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Research Report 235

FORMATION AND REDUCTION OF ICE FOG

Motoi Kumai

March 1969

U.S. ARMY MATERIEL COMMAND
TERRESTRIAL SCIENCES CENTER
COLD REGIONS RESEARCH & ENGINEERING LABORATORY
HANOVER, NEW HAMPSHIRE

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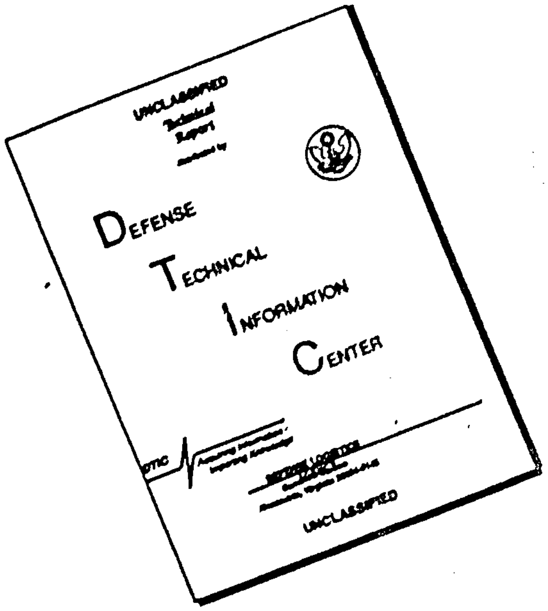

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PREFACE

This report was prepared by Dr. Motoi Kumai, Research Physicist, Research Division, Cold Regions Research and Engineering Laboratory (CRREL), U.S. Army Terrestrial Sciences Center (USA TSC). This report was published under DA Task 1T061102B52A02, *Research in Earth Physics - Cold Regions and Related Environments.*

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ABSTRACT

During January and February of 1962, 1963 and 1964, Fairbanks, Alaska, and vicinity was the site of a series of studies dealing with ice fog and ice crystals. This report presents the results of an investigation of the amount and extent of air pollution and ice fog in the area with special emphasis on reducing ice fog by decreasing the water vapor being emitted into the atmosphere. The major sources of water vapor at the two military installations in the region, Fort Wainwright and Eielson AFB, are the heating and power plants and their associated cooling ponds. In the populated areas around Fairbanks, a high aerosol concentration of about 10^5 particles/cm^3 exists, whereas in the uninhabited areas the concentration is extremely low (about 300 particles/cm^3). Much of the high concentration is due to the burning of coal for heat and power. Because the coal is of low grade it also emits about 350,000 kg of water vapor into the atmosphere on a day when the temperature is -40C. This water vapor condenses on the aerosols and produces ice fog. Anthracite or semi-bituminous coal would reduce the water vapor output to only $\frac{1}{3}$ of the amount produced by the low grade coal. Water vapor from cooling ponds can be reduced by freezing the surfaces of the ponds.

FORMATION AND REDUCTION OF ICE FOG

by

Motoi Kumai

PART I: COMBUSTION PRODUCTS AND AIR POLLUTION

Introduction

The Fairbanks, Alaska, vicinity has been the site of a series of studies dealing with ice fog and ice crystals beginning in 1962. Data were collected during the months of January and February of 1962, 1963 and 1964. The results of the first study were presented by Kumai (1964, 1966). The objectives were the identification of the nuclei of ice crystals, ice-fog crystals, and supercooled droplets; counts of condensation nuclei; and the measurement of ice-fog concentrations and liquid water content. In 1963, investigations dealt with meteorological conditions conducive to the occurrence and persistence of ice fog; observations of ice-crystal formation with water vapor and hydrocarbon ice-forming nuclei provided by combustion products from a power plant chimney and an automobile exhaust; design of a cascade impactor for use with a tethered blimp to collect fog droplets and ice-fog crystals; studies of the size relationship between ice-fog crystals and their nuclei; and a comparison of size distributions between some seeding agents and natural ice-fog crystals and their nuclei. The results of that research were presented by Kumai and O'Brien (1965).

Even though Alaska, as a whole, remains sparsely populated, in some areas air pollution has become a serious problem. Because of steep temperature inversions near the ground, a rather dense layer of smoke and other combustion products covers the cities of central Alaska for nearly 9 months of the year. A major source of these contaminative particles is the large quantity of coal and fuel oil consumed in heating homes and industries and in producing electric power.

This part of the paper presents a calculation of combustion products from Fort Wainwright, Alaska, and data on air pollution measured in January and February of 1962, 1963 and 1964 using a small-particle detector under various meteorological conditions.

Fuel consumption

The amount of coal used in the two power and heating plants at Fort Wainwright, Alaska, ranges between 500×10^3 kg/day and 700×10^3 kg/day when the temperature is -40C or below. During the same cold temperature conditions, about 3000 gallons of fuel oil are used each day at 50 different locations around the base.

Combustion products

A chemical analysis of the coal used at the Fort Wainwright and Eielson AFB power plants revealed that the coal is of low grade (Table I).

It is possible to calculate the amount of gaseous combustion products produced by the coal burned at the two military bases if it is assumed that the carbon is completely oxidized to CO_2. For CO_2, SO_2, and H_2O,

Table I. Chemical analysis of coal used in the Fairbanks area.

Substance	*% of total*
Moisture	23.00
Ash	10.00
Carbon	50.00
Oxygen	11.65
Hydrogen	3.90
Nitrogen	1.08
Sulfur	0.37
Total	100.00

$$CO_2\left(\frac{\text{kg}}{\text{kg of coal}}\right) = \frac{\text{C content}}{\text{kg coal}} \cdot \frac{\text{molecular wt } CO_2}{\text{atomic wt C}}$$

$$SO_2\left(\frac{\text{kg}}{\text{kg of coal}}\right) = \frac{\text{S content}}{\text{kg coal}} \cdot \frac{\text{molecular wt } SO_2}{\text{atomic wt S}}$$

$$H_2O\left(\frac{\text{kg}}{\text{kg of coal}}\right) = \frac{H_2 \text{ content}}{\text{kg coal}} \cdot \frac{\text{molecular wt } H_2O}{\text{molecular wt } H_2} .$$

Then, from Table I:

$$CO_2 = 0.50 \frac{CO_2}{C} = (0.50)(3.67) = \frac{1.84 \text{ kg}}{\text{kg of coal}}$$

$$SO_2 = 0.0037 \frac{SO_2}{S} = (0.0037)2 = \frac{0.0074 \text{ kg}}{\text{kg of coal}}$$

$$H_2O = 0.039 \frac{H_2O}{H_2} = (0.039)9 = \frac{0.35 \text{ kg}}{\text{kg of coal}} ;$$

The total moisture produced in each kg of coal must include the original moisture content. From Table I, 23% of the coal is moisture. Therefore,

$$\text{total water output} = \frac{0.35 \text{ kg}}{\text{kg of coal}} + \frac{0.23 \text{ kg}}{\text{kg of coal}} = \frac{0.58 \text{ kg}}{\text{kg of coal}} .$$

Domestic fuel oil has the approximate formula $C_{16}H_{34}$ with a density of 0.7751 and a sulfur content of less than 0.5%. The chemical formula upon combustion in air takes the form

$$2C_{16}H_{34} + 49O_2 \rightarrow 32CO_2 + 34H_2O .$$

The amount of combustion products then becomes

$$CO_2 = \frac{32CO_2}{2C_{16}H_{34}} = \frac{3.11 \text{ kg}}{\text{kg of fuel oil}}$$

Table II. Combustion products released at air temperatures of about -40C at Fort Wainwright, Alaska.

Combustion product	*Coal, 600 × 10³ kg (kg/day)*	*Fuel oil, 27 × 10³ kg (kg/day)*	*Total (kg/day)*
CO_2	1104×10^3	84×10^3	1188×10^3
SO_2	4×10^3	270	4×10^3
Ash	60×10^3	–	60×10^3
H_2O	348×10^3	37×10^3	385×10^3
Total	1516×10^3	121×10^3	1637×10^3

$$SO_2 = 0.005 \frac{SO_2}{S} = (0.005)2 = \frac{0.01 \text{ kg}}{\text{kg of fuel oil}}$$

$$H_2O = \frac{34 H_2O}{2 C_{16}H_{34}} = \frac{1.38 \text{ kg}}{\text{kg of fuel oil}} .$$

At Fort Wainwright, 600,000 kg of coal and 27,000 kg of fuel oil were consumed daily at an air temperature of about -40C, producing 380,000 kg of water vapor and 1,188,000 kg of CO_2.

The total quantities released into the atmosphere each day during about -40C temperatures are itemized in Table II.

In the Fairbanks area including Fort Wainwright, the amount of fuel used daily during severe cold weather conditions was estimated to be 1.4×10^6 kg of coal, 1.5×10^5 kg of fuel oil, and 9×10^4 kg of gasoline; the production of water vapor and CO_2 was calculated to be 1.3×10^6 kg and 4.1×10^6 kg respectively (Benson, 1965).

Measurement of aerosols

Aerosols in the atmosphere are of two types: those of natural origin from terrestrial and extraterrestrial sources and those of artificial origin from combustion products of heating and power plants, etc. Aerosols were counted with a small-particle detector which is a modified Nolan-Pollack counter. In this work, the air samples were expanded twice. The first expansion produced the necessary supersaturation condition within the sample, and condensation of fog particles on the aerosol nuclei occurred within a few milliseconds. However, the condensation reduced the supersaturation, and, in order to restore the earlier condition, a second expansion was necessary immediately following the first. A photoelectric determination of the attenuation of a light beam due to the fog particles was then made. The instrument has a range of from 2×10^2 to 10^6 particles per cm^3 when measuring particles with a radius over 10Å.

Results

Of the 100 kg of ash produced for each 1000 kg of coal burned at the power plant, only the small particles are emitted into the atmosphere through the stack. The large particles remain in the furnace. One of these larger particles, shadowed with chromium at an angle of 19°25' (Fig. 1) is seen to be a sintered aggregate composed of many solid combustion products.

Aerosols in the atmosphere were collected for examination on collodion-filmed grids by the use of a microscope stage impactor at Fort Wainwright. Many solid particles were observed in the size range of 0.01μ to 10μ diam. When subjected to an electron beam in the electron microscope,

Figure 1. Ash particles from a coal burning power plant.

Figure 2. Aerosols collected at Fort Wainwright.

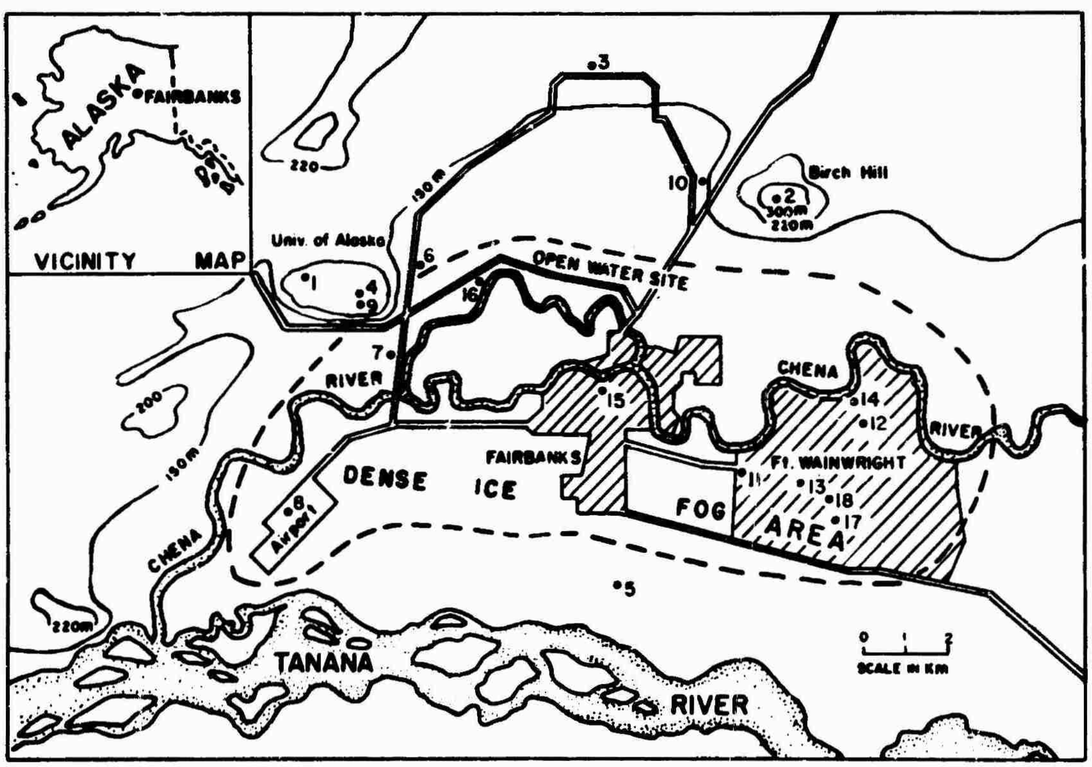

Figure 3. Location of condensation nucleus measurements (Table III) in Fairbanks area.

Table III. Condensation nucleus measurements during three winter seasons in the Fairbanks area.

Location (No. in Fig. 3)	*Number of aerosols per cm³* *Avg*	*Min*	*Max*	*No. of obs*
Ft. Wainwright:				
Main gate (11)	40,733	16,200	88,000	4
Hangar 1 (12)	43,928	400	470,000	51
Inside Hangar 1	41,096	4,000	110,000	30
Motor pool (13)	60,000	38,000	122,000	3
VOQ (14)	81,215	11,000	234,000	17
PX (17)	165,834	50,000	290,000	5
Hospital (18)	258,666	110,000	470,000	3
Fairbanks:				
Birch Hill (2)	1,488	700	1,700	6
Farmers Loop Road (3)	7,150	550	14,800	23
City dump* (5)	9,416	330	35,000	8
Farmers Loop at College Road (6)	16,054	2,750	57,000	14
Deadman Slough (7)	18,727	15,000	30,000	11
International Airport (8)	23,042	400	45,000	19
Inside office at Airport	55,000	53,000	57,000	2
Alaska Field Station (10)	38,914	700	139,000	17
Inside office of AFS	3,750	3,500	4,000	2
Downtown (15)	114,217	18,000	390,000	23
College Road (16)	118,000	93,000	143,000	2
College:				
Magnetic Observatory (1)	480	350	550	3
Geophysical Institute (4)	8,700	6,000	16,200	5
Roof of Geophysical Inst. (9)	36,500	27,000	40,000	8
Fox:				
Outside of permafrost tunnel	3,417	550	8,300	4
Gold dredge	10,500	10,000	11,000	2
Inside office at Fox	62,000	57,000	67,000	2
Permafrost tunnel after drilling	83,000	57,000	110,000	3
Eielson AFB:				
Cooling pond	76,000	62,000	88,000	4

* No material burning

some particles became unstable, while others, such as carbon particles, remained stable. Figure 2 shows an electron photomicrograph of several stable particles shadowed with chromium, mainly solid combustion products from local sources.

Condensation nuclei were counted at the locations shown in Figure 3 with the small-particle detector described above. The populated area including the city of Fairbanks and Fort Wainwright had nucleus counts in the range of 10^4 to 10^5 particles per cm^3. This concentration almost equals that of a large city such as Chicago. However, at locations outside of the populated area, except downwind, the concentration dropped to about 300 particles per cm^3, an extremely low value and close to that of the marine air at Thule, Greenland. The original data, including weather conditions, are tabulated in the Appendix; the average, minimum, and maximum values appear in Table III.

It is concluded that the main substances of condensation nuclei in populated areas are local combustion by-products.

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PART II: ICE FOG FORMATION FROM A COOLING POND

Introduction

The occurrence of -40C temperatures in central Alaska produces a situation conducive to the formation of dense ice fog in the inhabited areas. Factors contributing to the formation are the great amounts of condensation nuclei produced by the increased coal consumption and the large quantities of water vapor present in the atmosphere. The water vapor is primarily supplied by three sources: 1) the exhaust gases of vehicles and aircraft; 2) the flue gases of power and heating plants, and 3) the evaporation of water in the cooling ponds of power plants.

Richardson (1964) estimated that at an air temperature of -34C and a water temperature of 7.2C the rate of production of water vapor from the cooling pond at Eielson Air Force Base (5×10^4 m^2) is about 170,000 kg/day. The quantities and sizes of ice-fog crystals produced by the pond were measured during the winter of 1964. Condensation nucleus counts and meteorological observations were conducted simultaneously, and samples were collected for electron microscope investigation of their nucleation.

Meteorological conditions

Typical ice-fog meteorological conditions were present in the area on 10 February 1964. The water temperature in the pond was 8C. Air temperature and humidity as measured by an Assman psychrometer showed a dry-bulb temperature of -29.0C and a wet-bulb temperature of -29.2C. The wind direction at ground level was northeast at an estimated speed of 1 m/sec, whereas at the top of the power plant stack the smoke drifted west. Although the sky was clear, ice fog formed in the vicinity under these conditions.

Collection of ice-fog crystals

Ice-fog crystals form when water vapor condenses on the condensation nuclei present in the atmosphere. The supercooled fog droplets then freeze while cooling down to the ambient temperature of about -20C or lower.

For purposes of investigation, ice-fog crystals were collected on the downwind side of the cooling pond by precipitation on the filmed grids used in conjunction with the electron microscope. When the crystals were examined in an optical microscope it was found that the majority of them were spherical in shape, but many were hexagonal or columnar (Fig. 4). They were similar in shape to the crystals produced by exhaust water vapor of jet aircraft and automobile engines. The crystals larger than 50μ diam with irregular shapes in Figure 4 are the result of crystal growth on the precipitated crystals due to conditions of supersaturation of water vapor and do not represent the original size of the ice-fog crystals.

Nuclei of ice-fog crystals

Figure 5 shows the size distribution of ice-fog crystals collected at -30C. The most frequent diameter was about 15μ with the sizes ranging between 10μ and 50μ. The electron microscope made possible the observation of ice-fog nuclei and their electron diffraction patterns. Sizes of the nuclei as determined by electron microscope analysis ranged from 0.1μ to 2.2μ with the most frequent diameter being 0.4μ (Fig. 6). Figure 7 shows an electron photomicrograph of the largest nucleus among the specimens collected and its diffraction pattern. The pattern identifies this nucleus as being a solid combustion product with a crystalline structure. A comparison of crystal size with nucleus size reveals no particular relation between the two measurements (Fig. 8). Small crystals may have either relatively large or small nuclei indiscriminately. The size of a crystal depends primarily on the length of time it grows, after nucleation, in an atmosphere supersaturated with water vapor with respect to ice, and not on the size of the nucleus.

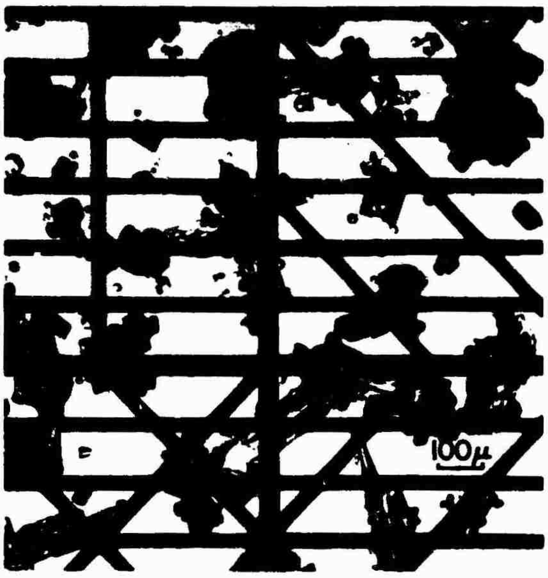

Figure 4. Ice-fog crystals on a filmed grid.

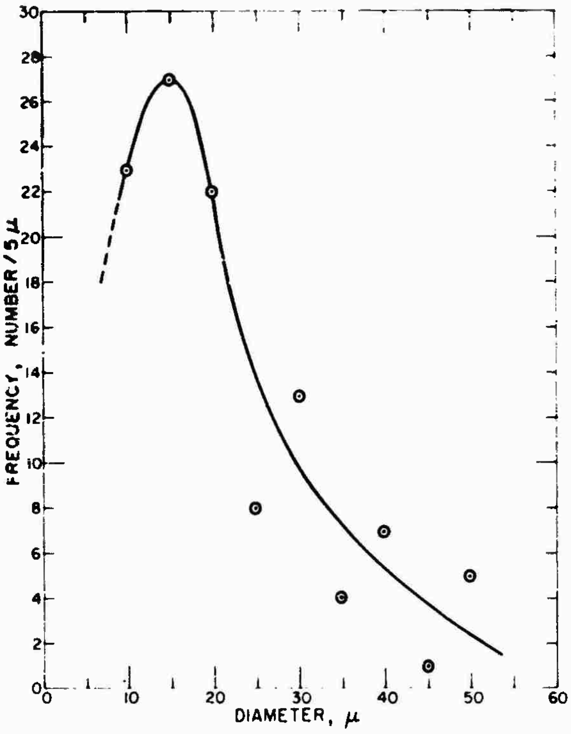

Figure 5. Size distribution of ice-fog crystals.

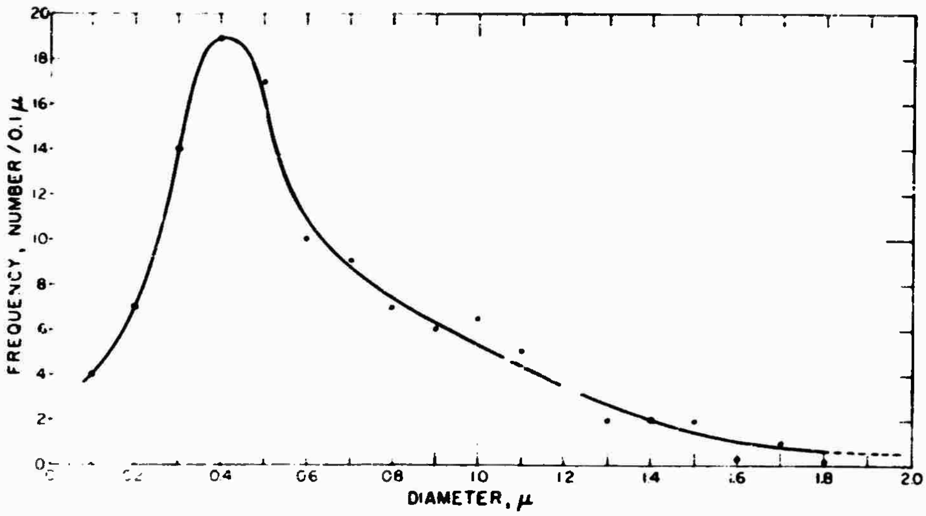

Figure 6. Size distribution of ice-fog nuclei.

a. Nucleus.

b. Electron diffraction pattern of the nucleus.

Figure 7. Nucleus of an ice-fog crystal collected at the cooling pond, Eielson Air Force Base, Alaska.

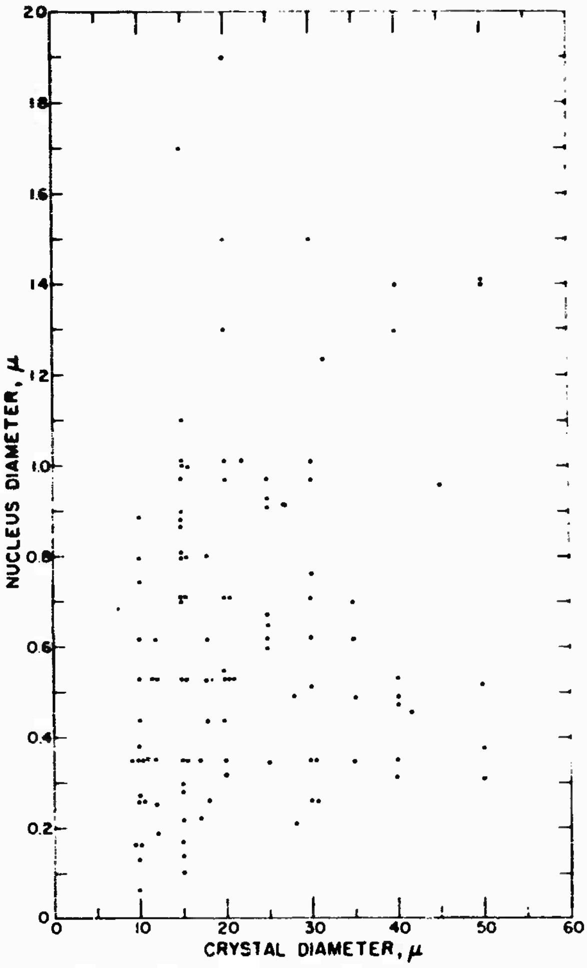

Figure 8. Relationship of nucleus to ice-fog crystal size.

As a result, it can be concluded that particles larger than 0.1μ are suitable as condensation nuclei for the formation of ice fog.

Nucleus counts using the small-particle detector described in Part I ranged from 70,000 to 80,000 per cm^3 in the ice-fog areas while at the same time the ice-fog concentration measured only about 100 crystals per cm^3. Therefore, a great number of nuclei of less than 0.1μ diam must exist in the free atmosphere during ice-fog conditions, but remain ineffective as ice-forming nuclei. These particles (Aitken nuclei, Junge, 1958) may be collected on the surface of the ice-fog crystals by Brownian movement. Aitken nuclei were generally found in the residue of the crystals investigated, and were usually clustered around the large ice-forming nucleus which was invariably present in the crystals such as is shown in Figure 7a.

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PART III: REDUCTION OF ICE FOG BY LIMITATION OF WATER VAPOR OUTPUT FROM COAL BURNING FACILITIES

Introduction

A major source of water vapor that freezes to produce ice fog is the burning of coal at the Eielson AFB and Fort Wainwright power plants. It has been estimated (Richardson, 1964) that at Eielson AFB, 40% of the ice fog may be attributed to the water vapor emanating from the power plant stack on the base. To decrease this condition, a five million dollar heat-exchange system (Taylor and Church, 1966) was installed to remove by condensation the water vapor released from the power plant stacks. During a test, water froze in the condensing pipes, plugging the system with ice and finally rupturing the pipes. Another attempt was made during the winter of 1955-56 to remove a significant amount of water vapor from the flue gases by the use of an ethylene-glycol dehumidifier which was designed for this purpose. On the first day of testing, the system lost over 23,000 liters of glycol through evaporation caused by exposure to the hot flue gases and through leaks in the system. These two attempts failed. Another solution to the problem might be to use a pre-dried coal or to use a different grade of coal during severe cold weather conditions.

Coal classification

To determine which grade of coal would be the most suitable, it is necessary to classify coal according to content and heating value. The established categories are anthracite, semi-bituminous, sub-bituminous, and lignite. An analysis of these types of coal, as ranked by the U.S. Bureau of Mines, is presented in Table IV. Included in the table is the type used at Eielson AFB and at Fort Wainwright, and the analysis of these coals indicates that they would be classified in the sub-bituminous group.

Table IV. Analysis of some types of coal produced in the United States.

	Proximate analysis coal as received				Ultimate analysis coal as received					Heating value	H_2O in flue gas
Rank, State	Moisture	Volatile matter	Fixed carbon	Ash	Sulfur	Carbon	H_2	O_2	N_2	Btu/lb	kg/kg of coal
*Anthracite, Pa.	2.80	1.16	88.21	7.83	0.89	84.36	1.58	1.91	0.63	13,298	0.170
*Semi-bituminous, W. Va.	3.50	15.0	78.30	3.20	0.60	84.39	4.20	2.73	1.38	14,800	0.403
*Bituminous, Ala.	3.16	31.05	59.56	6.23	1.20	78.28	4.98	4.78	1.37	14,141	0.480
*Sub-bituminous, Colo.	19.15	30.82	44.27	5.76	0.25	56.38	3.80	13.58	1.08	9,616	0.434
*Lignite, Wyo.	29.33	28.58	36.42	5.67	1.21	45.09	3.01	14.80	0.89	7,783	0.564
Eielson AFB coal	23.01	29.00	38.00	10.00	0.37	50.00	3.90	11.65	1.08	9,200	0.580
Hypothetical pre-dried Eielson AFB coal (3% H_2O)	3.00	--	--	12.60	0.47	63.00	4.92	14.65	1.36	11,600	0.472
Fort Wainwright coal	20.90	--	--	10.30	--	--	--	--	--	8,740	--

*Abstracted from the U.S. Bureau of Mines, Bulletin 22.

Theoretical analysis

The proximate analysis for determining the theoretical mass of air (m) required for the complete combustion of coal is given as follows (Severns, 1954):

$$m = 11.5C + 34.5(H - O/8) + 4.32S$$

where C, H, O and S represent the mass of carbon, hydrogen, oxygen, and sulfur, respectively, in a unit mass of coal.

The composition of dry air is shown in Table V.

Table V. Composition of dry air.

Composition	% by weight
Oxygen	23.19
Nitrogen	75.47
Argon	1.30
Carbon dioxide	0.04
Total	100.00

The theoretical mass of oxygen, m_o, required for oxidation of 1 kg of coal, and the mass of the other gases, m_n (nitrogen, argon, and carbon dioxide) which accompany the required amount of oxygen in a normal atmosphere may be calculated as follows:

$$m_o = 0.2319\,m$$

$$m_n = 0.7681\,m.$$

Any excess oxygen remaining after combustion, along with all of the other air gases, is exhausted through a stack. The theoretical gaseous content of flue gases from a stack is shown in Table VI.

Mixing ratio and dewpoint

It is possible to estimate the dewpoint of flue gases from coal combustion if the mixing ratio of the flue gases and the saturation mixing ratios over water at a given temperature are known. The mixing ratio is a dimensionless ratio of the mass of water vapor to the mass of dry air in a system of moist air. The saturation mixing ratio over water (γ_w) may be expressed by the equation

$$\gamma_w = \frac{0.62197\, f_w\, e_w}{P - f_w e_w}$$

where e_w is the saturation vapor pressure over water in the pure phase, f_w the correction factor for the departure of the mixture of air and water vapor from the ideal gas law, and P the total pressure in mb. Figure 9 gives the saturation mixing ratios over ice and over water for temperatures between -50C and +50C as quoted from the Smithsonian Meteorological Tables. The mixing ratios of the flue gases vary widely with the coal type, chemical composition of the coal, and with the amount of air in excess of the combustion requirements. The mixing ratios from combustion of anthracite coal, semi-bituminous coal, and the coal used at Eielson AFB, for both 30% and 50% excess air, have been tabulated in Table VI.

For the particular case at Eielson AFB, the mass of air required for combustion calculated from above is

$$m = \frac{6.609 \text{ kg}}{\text{kg of coal}}$$

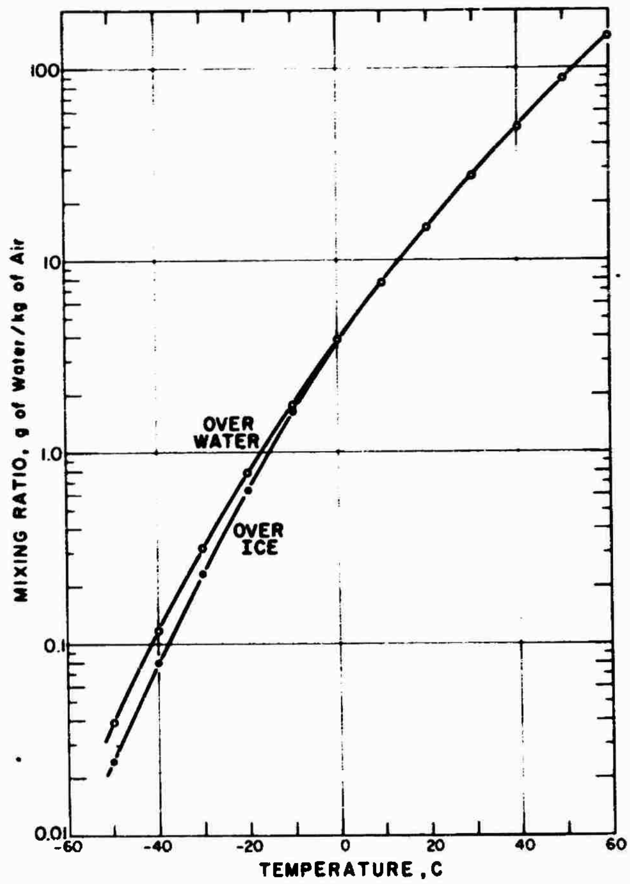

Figure 9. Saturation mixing ratio over water and ice at 1000 mb.

Table VI. Mixing ratio and dewpoint of flue gases* from coal combustion.

Flue gases	Eielson AFB coal, Excess air 30% kg/kg of coal	Eielson AFB coal, Excess air 50% kg/kg of coal	Pre-dried Eielson coal†, Excess air 30% kg/kg of coal	Pre-dried Eielson coal†, Excess air 50% kg/kg of coal	Semi-bituminous, Excess air 30% kg/kg of coal	Semi-bituminous, Excess air 50% kg/kg of coal	Anthracite, Excess air 30% kg/kg of coal	Anthracite, Excess air 50% kg/kg of coal
SO_2	0.0074	0.0074	0.0090	0.0090	0.0120	0.0120	0.0178	0.0178
CO_2	1.8400	1.8400	2.3100	2.3100	3.0100	3.0100	3.0900	3.0900
O_2	0.4590	0.7650	0.5800	0.9660	0.7700	1.2800	0.7070	1.1850
N_2	6.6040	7.6200	8.3300	9.6200	11.0300	12.7200	10.2000	11.7500
Total	8.9104	10.2324	11.2290	12.9050	14.8220	17.0220	14.0148	16.0428
H_2O (oxidation of H_2)	0.3500	0.3500	0.4420	0.4420	0.3680	0.3680	0.1420	0.1420
H_2O (moisture in coal)	0.2300	0.2300	0.0300	0.0300	0.0350	0.0350	0.0280	0.0280
Total H_2O	0.5800	0.5800	0.4720	0.4720	0.4030	0.4030	0.1700	0.1700
Mixing ratio (kg/kg) of flue gases	0.0651	0.0567	0.0420	0.0366	0.0272	0.0237	0.0121	0.0106
Dewpoint of flue gases	45C	42C	37C	35C	29C	27C	17C	15C

* Water vapor in the air is neglected in this calculation, because the water vapor is negligibly small during ice-fog weather conditions.

† The term "pre-dried Eielson coal" refers to the same coal as used at Eielson AFB, hypothetically dried to 3% moisture content.

$$m_o = 0.2319\,m = \frac{1.53\ \text{kg}}{\text{kg of coal}}$$

$$m_n = 0.7681\,m = \frac{5.08\ \text{kg}}{\text{kg of coal}}\ .$$

The mixing ratio and dewpoint for this coal are

$$\gamma_w = 0.0651$$

$$\text{dewpoint} = 45\text{C}.$$

As mentioned earlier, the total water output produced in burning 600×10^3 kg of coal is about 350×10^3 kg. Approximately the same figures apply to Fort Wainwright since a similar type and quantity of coal are used at both bases. Using the heat content of this grade of coal and the rate of consumption, it is concluded that the heating requirement at each base is about 11.04×10^9 Btu per day during severe cold weather conditions. The amounts of coal of various grades which would meet this requirement are itemized in Table VII, along with the total water output of the stated amount of coal.

From Table VII it can be seen that anthracite coal would produce only $\frac{1}{5}$ of the water vapor of the coal used at Eielson AFB (or Fort Wainwright) for the same heating value.

There is a considerable difference in the dewpoint between stack gases produced from different grades of coal (Table VI). However, regardless of the coal used, there is a considerable difference between the temperature of the gases in the stack of a coal burning plant (about 260C) and the dewpoint of the flue gas (45C or lower).

It should be noted in passing that coal with a relatively low sulfur content is preferable, thereby limiting SO_2 and reducing health hazards, especially during ice-fog weather conditions, when sharp temperature inversions exist near the ground.

Discussion

It seems evident that one of the important contributors to ice-fog formation is the water vapor from coal burning power plants. The failure of the attempt at glycol dehumidification of stack gases at Eielson AFB has been attributed to the unexpected degree of carry-over of glycol due to the exceptionally high flow of air necessary for combustion during extreme heating requirement periods. The glycol, which normally should have run off to a glycol still, was scattered by the high velocity stack gases and, mixing with wash water, was wasted out of the water outlet.

Table VII. Flue gases from an amount of coal whose heating value is 11.04×10^9 Btu.

Flue gases	Eielson coal 600×10^3 kg (1.2×10^6 lb) Excess air		Dried (3% H_2O) Eielson coal 492×10^3 kg (0.983×10^6 lb) Excess air		Semi-bituminous 373×10^3 kg (0.746×10^6 lb) Excess air		Anthracite 415×10^3 kg (0.830×10^6 lb) Excess air	
	30% ($\times 10^3$)	50% ($\times 10^3$)	30% ($\times 10^3$)	50% ($\times 10^3$)	30% ($\times 10^3$)	50% ($\times 10^3$)	30% ($\times 10^3$)	50% ($\times 10^3$)
SO_2	4.44	4.44	4.62	4.62	4.48	4.48	7.38	7.38
CO_2	1104.00	1104.00	1135.00	1135.00	1122.00	1122.00	1280.00	1280.00
O_2	275.40	459.00	286.00	476.00	288.00	440.00	293.00	492.00
N_2	3980.00	4572.00	41[illegible]	4730.00	4120.00	4380.00	4230.00	4870.00
Sub-total	5363.84	6139.44	5525.62	6345.62	5534.48	5946.48	5810.38	6649.38
H_2O	348.00	348.00	232.00	232.00	150.50	150.50	70.60	70.60
Total	5711.84	6487.44	5757.62	6577.62	5684.98	6096.98	5880.98	6719.98

Table VIII. Occurrences of ice fog at Fairbanks.

Year	*Number of occurrences*	*Total hours*
1957	12	287
1958	5	62
1959	20	239
1960	6	121
1961	19	375
1962	21	297

Even disregarding this problem, the temperature difference between the average flue gas in a chimney and the dewpoint of the flue gas is so great that the economical elimination of water vapor in flue gas by a glycol dehumidifier seems problematical. However, the development of some means of reduction of water vapor, SO_2, and solid combustion products from flue gases constitutes an important research problem which must be solved in order to reduce ice fog and air pollution.

The water vapor output of anthracite coal has been shown to be only ¼ of the water output of the coal used at Fort Wainwright or Eielson AFB, for an equivalent heating value. It would appear from previous calculations that a coal having a high heating value and low hydrogen and moisture content, such as an anthracite or bituminous coal, should produce less ice fog than the sub-bituminous grades. The problem arises, however, as to whether it is feasible from the standpoint of cost, availability, and possible furnace modifications to utilize high grade coal in furnaces designed primarily for sub-bituminous grades. The cost of high grade coal would undoubtedly be great in comparison to the coal now used because of the greater transportation costs. Anthracite coal, for example, would probably have to be shipped from the "lower 48" whereas the sub-bituminous coal is mined in the Alaska Range.

In connection with the previous statement, it may well be important to consider that the ice-fog problem is a discontinuous phenomenon. Table VIII gives the frequency of occurrence of ice fog (visibility under 7 miles) and the total number of hours of ice fog, by years, from 1957 to 1962. Sixty percent of all ice fog occurrences persisted for less than 6 hours. The total duration of ice fogs dense enough and persistent enough to warrant countermeasures is equivalent to approximately 10 days during a given winter. If it is feasible from an engineering standpoint to use higher grades of coal in the Eielson AFB and Fort Wainwright power plants, then approximately 3800×10^3 kg of high grade coal would suffice for heating purposes during the equivalent 10-day ice-fog period. If it is impossible or impractical to obtain anthracite or semi-bituminous coal, it might be feasible to pre-dry the present type of coal to a moisture content of about 3%, at least for coal to be used during extremely cold weather. Even this measure might lessen the density of the ice fogs produced.

There are many sources of water vapor other than the stack gases of the power plants. As mentioned earlier, Richardson (1964) estimated that the water vapor evaporating from the cooling pond at Eielson AFB is about 170,000 kg/day, an amount of considerable significance in comparison with the 350,000 kg/day produced by the combustion of coal. A reduction of water vapor from the cooling pond was attempted during the winter of 1964-65 by allowing the surface of the pond to freeze over (Taylor and Church, 1966). This was accomplished by letting the hot cooling water (60C) from the steam turbines collect in a deep trench rather than return to the pond. The attempt was only partially successful, due to a lack of water to replenish the supply thereby allowing only about half of the pond to freeze over. This problem is expected to be eliminated by the construction of a ditch to supply more water from a second pond located nearby.

Obviously, therefore, the ice-fog problem is not to be solved by the reduction of water vapor from one source alone. However, each major source of water vapor needs to be considered and corrective action taken as appropriate to each source. The revision of coal consumption may be one link in a chain of corrective measures which will reduce ice fog so that eventually it will impose less restriction on cold weather operations.

Literature cited

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APPENDIX A: CONDENSATION NUCLEUS COUNTS IN THE FAIRBANKS AREA

Date	Location	Time (Local)	Number	Vis (km)	Weather	Wind Dir	Wind m/sec	Temp (C)
18 Jan 62	Birch Hill	1330	2,000/cm³	0.4	Fog	S	1.5	-12
		1392	2,000	0.4	Fog	S	1.5	-12
	PX	1435	60,000	2.4	Fog	SSE	2.5	-12
		1437	60,000	2.4	Fog	SSE	2.5	-12
		1440	50,000	2.4	Fog	SSE	2.5	-12
	Hangar 1	1445	15,000	2.4	Fog	SSE	2.5	-12
		1447	15,000	2.4	Fog	SSE	2.5	-12
	Inside of Hangar 1	1450	70,000	-	-	-		-
		1452	80,000	-	-	-		-
		1453	40,000	-	-	-		-
		1455	65,000	-	-	-		-
		1500	52,000	-	-	-		-
		1501	48,000	-	-	-		-
		1502	48,000	-	-	-		-
		1503	58,000	-	-	-		-
		1504	48,000	-	-	-		-
		1505	52,000	-	-	-		-
		1506	48,000	-	-	-		-
		1507	58,000	-	-	-		-
22 Jan 62	Magnetic Observatory	1400	350	6.4	Blowing snow	WSW	7.7	-12
		1401	550	6.4	Blowing snow	WSW	7.7	-12
		1402	550	6.4	Blowing snow	WSW	7.7	-12
	Farmers Loop Road	1440	4,000	3.2	Blowing snow	WSW	8.7	-12
		1441	2,300	3.2	Blowing snow	WSW	8.7	-12
		1442	2,300	3.2	Blowing snow	WSW	8.7	-12
		1444	2,700	3.2	Blowing snow	WSW	8.7	-12
	Alaska Field Station	1500	1,300	3.2	Blowing snow	WSW	8.7	-13
		1501	1,000	3.2	Blowing snow	WSW	8.7	-13
		1502	1,600	3.2	Blowing snow	WSW	8.7	-13
		1505	700	3.2	Blowing snow	WSW	8.7	-13
	Inside office of Alaska Field Station	1510	3,500	-	-	-		22
		1511	4,000	-	-	-		22
	Birch Hill, west	1600	1,700	4.8	Blowing snow	SW	5	-14
		1601	800	4.8	Blowing snow	SW	5	-14
		1602	700	4.8	Blowing snow	SW	5	-14
		1603	700	4.8	Blowing snow	SW	5	-14
	Hangar 1	1700	9,500	4.8	Light snow	SW	5	-13
		1701	2,700	4.8	Light snow	SW	5	-13
		1702	2,300	4.8	Light snow	SW	5	-13
		1703	32,000	4.8	Light snow	SW	5	-13
		1704	1,800	4.8	Light snow	SW	5	-13
	Downtown Fairbanks	1735	18,000	4.8	Light snow	SW	5	-12
		1736	19,000	4.8	Light snow	SW	5	-12
		1737	37,000	4.8	Light snow	SW	5	-12
		1738	16,000	4.[illegible]	Light snow	SW	5	-12
	International Airport	1755	16,000	4.8	Light snow	SW	6.7	-13
		1757	30,000	4.8	Light snow	SW	6.7	-13
		1759	45,000	4.8	Light snow	SW	6.7	-13
		1801	19,000	4.8	Light snow	SW	6.7	-13
	Geophysical Institute	1820	7,500	4.8	Light snow	SW	6.7	-13
24 Jan 62		2030	6,000	6.4	Ice fog	Calm		-34
		2032	4,000	6.4	Ice fog	Calm		-34
	Hangar 1	2310	5,000	1.6	Ice [illegible]g	NNE	1.5	-37
			11,000	1.6	Ice tog	NNE	1.5	-37
1 Feb 62	Roof of Geophysical Institute	1215	45,000	16	Ice crystals	SE	1.5	-20
		1217	40,000	16	Ice crystals	SE	1.5	-20
		1219	40,000	16	Ice crystals	SE	1.5	-20
		1221	27,000	16	Ice crystals	SE	1.5	-20
		1223	35,000	16	Ice crystals	SE	1.5	-20
		1225	40,000	16	Ice crystals	SE	1.5	-20
		1227	30,000	16	Ice crystals	SE	1.5	-20
		1229	35,000	16	Ice crystals	SE	1.5	-20
	Deadman Slough	1255	18,000	24	Ice crystals	SE	1.5	-22
		1257	18,000	24	Ice crystals	SE	1.5	-22
		1259	15,000	24	Ice crystals	SE	1.5	-22
		1301	16,000	24	Ice crystals	SE	1.5	-22
		1303	16,000	24	Ice crystals	SE	1.5	-22
		1305	19,000	24	Ice crystals	SE	1.5	-22
		1307	18,000	24	Ice crystals	SE	1.5	-22
		1309	19,000	24	Ice crystals	SE	1.5	-22
		1311	30,000	24	Ice crystals	SE	1.5	-22
		1313	18,000	24	Ice crystals	SE	1.5	-22
		1315	19,000	24	Ice crystals	SE	1.5	-22

Date	Location	Time (Local)	Number	Vis (km)	Weather	Wind Dir	Wind m/sec	Temp (C)
25 Jan 63	VOQ, Ft. Wainwright	2220	11,000/cm³	8.0	Fog	NNW	4	-6
		2224	13,500	8.0	Fog	NNW	4	-6
		2226	13,500	8.0	Fog	NNW	4	-6
		2228	13,500	8.0	Fog	NNW	4	-6
		2230	13,500	8.0	Fog	NNW	4	-6
		2232	16,200	8.0	Fog	NNW	4	-6
		2234	16,200	8.0	Fog	NNW	4	-6
		2236	12,200	8.0	Fog	NNW	4	-6
		2238	13,500	8.0	Fog	NNW	4	-6
		2240	13,500	8.0	Fog	NNW	4	-6
		2242	13,500	8.0	Fog	NNW	4	-6
27 Jan 63		1330	116,000	16	Clear	SE	1.5	-14
		1333	116,000	16	Clear	SE	1.5	-14
		1334	134,000	16	Clear	SE	1.5	-14
		1336	104,000	16	Clear	SE	1.5	-14
		1338	234,000	16	Clear	SE	1.5	-14
	International Airport	1400	62,000	24	Ice crystals	Calm		-13
		1402	35,000	24	Ice crystals	Calm		-13
29 Jan 63	Hangar I	1302	72,000	24	Cloudy	NNE	1	-14
		1322	25,000	24	Cloudy	NNE	1	-14
	Downtown Fairbanks	1345	88,000	24	Cloudy	NW	1	-14
		1347	122,000	24	Cloudy	NW	1	-14
		1349	116,000	24	Cloudy	NW	1	-14
	International Airport	1405	9,200	24	Cloudy	NW	1	-14
		1407	10,000	24	Cloudy	NW	1	-14
	Farmers Loop Road	1440	700	24	Cloudy	SE	1	-15
		1442	700	24	Cloudy	SE	1	-15
		1450	7,500	24	Cloudy	SE	1	-15
		1452	7,500	24	Cloudy	SE	1	-15
	Farmers Loop at College Road	1510	7,500	24	Cloudy	SE	1	-15
		1512	9,200	24	Cloudy	SE	1	-15
30 Jan 63	Hangar I	1630	470,000	0.8	Fog	Calm		-10
		1632	72,000	0.8	Fog	Calm		-10
		1634	67,000	0.8	Fog	Calm		-10
		1636	62,000	0.8	Fog	Calm		-10
		1638	133,000	0.8	Fog	Calm		-10
3 Feb 63	Inside Hangar I	1325	10,000	-	-	-		-
		1327	12,200	-	-	-		-
		1329	12,200	-	-	-		-
	Hangar I	1330	11,000	16	Clear	Calm		-29
		1332	10,000	16	Clear	Calm		-29
		1334	11,000	16	Clear	Calm		-29
		1336	7,500	16	Clear	Calm		-29
		1338	13,500	16	Clear	Calm		-29
		1340	16,200	16	Clear	Calm		-29
4 Feb 63	Inside Hangar I	1140	110,000	-	-	-		10
		1142	110,000	-	-	-		10
	Hangar I	1150	57,000	3.2	Ice Fog	Calm		-34
		1152	16,000	3.2	Ice Fog	Calm		-34
		1154	11,000	3.2	Ice Fog	Calm		-34
		1156	25,000	3.2	Ice Fog	Calm		-34
	Downtown Fairbanks	1235	25,000	3.2	Ice Fog	Calm		-30
		1237	25,000	3.2	Ice Fog	Calm		-30
	Alaska Field Station	1250	6,700	2.4	Ice Fog	Calm		-32
		1252	6,100	2.4	Ice Fog	Calm		-32
	Farmers Loop Road	1330	16,200	2.4	Ice Fog	Calm		-33
		1332	14,000	2.4	Ice Fog	Calm		-33
		1335	12,200	2.4	Ice Fog	Calm		-33
		1337	13,500	2.4	Ice Fog	Calm		-33
	Geophysical Institute	1345	16,200	4.8	Ice Fog	Calm		-32
		1347	11,000	4.8	Ice Fog	Calm		-32
5 Feb 63	VOQ, Ft. Wainwright	1420	88,000	4.8	Ice Fog	Calm		-32
		1422	93,000	4.8	Ice Fog	Calm		-32
20 Jan 64	Inside Hangar I	2230	29,000	-	-	-		10
		2233	35,000	-	-	-		8
		2235	35,000	-	-	-		9

APPENDIX A

Date	Location	Time (Local)	Number	Vis (km)	Weather	Wind Dir	Wind m/sec	Temp (C)
20 Jan 64	Hangar 1	2249	880/cm³	3.2	Ice Fog	Calm		-40
		2251	400	3.2	Ice Fog	Calm		-40
		2255	880	3.2	Ice Fog	Calm		-40
	Inside Hangar 1	2303	4,000	-	-	-		12
		2304	8,300	-	-	-		12
		2305	8,300	-	-	-		12
		2306	4,000	-	-	-		12
		2307	7,500	-	-	-		12
	Hangar 1	2313	2,350	3.2	Ice Fog	Calm		-41
		2314	2,750	3.2	Ice Fog	Calm		-41
		2315	3,200	3.2	Ice Fog	Calm		-41
		2316	3,200	3.2	Ice Fog	Calm		-41
		2317	8,300	3.2	Ice Fog	Calm		-41
		2318	3,200	3.2	Ice Fog	Calm		-41
		2320	4,000	3.2	Ice Fog	Calm		-41
25 Jan 64	Inside Hangar 1	1530	27,400	-	-	-		10
		1535	23,000	-	-	-		10
	College Road	1600	93,000	24+	Clear	NNW	1	-28
		1605	143,000	24+	Clear	NNW	1	-28
	Downtown Fairbanks	1620	110,000	24+	Clear	NNW	1	-28
		1630	82,000	24+	Clear	NNW	1	-28
	Main Gate, Fort Wainwright	1645	16,200	24+	Clear	NNE	1.5	-29
	Inside Hangar 1	1655	17,800	-	-	-		10
27 Jan 64	Outside permafrost tunnel	1425	550	16	Cloudy	S	2.5	-14
	Inside office, permafrost tunnel	1430	67,000	-	-	-		10
		1432	57,000	-	-	-		10
	Outside permafrost tunnel	1435	1,800	16	Cloudy	S	2.5	-14
	Inside permafrost tunnel	1440	57,000	-	-	-		-14
		1442	82,000	-	-	-		-14
		1444	110,000	-	-	-		-14
30 Jan 64	Main gate, Fort Wainwright	1442	82,000	24	Cloudy	Calm		-18
		1444	88,000	24	Cloudy	Calm		-18
30 Jan 64	City dump	1453	23,000	24	Cloudy	Calm		-18
		1455	35,000	24	Cloudy	Calm		-18
	Downtown Fairbanks	1507	139,000	24	Cloudy	Calm		-18
		1509	133,000	24	Cloudy	Calm		-18
	Alaska Field Station	1520	110,000	24	Cloudy	Calm		-18
		1522	93,000	24	Cloudy	Calm		-18
	Farmers Loop Road	1630	2,750	24	Cloudy	Calm		-19
		1632	2,050	24	Cloudy	Calm		-19
	Farmers Loop at College Road	1639	57,000	24	Cloudy	Calm		-19
		1641	10,000	24	Cloudy	Calm		-19
	International Airport	1654	14,800	24	Cloudy	Calm		-19
		1656	13,500	24	Cloudy	Calm		-19
1 Feb 64	PX, Ft. Wainwright	1329	290,000	24	Cloudy	S	3	-10
		1331	260,000	24	Cloudy	S	3	-10
	Downtown Fairbanks	1445	290,000	24	Cloudy	S	3	-10
		1447	390,000	24	Cloudy	S	3	-10
	Alaska Field Station	1507	16,200	24	Cloudy	S	2	-10
		1509	21,000	24	Cloudy	S	2	-10
	Farmers Loop Road	1521	6,700	24+	Cloudy	WSW		-10
		1523	9,200	24+	Cloudy	WSW		-10
	Farmers Loop at College Road	1554	9,200	24+	Cloudy	WSW	2	-10
		1556	17,800	24+	Cloudy	WSW	2	-10
		1558	13,500	24+	Cloudy	WSW	2	-10

24+: over 24 km

APPENDIX A

Date	Location	Time (Local)	Number	Vis (km)	Weather	Wind Dir	Wind m/sec	Temp (C)
1 Feb 64	International Airport	1605	27,400	24+	Cloudy	Calm	-	-10
		1607	41,000	24+	Cloudy	Calm		-10
3 Feb 64	Motor pool, Ft. Wainwright	1330	38,000	24	Cloudy	SW	4	-20
		1332	122,000	21	Cloudy	SW	4	-20
	Alaska Field Station	1357	23,000	16	Snow	SW	3.5	-20
		1359	27,000	16	Snow	SW	3.5	-20
	Farmers Loop Road	1510	1,280	16	Snow	SW	3.5	-22
		1512	1,080	16	Snow	SW	3.5	-22
		1514	550	16	Snow	SW	3.5	-22
	Farmers Loop at College Road	1520	2,750	16	Snow	SW	3.5	-22
		1522	3,200	16	Snow	SW	3.5	-22
	International Airport	1533	400	16	Snow	SW	3.5	-22
		1533	400	16	Snow	SW	3.5	-22
	International Airport (5 m from building)	1533	45,000	16	Snow	SW	3.5	-22
	Downtown Fairbanks	1552	21,000	16	Snow	SW	4	-22
		1554	38,000	16	Snow	SW	4	-22
	City dump	1607	330	16	Snow	SW	4	-22
		1609	400	16	Snow	SW	4	-22
	Hangar I	1625	23,000	16	Snow	SW	4	-22
		1627	25,000	16	Snow	SW	4	-22
6 Feb 64		1338	88,000	24	Cloudy	NE	1	-6
		1340	77,000	24	Cloudy	NE	1	-6
	Hospital	1350	470,000	24	Cloudy	NE	1	-6
		1352	196,000	24	Cloudy	NE	1	-6
		1354	110,000	24	Cloudy	NE	1	-6
	Downtown Fairbanks	1402	[illegible]	24	Cloudy	NE	1	-6
		1404	290,000	24	Cloudy	NE	1	-6
	Gold dredge	1433	10,000	24	Cloudy	NE	1	-6
		1435	11,000	24	Cloudy	NE	1	-6
	Outside of permafrost tunnel	1510	7,500	24	Cloudy	NE	1	-6
		1512	8,300	24	Cloudy	NE	1	-6
	Alaska Field Station	1527	11,000	24	Cloudy	NE	1	-6
		1529	17,800	24	Cloudy	NE	1	-6
	Farmers Loop Road	1548	9,200	24	Cloudy	NE	1	-6
		1550	9,200	24	Cloudy	NE	1	-6
	Farmers Loop at College Road	1602	21,000	24	Cloudy	N	3.5	-7
		1604	27,400	24	Cloudy	N	3.5	-7
	Airport	1615	27,400	24	Cloudy	N	3.5	-7
		1617	27,400	24	Cloudy	N	3.5	-7
	City dump	1722	7,500	24	Cloudy	NE	3	-5
		1724	8,300	24	Cloudy	NE	3	-5
7 Feb 64	Hangar I	1610	49,000	24	Cloudy	Calm		-2
		1612	53,000	24	Cloudy	Calm		-2
9 Feb 64	Inside Hangar I	1050	62,000	-	-	-		10
		1052	77,000	-	-	-		10
	Hangar I	1055	23,000	3.2	Ice crystals	SW	1.5	-24
		1057	23,000	3.2	Ice crystals	SW	1.5	-24
		1422	49,000	16	Clear	SW	3.5	-24
		1424	16,200	16	Clear	SW	3.5	-24
		1426	16,200	16	Clear	SW	3.5	-24
	Alaska Field Station	1440	139,000	16	Clear	SW	3.5	-24
		1442	77,000	16	Clear	SW	3.5	-24
	Farmers Loop Road	1500	9,200	16	Clear	SW	3.5	-24
		1502	14,800	16	Clear	SW	3.5	-24
	Farmers Loop at College Road	1530	25,000	16	Clear	SW	3.5	-24
		1532	19,400	16	Clear	SW	3.5	-24

24+: over 24 km

APPENDIX A

Date	Location	Time (Local)	Numbe	Vis (km)	Weather	Wind Dir	Wind m/sec	Temp (C)
9 Feb 64	International Airport	1542	550/cm³	16	Clear	SW	3.5	-24
		1544	770	16	Clear	SW	3.5	-24
	Inside office at airport	1555	57,000	-	-	-		20
		1557	53,000	-	-	-		20
	City dump	1615	400	16	Clear	SW	3	-24
		1617	400	16	Clear	SW	3	-24
	Downtown Fairbanks	1625	53,000	16	Clear	SW	3	-24
		1627	57,000	16	Clear	SW	3	-24
10 Feb 64	Hangar 1	0950	128,000	1.6	Ice Fog	N	1	-33
		0952	122,000	1.6	Ice Fog	N	1	-33
	Cooling pond, Eielson AFB	1310	88,000	8	Ice Fog	N	1.5	-29
		1312	62,000	8	Ice Fog	N	1.5	-29
		1314	82,000	8	Ice Fog	N	1.5	-29
		1316	72,000	8	Ice Fog	N	1.5	-29
	Hangar 1	2330	99,000	11	Clear	NE	4.5	-28
		2332	72,000	11	Clear	NE	4.5	-28
	Main gate, Fort Wainwright	2335	21,000	11	Clear	NE	4.5	-28
	Downtown Fairbanks	2345	99,000	11	Clear	NE	4.5	-28
		2345	110,000	11	Clear	NE	4.5	-28

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13. ABSTRACT

During January and February of 1962, 1963 and 1964, Fairbanks, Alaska, and vicinity was the site of a series of studies dealing with ice fog and ice crystals. This report presents the results of an investigation of the amount and extent of air pollution and ice fog in the area with special emphasis on reducing ice fog by decreasing the water vapor being emitted into the atmosphere. The major sources of water vapor at the two military installations in the region, Fort Wainwright and Eielson AFB, are the heating and power plants and their associated cooling ponds. In the populated areas around Fairbanks, a high aerosol concentration of about 10^5 particles/cm^3 exists, whereas in the uninhabited areas the concentration is extremely low (about 300 particles/cm^3). Much of the high concentration is due to the burning of coal for heat and power. Because the coal is of low grade it also emits about 350,000 kg of water vapor into the atmosphere on a day when the temperature is -40C. This water vapor condenses on the aerosols and produces ice fog. Anthracite or semi-bituminous coal would reduce the water vapor output to only 1/5 of the amount produced by the low grade coal. Water vapor from cooling ponds can be reduced by freezing the surfaces of the ponds.

14. Key Words

Alaska-meteorology
Ice fog
Ice crystals
Air pollution
Water vapor
Condensation nuclei

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