the lines from Fort Wainwright to the treatment plant at times of generally low domestic water usage.

Waste heat use

An ideal method would be one that cheaply uses the waste heat and imposes no additional maintenance and manpower requirements on the power plant. Using the cooling water to heat hangar floors or landing strips is one possibility. However, extensive glycol-filled lines and a heat exchanger present considerable costs.

Greenhouses might use the water for space heating (with heat pumps) and to heat the soil. The possibility of making land available near the plant for a commercial greenhouse growing high-value crops such as roses and tomatoes for the Alaskan market should be further investigated. Limited research is currently being conducted by the University of Alaska and CRREL in this area.

Since the cooling water is a low quality heat source it cannot be used directly for residential heating. Heat pumps can use low quality heat sources economically and efficiently (Aamot 1974). However, the existing district heating system at Fort Wainwright could not be economically converted.

Catch the fog or redirect it

Fog has the tendency to adsorb to available surfaces. For example, ice crystals can be seen accumulated in abundance on the fences on either side of Airport Way, one of Fairbank's main roads. The fog generated by passing vehicles attaches itself readily when it comes close to the fence. We suspect that if surfaces are made available, much of the cooling pond ice fog would attach itself and reduce the amount of free floating fog, improving visibility.

Fish nets

One way of making a surface available is by hanging large fish nets over the pond. Trolling nets large enough to cover the 150-m by 300-m (500-ft by 1000-ft) pond are readily available in Alaska. A structure on which to hang the nets would have to be installed.

While solid ice would adhere firmly to the net mesh and could not be shaken loose, the heavy hoar-frost-like accumulation of ice fog could easily be shaken off, either by wind or people. Ice dropping back into the pond would take heat to melt and would lower the water temperature and thus reduce evaporation and ice fog. The capital costs for this method would be for the supporting structure and nets. The netting alone would cost approximately $200,000. We envision a support structure of poles along the perimeter of the pond with cables run between. This system would not completely suppress ice fog, but used in conjunction with hexadecanol it may reduce ice fog to the point where it is no longer a danger to traffic on the Richardson Highway.

Fences

A similar but more durable and permanent fog catching system would be partially "caging" the pond with cyclone fencing. It has been noticed that fencing along Airport Way in Fairbanks adsorbs ice fog and gets heavily coated with hoar frost. The ice fog is visibly contained within the fenced roadway. Perhaps tall fences could be placed along the south shore of the cooling pont to "catch" any fog headed toward the Richardson Highway. When the hoar frost becomes too thick and the fog starts sneaking around the edge of the fence it will be necessary to have a mechanism for shaking the ice loose.

Trees

The aspen trees now growing on the slope of the pond levee get heavily coated with ice, but denser stands of evergreens would be more effective barriers. A combined planting of spruce and quick-growing willow along the levee could adsorb a considerable amount of the ice fog and the fog would perhaps be forced above the roadway. However, the local meteorological conditions, not a barrier at the pond, would determine the fog's altitude and effect upon Richardson Highway visibility.

Suppress evaporation from pond

In evaluating methods of ice fog suppression, it must be remembered that cooling is the function of the pond, and that evaporation provides a substantial part of heat dissipation from the pond. To eliminate ice fog, evaporation must be suppressed, but only during extremely cold weather.

The studies reviewed in the literature almost exclusively deal with the suppression of evaporation from stock tanks and ponds, and irrigation and municipal water impoundments to prevent the loss of a scarce resource in a hot and arid climate. While the loss of cooling is undesirable under those circumstances, as an increase in the water temperature increases evaporation, it does not impair the function of the reservoir. On a cooling pond, however, evaporative cooling must take place during warmer weather.

Plastic sheet

Polyethylene sheeting has been suggested as a cover for the pond. Behlke and McDougal (1973) found it effective when used on a small evaporation pan. Unfortunately, these results cannot be extended to a body of moving water approximately 46,000 m^2 (500,000 ft^2) in size.

In order to allow heat to dissipate, the sheet has to be in contact with the water surface. Water moves through the pond at approximately 0.113 m/min, producing a drag of approximately 900 N (200 lbf) (McFadden and Collins 1978), which is sufficient to tear the sheet from its moorings. In order to obtain a sheet of the required size, narrower sheets would have to be welded together, posing a problem of some magnitude.

Even if a sheet of the required size could be obtained, or assembled on the site, to stretch it over the water surface and secure it without tearing it is a problem of considerable, if not insurmountable, magnitude. Even if this problem could be solved at all, much less economically, rain and snow would collect on the sheet and push it under water, leaving the rain or meltwater to create ice fog.

Clear polyethylene sheeting deteriorates in one season of exposure to ultraviolet light. Black sheeting could possibly last three seasons (McFadden and Collins 1978); however, it would have to be removed in the spring, folded or rolled to be stored, and reapplied in the fall. It is doubtful that a sheet of this size and weight could be handled five times without tearing; one season would be a more reasonable life expectancy.

Any holes cut into the sheet to secure it to some supporting structure would act as starting points for tears. Even if the sheet's weight is totally supported by the water, the drag of the moving water, added to rain or snow, would impose considerable loads on the sheet's anchor points. If the sheet were ever to tear and part of it enter the power plant intake line, it would result in the immediate shut-down of the plant, with consequences that could be catastrophic. Since the strength of polyethylene sheeting is greatly diminished when it is cold, the already considerable likelihood of a failure would increase with low temperatures, increasing the possibility of a plant shut-down at a time of high power demand. This alone should rule out a polyethylene sheet cover. Heavier, wire-mesh reinforced polyethylene sheeting is available at much higher cost. However, even if such material could be procured in the required size, its weight alone would make installation and removal with storage totally impractical.

Floating ball covers

Hollow plastic (polypropylene) spheres, Styrofoam balls, or chopped Styrofoam are other possible evaporation suppressing covers (Myers and Frasier 1970). However, all could clog intake screens, and would be prone to piling by wind. Removal and storage would be extremely difficult and labor intensive.

Styrofoam sheets

Covering the pond with floating sheets of Styrofoam would largely, though not completely, eliminate the fog. It would also eliminate evaporative cooling, so during the warm season the sheets would have to be removed and stored. The Fort Wainwright pond, with a surface area of approximately 46,000 m^2 (500,000 ft^2), would require about 15,625 (122 x 244 cm) sheets. At a Fairbanks cost of $8.69 per 25-mm-thick white Styrofoam sheet, material cost alone would be $135,781.

The soft white beadboard Styrofoam would quickly be abraded by wave action. Substituting high density extruded foam raises the material cost to $240,625. Because of abrasion, breakage and relatively low resistance to deterioration from ultraviolet light, we estimate that 25% of the sheets would have to be replaced yearly. Wind would tend to push the light sheets onto shore and debris from the sheets could clog intake screens.

Rafts

As an alternate to the unwieldy full-size cover of polyethylene sheeting, polyethylene-covered rafts have been suggested (McFadden and Collins 1978). These rafts would have an open 244-cm frame of Styrofoam and plywood covered with polyethylene sheeting, a hole in the center to allow rain and melt-water to drain, and a weight in the center of the sheet around the hole to assure that any water will drain through the hole into the pond. This scheme combines all the drawbacks of either the Styrofoam sheet or polyethylene cover methods, in addition to requiring a special weight, which may not stay centered.

Silicon film cover

The evaporation process is partially driven by solar energy, which is absorbed at the water surface. Placing a reflecting film on the surface would be one method of suppressing evaporation. Yellow materials reflect light at wave lengths where solar energy has its peak intensity, so yellow monolayers are best. Gainer et al. (1969) reported that a yellow silicone oil film reflected solar energy about 1.7 times better than the plain water surface. Although it sometimes did not form a monolayer, it did reduce evaporation by a minimum of 10%. In addition, the film was found to be extremely difficult to remove from a water surface.

Oil film cover

Ethylene glycol monobutyl ether, a chemical marketed by Shell Oil Company, was investigated by McFadden (1974). It is a clear liquid that spreads well and has a low vapor pressure. According to the manufacturer, it is nontoxic and biodegradable. Tests showed it to suppress evaporation by 60%. No supporting grid is required and one application lasted through the cold season. This long life, however, becomes detrimental during warm weather because there is no effective means of removal.

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