ENGINEERING RESEARCH INSTITUTE
THE UNIVERSITY OF MICHIGAN
ANN ARBOR

Interim Technical Report No. 5

EFFECTIVENESS OF AIR CLEANERS OPERATING IN ATMOSPHERES CONTAINING SNOW

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Project 2233

DETROIT ARSENAL, DEPARTMENT OF THE ARMY
CONTRACT NO. DA-20-089-ORD-36962
CENTER LINE, MICHIGAN

November 1956

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OBJECTIVE

Snow or ice particles made air-borne by vehicle motion and tread action are induced into the main-engine air-induction system of a combat tank. The accumulation of such particles in the air-induction system, particularly in the air cleaners, may cause a reduction in the combustion air flow and a decrease in available power. The power loss may be serious and may limit engine operation to a short time period. This report is concerned with some understanding of the snow-ice—induced power-loss problem and the investigation of remedial measures.

ABSTRACT

If snow particles could be denied entry into the air cleaner or confined to the air cleaner only, the study of engine power loss caused by the accumulation of snow in the air-induction system might be limited to a study of the properties of the air-borne snow and the operation of air cleaners in atmospheres containing these particles. This was the approach made.

A study of the general properties of snow and ice was made and a résumé of this study, including a bibliography, is included.

An experimental study showed that part of the induced snow will remain in either a wet or a dry air-cleaner reservoir, part will be trapped in the filter element and part will pass downstream into the air-induction system. Snow collection efficiency in the air cleaner is a function principally of reservoir fluid temperature and the rate of snow induction. Collection efficiencies are generally less than 80 percent. Air-cleaner pressure drop reaches a maximum and air flow rate a minimum for a given snow volume in the cleaner. Addition of more snow does not change these values for this "blocked" condition. Snow in the air cleaner may reduce the air flow rate by a factor of nearly 4.

A supplement to this report is a time-lapse motion-picture film showing an air-cleaner section in operation inducing air containing snow through the cleaner. Test operation of this air-cleaner section (at start) corresponds to a total air flow of about 350 cfm through an air cleaner. Snow used in these tests was always less than 1.0 mm in maximum dimension and less than

0.5 mm in some tests. The motion pictures show that most of the snow induced into an air cleaner could be denied entry by an inertia-type precleaner.

Application of heat to the airstream prior to entry into the air cleaner or heating the air-cleaner body are possible control methods. It should be feasible to develop a snow-removing, heated-reservoir, pre-cleaner kit suitable for or adaptable to vehicles now in the field.

CHAPTER I

SUMMARY OF SNOW AND ICE CHARACTERISTICS[1]

Snow is a porous mixture of ice, air, and water. The physical properties vary widely with the properties and proportions of each of the constituents. Temperature is also a major control on these physical properties in three ways: (1) Water is present in snow only at the melting temperature of ice; (2) the moisture content of air varies with temperature; (3) the properties of ice vary appreciably with temperatures near the melting point.

Size and shape of the ice crystals affect the physical properties of snow. Some snow shapes are fragile, others more compact. Interlocking of the crystal branches may produce a structural effect. Aging may cause the grains to bond into an ice network which adds greatly to structural strength. This bonding is a characteristic of dry snow.

Surface tension has an important and variable effect on the cohesive properties of wet snow, where there are many air-to-water intersurfaces. There is a proportion of air to water in snow which results in maximum cohesion for given grain size. Loose, dry snow has little cohesion. Slightly wet snow composed of slender, branched crystals has high cohesion, which is reduced by any melting that destroys the lacy structure. Coarse snow with large grains and slush with a high proportion of water to air have low cohesion. When new, wet snow is compressed the crystals are broken and pressed together, increasing the active surface-tension interfaces and increasing cohesion. Compression also forces most of the air and water out of the snow, but some water remains as a film between the snow grains. After compression ceases, the water film freezes and the snow becomes hard and icy.

Snow may be typed broadly by

(1) ice, water, and air composition,
(2) temperature,
(3) grain or crystal size and shape, and
(4) degree of grain bonding.

[1]Much of this résumé was obtained from <u>Canadian Survey of Physical Characteristics of Snow</u>, by G. J. Klein, National Research Council of Canada.

The International Classification for Snow[2] and other publications[3] give details, including instrumentation and usage, for a snow classification system. Major variables are:

Solid Precipitation
- Classes of particle
- Size of particle

Deposited Snow
- Specific gravity or density
- Free water content
- Impurities

Structure
- Grain shape
- Grain size
- Compressive yield strength
- Tensile strength
- Shear stress at zero normal stress
- Hardness
- Snow temperature

Snow-Cover Measurements
- Vertical layer coordinate
- Total depth of snow cover
- Depth of daily new snowfall
- Inclination of snow surface
- Water equivalent of snow cover
- Ratio of snow-covered area to total area
- Age of snow deposit

When water freezes, the resulting ice approximates the shape of the water prior to freezing. When the solid is formed by sublimation, the shape is that of a crystal. Freezing produces ice and rime while sublimation yields crystals of snow and hoar. The snowflake pattern depends mainly on the rate of growth of the flake. Slow growth produces the more solid forms while rapid growth results in plane crystals of slender proportions and open pattern. Usually the rate of growth is not constant, resulting in flakes of complex patterns. Not all snowflakes are perfect. Single-crystal flakes are called "simple snowflakes." "Compound snowflakes" are composed of several partially melted flakes stuck together. At low temperatures there is a small amount of moisture available for snowflake growth and the flakes are of hexagonal plate or column form. At moderate formation temperatures the flakes are larger and

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[2] The International Classification for Snow, issued by The Commission on Snow and Ice of the International Association of Hydrology, published by the Associate Committee on Soil and Snow Mechanics, T. M. 31, National Research Council, Ottawa, Canada.

[3] See bibliography at end of report.

mostly of complex pattern. At freezing temperatures there are compound snowflakes or "sleet." Snowflakes covered with a thick coating of rime are roughly spherical and are termed "graupeln" or "soft hail." A layer of graupeln has a dull, chalky-white appearance and is the sole form of freshly fallen snow suitable for skiing. When flakes pass through a series of melting and freezing stages, with moisture added between stages, they become coated with successive layers of ice and are called "hail."

Immediately after snow has fallen, changes begin to occur in its structure. The slender crystal branches begin to evaporate and recondense on the more solid parts of the crystals, which gradually become small irregular grains. As the crystals change shape they become more compact and the snow cover changes in two stages. In the first stage, the crystals lose all their feathery structure and become small and granular, and the snow is termed "settled." In the second stage the grains grow in size and bond together. Sun, rain, and thawing conditions may take a role in the second stage.

SNOW-COVER CHANGES BY WIND ACTION

Fallen snow contains much air. New, dry snow is about 90 percent air by volume and hard crust about 50 percent. Wind blowing over the snow surface induces air flow within the porous interconnected passages of the snow layer and greatly accelerates settling. Snow structure changes due to wind action depend on the temperature, relative humidity, strength, and duration of the wind. When the air temperature is below freezing, wind accelerates evaporation and sublimation. Evaporation predominates when the wind is dry, and the snow settles with little tendency for the grains to bond. A very dry wind tends to loosen grains that have bonded previously. With winds of high humidity, sublimation predominates and causes bonding of the snow grains and hardening of the snow, called wind packing. When new snow is compressed its crystals become broken, the fragments lie closely together, and slight wind action will bond the grains and harden the snow. When old snow drifts by wind action, the grains become rounded by friction and lose all outward crystalline appearance.

SNOW-COVER CHANGES BY MELTING AND FREEZING

Sublimation always produces forms that have crystalline facets, but melting followed by freezing produces forms devoid of facets. The amount of melting determines the extent of the change. Repeated thawing and freezing usually produces a coarse snow. During thawing the smaller grains melt more readily than the larger grains, and if there is no appreciable run-off, nearly all the thaw water will be distributed in a nearly uniform coating on the remaining grains. When freezing occurs the larger grains will have grown at the expense of the smaller grains. The rate of seepage of thaw water through snow is low, usually between 0.3 and 2 inches per minute.

In summary, snow may have an almost infinite variety. Its grain size may vary from 0.2 to 9 mm, its specific gravity from below 0.03 up to 0.52 for wet, old snow (slush may have a specific gravity up to 0.85), and the degree of bonding varies widely.

As some testing might be done at Churchill, known data on snow in this area may be of interest. Most of the snow cover is deposited by wind and only about one-quarter by direct precipitation. Strong winds in low temperatures rapidly transform new snow into settled old snow, with crystal facets produced by sublimation when no recent melting has occurred. This snow has considerable sparkle in bright sunlight. The surface grains usually are less than 1 mm but may be as large as 6 mm.

CHAPTER II

POSSIBLE METHODS FOR REDUCTION OF ENGINE POWER LOSS CAUSED BY SNOW ACCUMULATION IN AIR-INDUCTION SYSTEM

Reduction of the snow mass taken in by an engine air-induction system, snow elimination at the air-cleaner component, or passage of the snow into the engine in a noninjurious form might be accomplished by one or more of the following methods.

OBTAINING AIR SUPPLY OF LOWER SNOW CONTENT

The advantage of reducing the snow content of the engine air-induction system is apparent. Locating the air entry must, however, be a compromise based on conflicting design demands. For example, a folding snorkel erected from a tank engine deck would not rotate with the turret, but could be collapsed upon demand for gun rotation. Such a snorkel tube might be constructed of canvas supported by a telescoping rod.

SNOW PRECIPITATION BY ELECTRIC OR SONIC MEANS

This was not studied. The methods may be feasible but they appear unsuitable because of complexity, power and space requirement, initial cost, logistic problems, and probably reliability.

CHEMICAL TREATMENT

It was planned to demonstrate experimentally at least one chemical effect, but a dearth of snow during this phase of the study precluded this experiment. Various salts might be introduced into the air cleaner, which might initiate melting or sublimation of snow collected.

There are some materials (e.g., ammonia) which are said to reduce the adhesion properties of snow and ice. It seems likely that the use of such materials merely would transfer the snow accumulation from the air cleaner to some other engine component or introduce new problems in components of the engine or in the engine itself.

MECHANICAL AIR CLEANING

Mechanical air cleaning, from the viewpoint of both filtration and separation is discussed in some detail in Chapter III. A precleaner seems feasible.

HEAT ADDITION

Heat addition might be used in several ways to avoid the effects caused by snow and ice induced into the air cleaner. Calculations and comments for two methods are listed below and apply to a complete air cleaner. Data are based on experimental values obtained by test of a one-quarter section air cleaner, as discussed later.

Heat Addition Required to Melt Snow Removed in Air Cleaner.—When the cleaner is allowed to block completely, the following data apply:

Air-cleaner weight	56.8 lbs.
Reservoir oil weight	7.9 lbs.
Snow weight	12.8 lbs.
Specific Gravity of Snow	0.363

Assuming that there is no heat loss from the air-cleaner body, that there is snow only in the cleaner, and that use of mean specific heats is permissible, 3605 Btu would be required to heat up the air cleaner and melt all snow in it. If the heat delivered from a 60,000-Btu-per-hour personnel heater could be temporarily diverted to snow melting, the melting period would be some 4 min. If the cleaner were blocked, the combat-vehicle engine would not be in operation during this period. Insulation of the air cleaner is indicated. The calculations were made for ambient air at -60°F and air-cleaner components heated to +40°F.

Heat Addition Necessary to Heat Engine Induction Air Above the Melting Temperature of Ice.—A medium combat-tank engine equipped with two air cleaners demands about 1000 pounds of air per hour per air cleaner at the idle condition. If 125 cfm of air heated to 300°F were included in the air requirement, then the air-mixture temperature would be about 80°F when the atmosphere ambient-air temperature is -65°F. The heat addition could be supplied by a 40,000-Btu-per-hour heater. Actual heat addition and temperature requirement would be a function of geometric design, but this heating method seems feasible for the engine idle condition and might be useful in the prevention of any build-up of snow in the air cleaner.

CHAPTER III

EXPERIMENTAL PROGRAM ON MECHANICAL AIR CLEANER FOR SNOW REMOVAL

The mechanical air cleaners now in service on military vehicles are partially effective in removing snow from the induced air, but cause trouble themselves at times. An experimental study was instituted to measure quantitatively the performance of an oil-bath air cleaner. This is especially needed when it is realized that removal of snow particles prior to their entry into the air cleaner or in the air cleaner itself would be more desirable than addition of other devices downstream of the cleaner.

Some of the variables which may affect snow passage or retention in the air cleaner are

(1) rate of snow induction,
(2) air-cleaner and oil-reservoir temperature,
(3) interior air-cleaner surface condition—wet or dry—,
(4) physico-chemical properties of reservoir fluid,
(5) concentration of snow in the air feed,
(6) air flow rate through air cleaner,
(7) temperature of air flowing through cleaner,
(8) humidity of air flowing through air cleaner,
(9) snow particle size,
(10) snow particle shape,
(11) snow specific gravity,
(12) snow temperature,
(13) snow free-water content, and
(14) snow cohesiveness.

Only the effect of the first five parameters was studied in this investigation, an attempt being made to maintain the rest of the variables constant.

EQUIPMENT AND PROCEDURE

A quarter section of a Donaldson oil-washed air cleaner with removable tray was used in this study. Clear Plexiglas face plates were installed longitudinally to permit visual and photographic observation of the filter in operation. Care was taken that no air leakage took place between the 1/2-inch-thick Plexiglas plate and its juncture with the filter section.

The exit of the air cleaner was connected with four-inch flexible hose to the inlet of a turbine-type blower.[4] The air leaving the blower passed through two-inch pipe and a rotameter,[5] graduated at intervals of 100 cfh from 0 to 10,000 cfh. The air was then exhausted to the atmosphere.

The static pressure immediately downstream of the air cleaner was measured with a 50-inch Meriam manometer graduated at 0.1-inch intervals and filled with methanol. The pressure upstream of the rotameter was obtained with a 0-to 60-inch (water) dial gauge. Temperatures were measured with an alcohol thermometer graduated from -50° to +50°C in subdivisions of 0.2°C.

The entire apparatus was installed in a cold room maintained at -14°C during these experiments. In a typical experiment some 2000 grams of snow passed through the air cleaner and into the blower; therefore, it was necessary to store the blower, rotameter, and piping in a warm room after the completion of the experiment to melt and remove the snow lodged in this equipment. The equipment would then be reassembled in the cold room for the next experiment.

The snow fed to the air cleaner was weighed on a triple-beam balance whose smallest increment was 0.1 gram. The weight of the entire filter unit after plugging was obtained on a 50-16 capacity Toledo scale. The dimensions of the snow particles were obtained with the use of an Edmond optical comparator with graduated objective, while the grain shape of the snow was observed with a 50-power microscope. The snow was filtered through galvanized screen of these average screen dimensions.

wire diam = 0.01 inch
opening size = 1.2 x 1.8 mm.

The snow was manually screened into the open inlet of the filter section in pulses of about one-minute duration with 1- to 2-minute intervals between the snow-loading pulses. For the over-all time of the run the snow input rate ranged, in different runs, from 2 to 9 gm/sec and the actual rate for the one-minute loading pulse was of the order of 6 to 10 gm/sec. The average density of the introduced snow cloud would range from 4 to 7 gm/cu ft of air-snow cloud.

The snow used in the filter tests was snow obtained from snow cover on Willow Run Airport, Ypsilanti, Michigan. The snow was usually stored in a cold room prior to testing. Characteristics of the snow after screening and ready for entry into the filter were:

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[4] Spencer Turbine Co., Hartford, Conn., serial No. 42520.

[5] Selas Floscope, Selas Corp. of America, Catalogue No. B-C-1.

Grain size	-	0.5 to 1.0 mm
Grain shape	-	rounded-facet ice crystals having appearance of old snow
Specific gravity	-	0.3 to 0.4
Temperature	-	always less than 0°C.

Note that the snow temperature was always less than 0°C; thus the free-water content of the snow was zero.

Prior to snow introduction, the air flow through the cleaner was about 500 pounds per hour, with an initial air-pressure drop across the cleaner of about 8.5 inches of water.

EXPERIMENTAL RESULTS

A summary of the experimental data obtained in this brief study of air cleaners is presented in Table I.

Submitted with this report is a 16-mm color movie taken during tests no. 6, 7, 10, and 11. This time-lapse movie shows the build-up of snow in the filter element as well as the flow pattern of snow through the air cleaner.

The first run shown in the movie (test no. 6) is for a low snow feed rate and a low oil temperature (SAE 20, -12°C). The next run shown (test no. 7) was at the same snow feed rate but at a higher oil temperature (+14.6°C). The fact that some 3.6 pounds of snow (1627gm) passed completely through the filter element before blocking occurred is illustrated in the movie by showing the amount of snow lodged downstream of the air cleaner. The collection efficiency of the air cleaner in this run with 0.3 to 0.5-mm-diam snow particles was 47 percent of the snow fed.

The third run shown (test no. 10) was at an oil temperature (-14°C) similar to the first run shown but with the snow feed rate (480 gm/min) almost four times as great. A comparison of these two experiments indicates that increasing the feed rate from 118 gm/min to 480 gm/min lowers the collection efficiency of this cleaner with cold oil from 78 to 39 percent.

In the last run shown in this movie, the filter element was removed and no fluid was present in the reservoir. A considerable amount of snow at a very rapid feed rate was required to plug this configuration. The flow pattern rounding the corner at the bottom of the cleaner (where blockage always occurred) is evident in the movies.

The graphs of data presented in the movie are also reproduced in this report. In Fig. 1, a plot of snow collection efficiency versus oil

TABLE I

EXPERIMENTAL DATA: AIR-CLEANER SNOW TESTS

Test Number		3	4	5	6	7	8	9	10	11
Date		1-25-55	1-27-55	1-28-55	2-1-55	2-2-55	2-4-55	2-9-55	2-11-55	
Air-cleaner fluid		None	Glycol	SAE 20 Oil	SAE 20 Oil	SAE 20 Oil	SAE 20 Oil	SAE 20 Oil	SAE 20 Oil	None
Fluid temperature at start, °C		—	-13	+7	-12	+14.6	+1.5	+33.5	-14	—
Test time, minutes		54	34	61	10	27	22	24	7	20
Avg. test-room ambient, °C		-5.9	-14.25	-14.9	-11.9	-15	-12.4	-10	-14	-12
Cleaner air flow, cfh	max	5600	5800	5800	5250	5500	5900	5800	5900	5950
	min	1700	2000	1050	1900	1600	1600	-(a)	1700	-(a)
Cleaner ΔP, in. H_2O	max	21.6	33.9	23.4	38.3	40.1	28.9	36.8	32.8	35.2
	min	6.6	7.8	7.2	7.3	7.3	7.6	8.1	6.8	6.5
Snow particle size, max, mm		0.5	0.5	0.5	1.0	0.3-0.5	0.5	0.5-1.0	0.5-1.0	0.3
Specific gravity of snow		0.32*	0.32*	0.32*	0.34	0.38	0.36	0.38	—	—
Snow temperature, °C		-6	-5	-13	-3.5	-12	-12	-14	-5	-7
Avg. Snow Feed Rate, gm/min		74	85	121	165	113	188	164	481	
Total snow input, gm		4005	2888	7402	1652	3049	4154	3928	3337	—
Snow Entrainment in cleaner, gm		1180	1988	1262	1287	1422	1377	958	1286	—
Collection efficiency		0.295	0.69	0.17	0.78	0.47	0.33	0.24	0.38	

*As measured 2-1-55

(a) Rotameter frozen

Test 11—No filter element in cleaner

Tests 1 and 2 made at atmospheric temperature and not reported

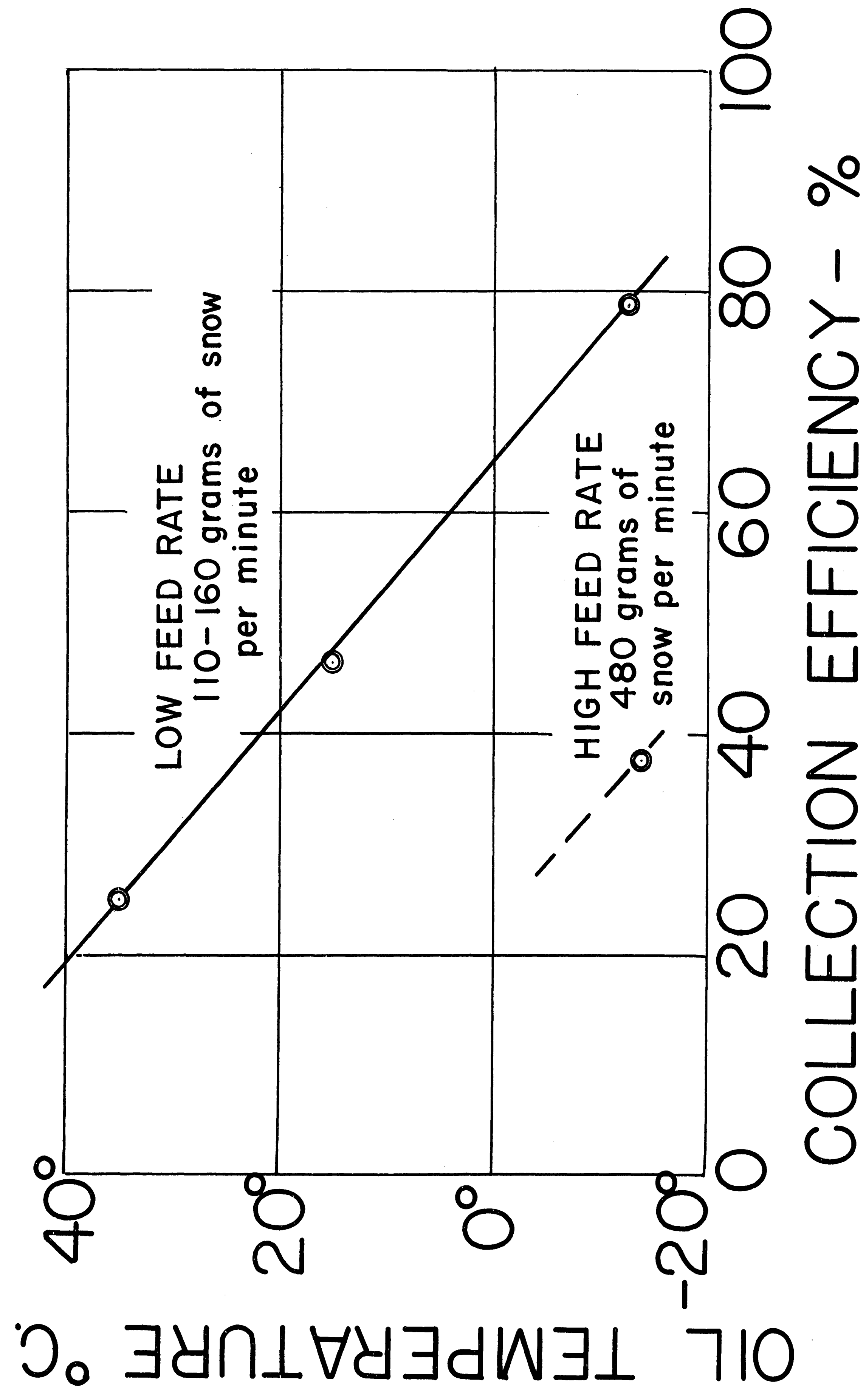


Fig. 1. Oil temperature vs collection efficiency.

temperature is shown. Increasing the oil-reservoir temperature results in a marked decrease in collection efficiency, the efficiency at low snow feed rates decreasing from 78 percent at -12°C to 24 percent at +34°C. The decrease in collection efficiency with increased feed rate has been previously mentioned but is also apparent from this graph.

The reduction in flow rate through the air cleaner as the total weight of induced snow accumulates is apparent in Fig. 2, where data for low and high feed rate runs (tests 6 and 10) are presented. Note that the flow rate is reduced to the same value (30 cfm) in both cases when blockage occurs, even though the total weight of snow fed at a high feed rate was twice as great as the total amount of snow fed at the lower feed rate.

The pressure loss through the air cleaner as a function of the total amount of snow fed is presented in Fig. 3 for both low and high feed rates with cold oil in the reservoir. Of course, the increase in pressure loss occurred at the same time (or at the same weight of snow fed) as the corresponding decrease in flow rate. In all of the runs the pressure loss increased at the greatest rate during the first minute of operation in the snow cloud.

The most consistent observation made during these runs was that the amount of snow collected in the air cleaner was a constant, regardless of the total amount of snow fed, the feed rate, the time interval over which the experiment was conducted (one run was interrupted for a two-hour period), and the temperature of the oil in the reservoir, if less than 15°C. This is illustrated in Fig. 4. Even in the run (test no.3) in which no oil was present in the reservoir, the weight of snow collected in the quarter-section air cleaner was about the same value.

Only when the reservoir oil was replaced by ethylene glycol was the value substantially increased, presumably due to the increased solubility of snow in the ethylene glycol compared to its solubility in SAE 20 oil.

The effect of different reservoir fluids on the snow collection efficiency of this type of air cleaner is presented in Fig. 5. All four runs were performed at the same low temperature (-12° to -14°C) and the top three runs were at a low feed rate. In the last run (which is the last run shown in the accompanying movie), with the filter element itself removed, it was necessary to feed the snow at a very large feed rate to obtain blocking. The low collection efficiency obtained when no fluid is present in the reservoir is evident from an examination of this chart.

In the usual experiment, not more than 1450 gm of snow lodging in the filter section reduced the air flow to a steady value of the order of 150 lb per hour and increased the filter air-pressure drop to a steady value ranging from 30 to 40 inches of water.

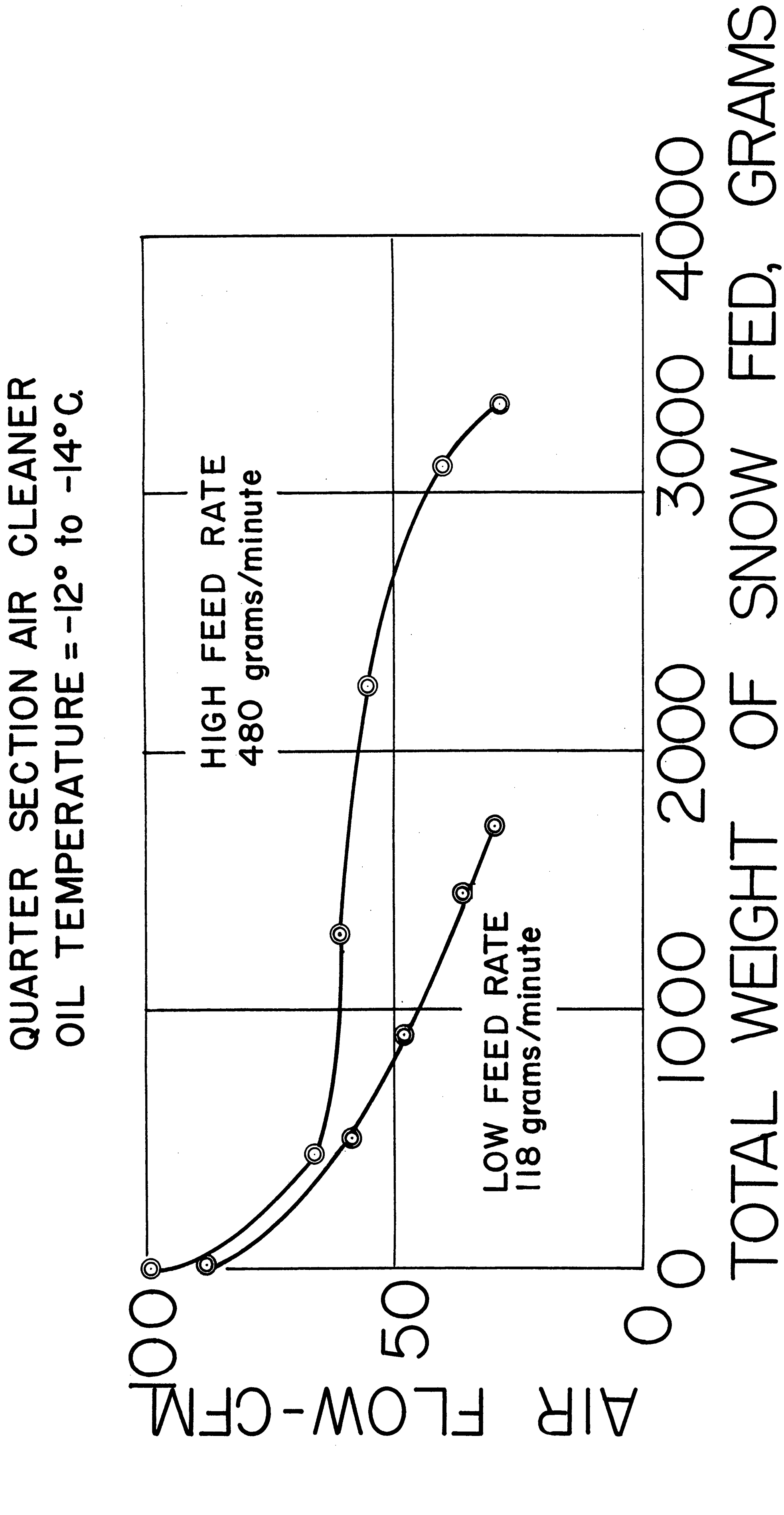


Fig. 2. Flow vs weight of snow fed.

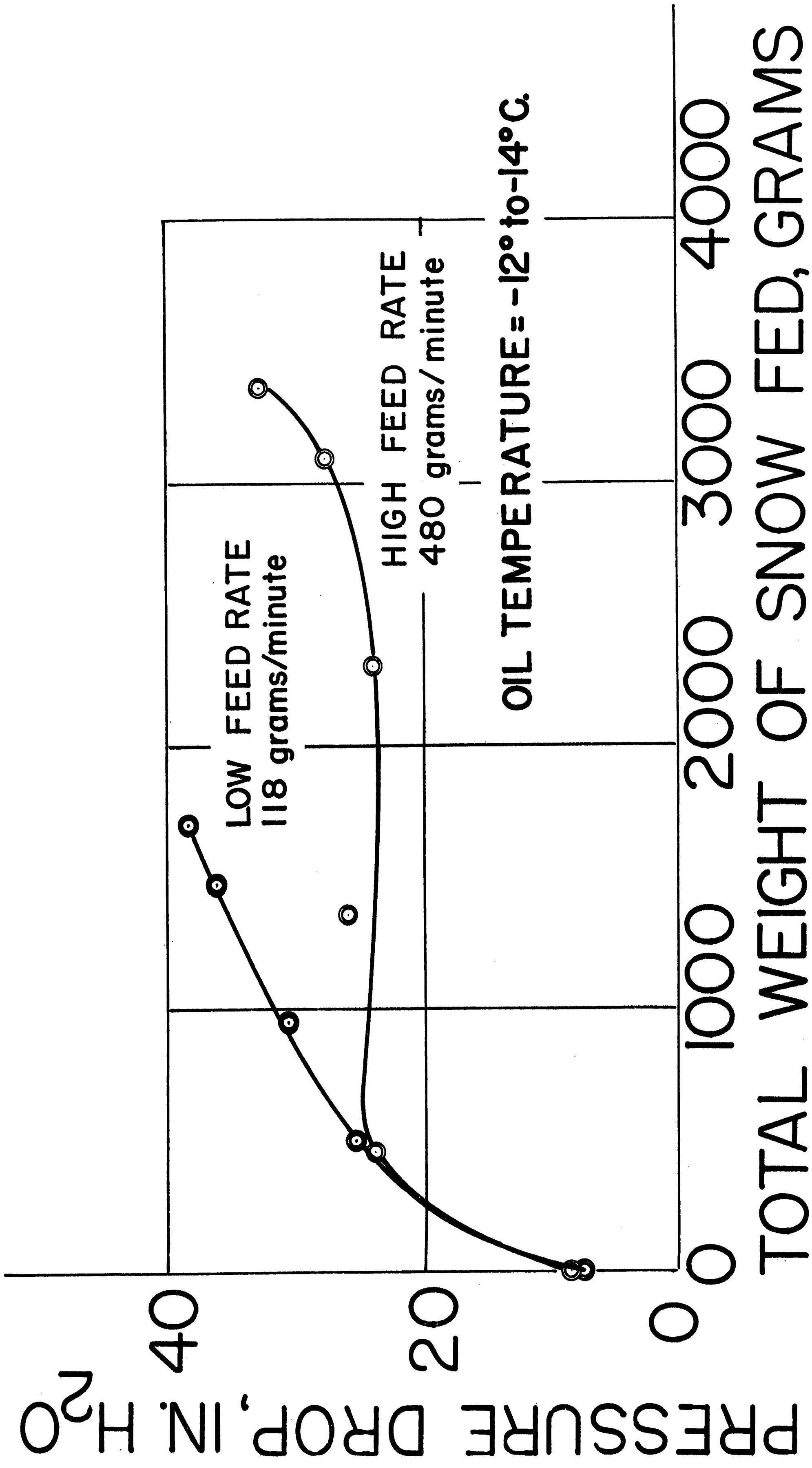


Fig. 3. Pressure loss vs weight of snow fed.

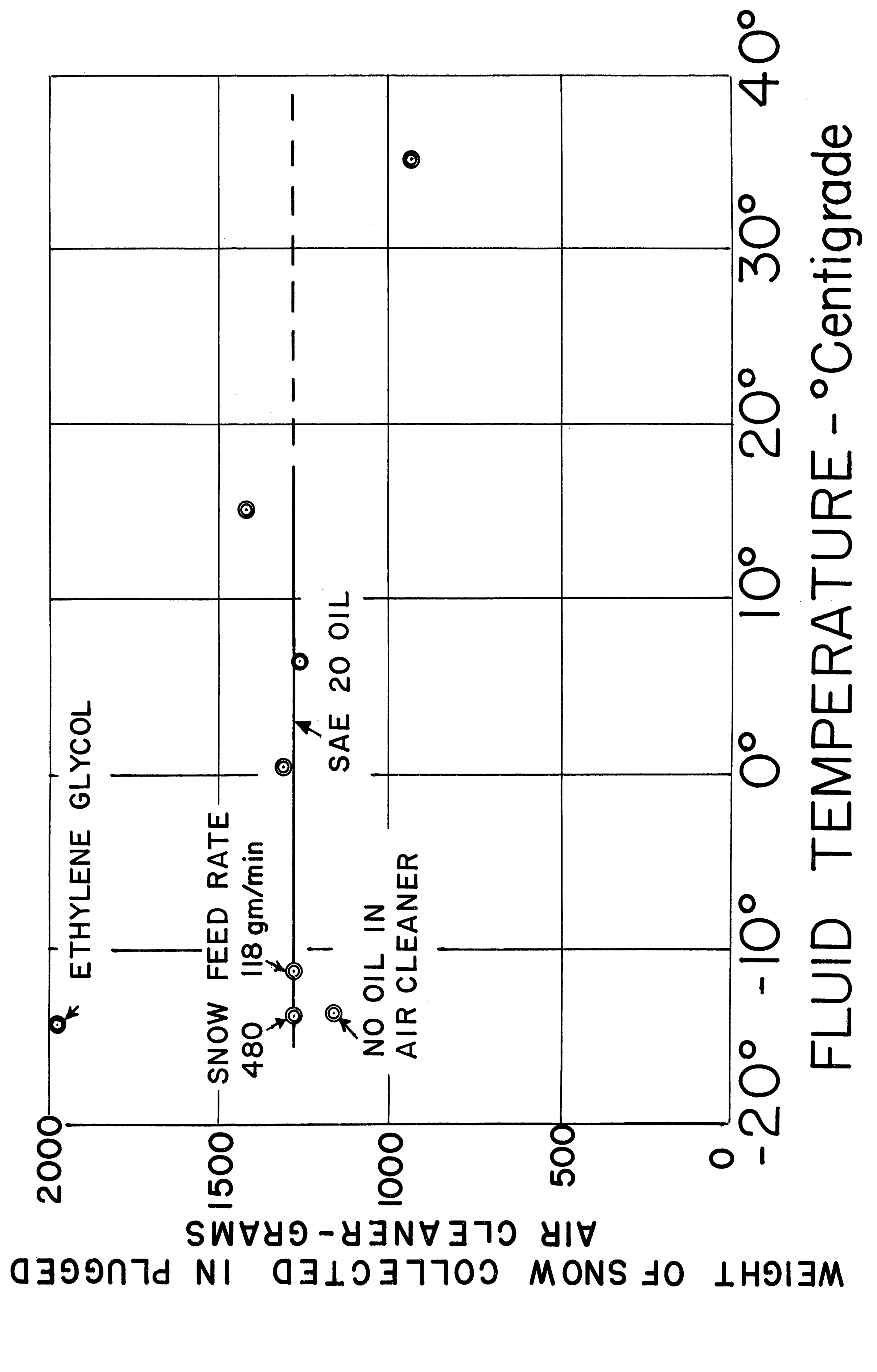


Fig. 4. Weight of snow collected vs oil temperature.

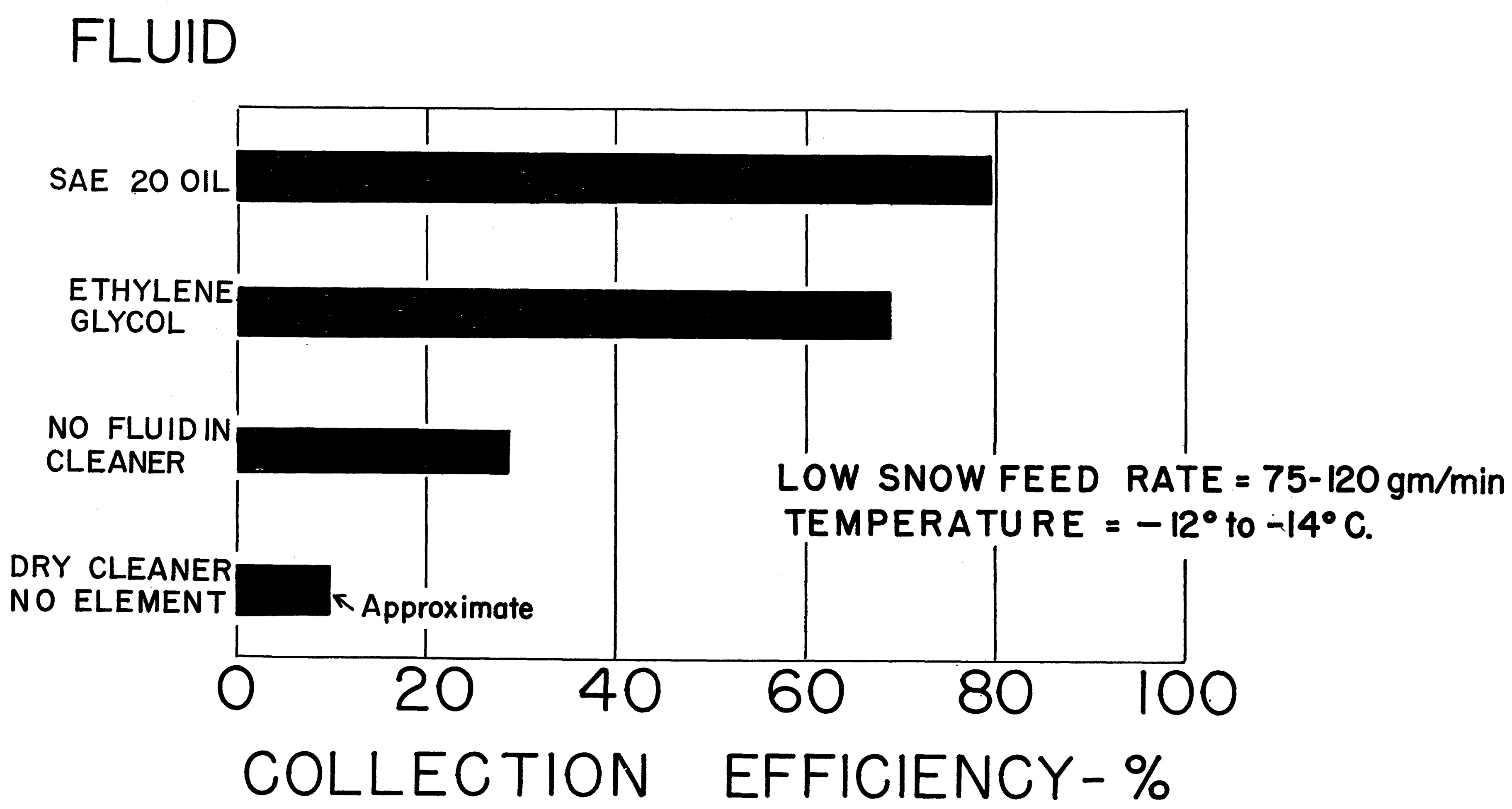


Fig. 5. Effect of different reservoir fluids on snow collection efficiency.

Thus the snow build-up in the filter section reduced the air flow by a factor of 3-3 1/2 and increased the pressure loss by a factor of 4-5. The pressure-loss coefficient,

$$c_f = \frac{2(\Delta P)}{\rho v^2} ,$$

is increased by a factor of 40 to 50.

Extrapolating the readings from the one-quarter symmetrical filter section, the complete filter would be passing 2000 lb of air per hour when clean and 750 lb per hour for a snow build-up in the filter of 12.8 lb. This is less air than needed for idling on many vehicles.

VISUAL AND PHOTOGRAPHIC OBSERVATIONS

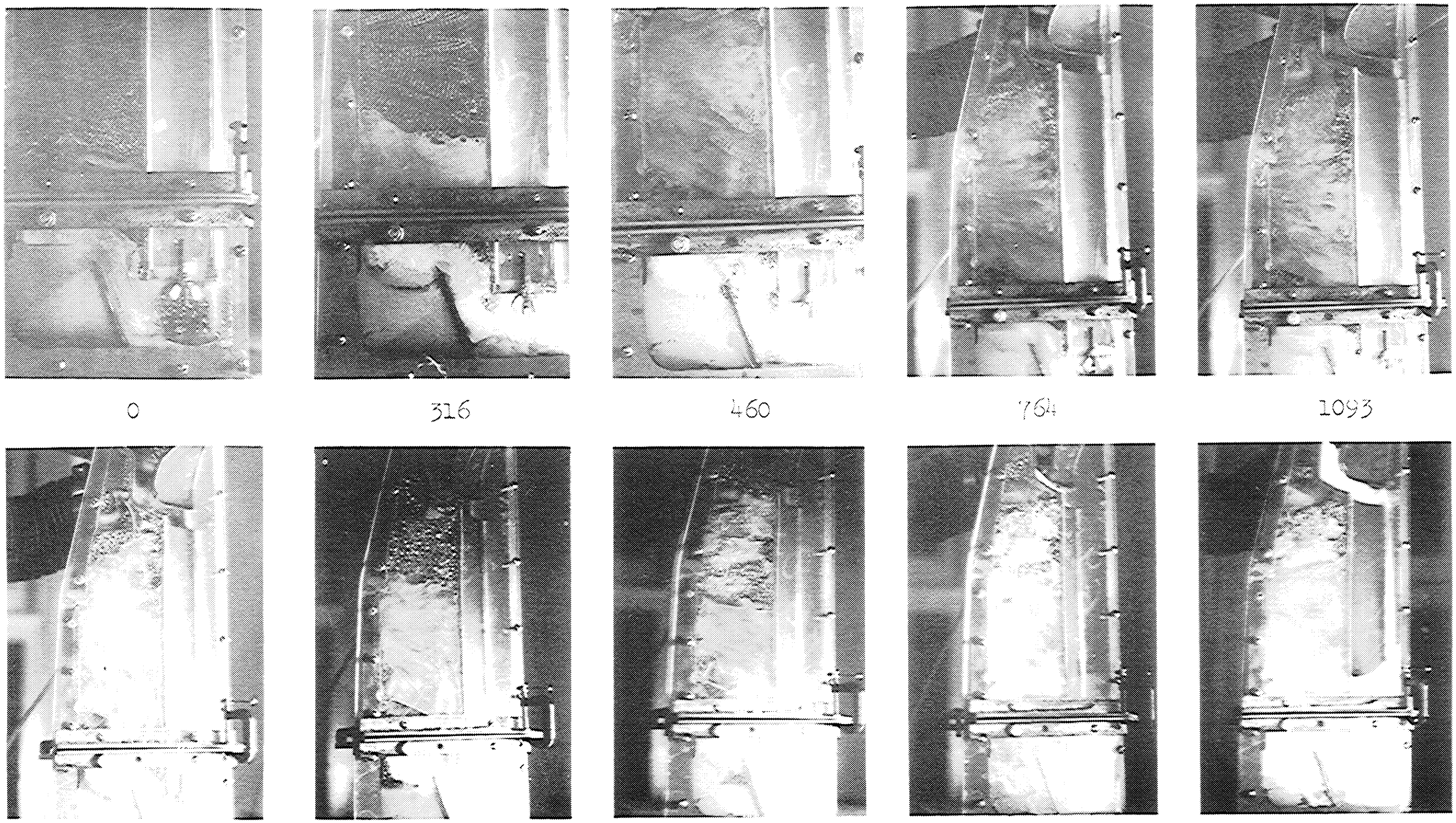
Snow entering the air cleaner could proceed as follows:

(1) Through the screen element and out the clean-air outlet.
(2) Adhere to parts of the screen element.
(3) Build-up in the oil reservoir.

Visually it was observed that the snow build-up followed a pattern. Much of the initial snow input appeared to pass completely through the cleaner, but some snow remained both in the cleaner filter element and in the oil reservoir. This action took place for a wet or a dry oil reservoir. It was observed, however, that more snow would pass through the cleaner when the oil reservoir was dry. The next step in the pattern was a reduction in the ratio of snow passed through to that remaining in the cleaner. Snow continued to build up in both the filter element and in the oil reservoir. Additional snow introduction followed the same general trend and the air cleaner was considered blocked by snow when the air flow was reduced to a value which could not be further reduced by additional snow introduction.

Figure 6 is a photograph of the filter exit, showing snow lodged in it, as at the end of the test no. 7. Still photographs of the quarter-section air cleaner at various stages in test no. 4 (ethylene glycol in filter) and in test no. 3 (no oil in filter) are shown in Figs. 7 and 8. In Fig. 9, some streak photographs, obtained by letting steam condense and freeze on the transparent face plates, are presented. A much better understanding of the internal flow in the air cleaner may be obtained by viewing the 16-mm movie submitted than by examination of these photographs.

Fig. 6. Photograph of air-cleaner exit.



0 316 460 764 1093

1524 1893 2303 2749 2888

Fig. 7. Photographs of air cleaner with ethylene glycol reservoir fluid. Photograph sequence of snow accumulation from start to "blocking." Total snow input into cleaner noted in grams (Test No. 4).

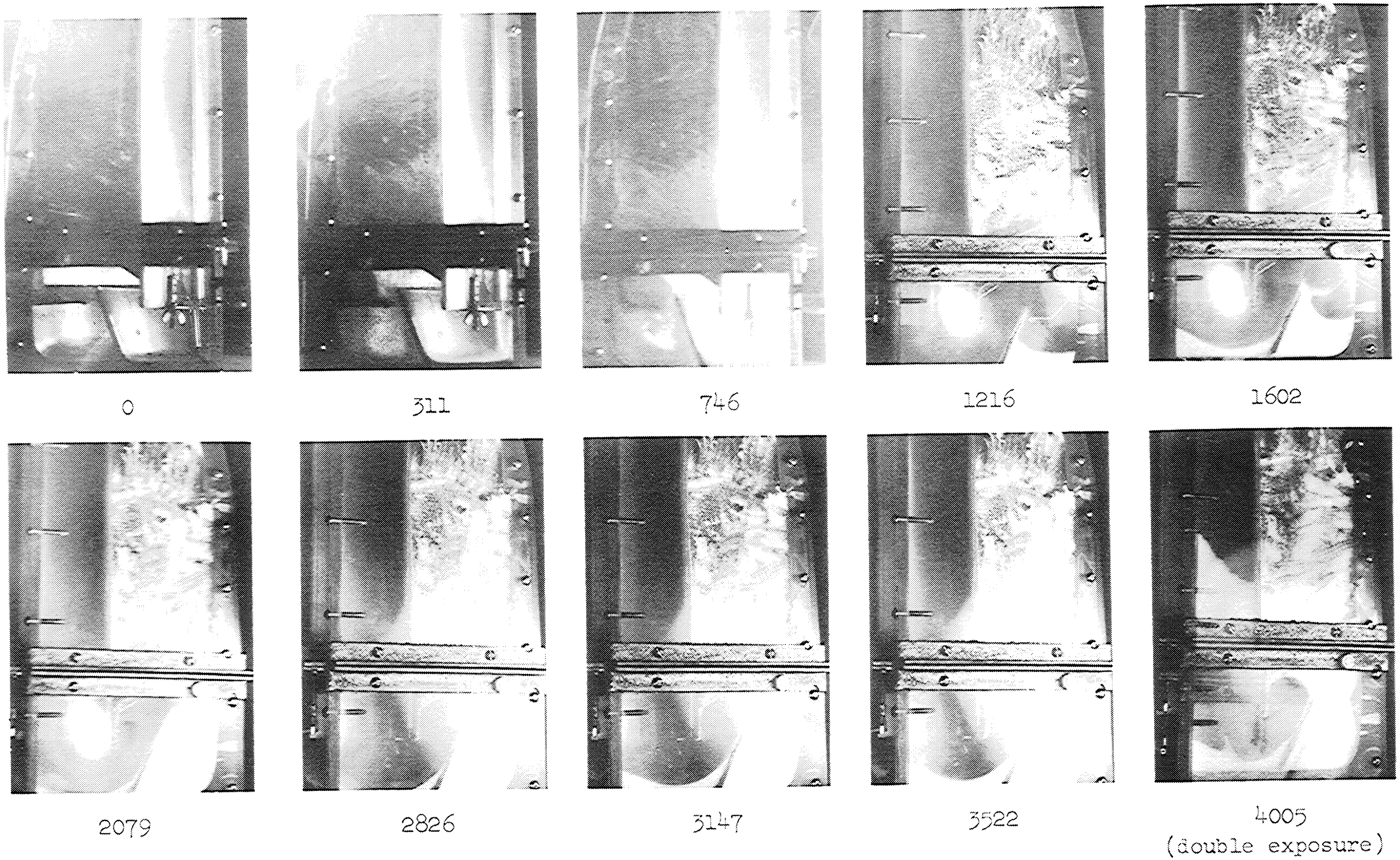


Fig. 8. Photographs of air cleaner with no reservoir fluid. Sequence of snow accumulation from start to "blocking." Total snow into cleaner noted in grams (Test No. 3).

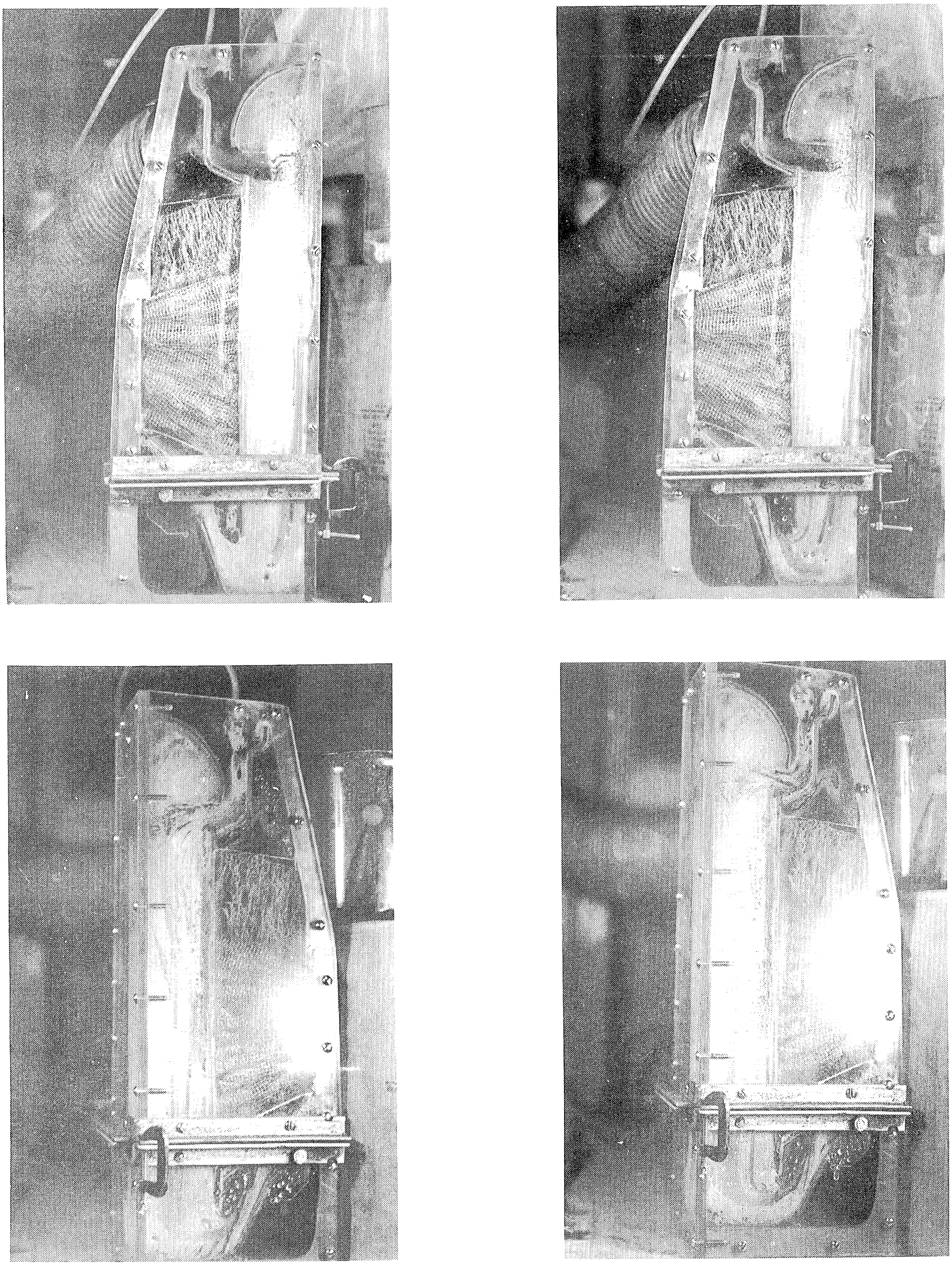


Fig. 9. Photographs of steam condensing on air cleaner face plate. Flow rate through quarter section = 100 CFM.

PRECLEANER CONSIDERATION

Consider a particle of snow in an airstream which is turning a corner. If we equate the centrifugal force on the particles to the drag force acting on the particle, we may write

$$C_D \frac{\rho A V_D^2}{2} = \frac{w}{g_c} \frac{V_t^2}{R},$$

where

C_D = drag coefficient,
ρ = density of snow particle,
A = projected area of snow particle,
w = mass of snow particle,
g_c = conversion factor for mass and force units,
R = radius of curvature of particle streamline,
V_D = displacement of velocity of snow particle, normal to V_t, and
V_t = tangential velocity of snow particle.

Rearranging, we write

$$V_D = \frac{V_t}{\sqrt{R}} \sqrt{\frac{2w}{g_c \rho A C_D}}$$

so that the displacement velocity is directly proportional to the tangent velocity and inversely proportional to the square root of the radius of curvature, if the physical properties and dimensions of the snow particle remain constant.

Assume that a precleaner is desired to remove snow particles of 1/2-mm dimension entering the air cleaner. If the inlet velocity of the snow-air mixture is 70 ft/sec and an average radius of curvature is 3 inches, the snow particles will be deflected about 0.6 inch making a 90° turn. Hence, a very simple precleaner consisting of a 90° elbow and provision for removing the collected snow would be feasible. The snow thus collected could be removed continuously by applying heat and draining the liquid water.

CHAPTER IV

CONCLUSIONS

1. The air-flow reduction caused by accumulation of snow in the air cleaner is of such a magnitude for a blocked air cleaner that engine idling may not be possible.

2. The snow collection efficiency of a quarter-section Donaldson-type oil-washed air cleaner, operating in air atmosphere at -14°C is reduced:

   a. From 78 to 39 percent when the snow feed rate is increased from 118 to 480 gm/min, and the SAE 20 oil temperature is -12°C;
   b. From 78 to 47 percent at a snow feed rate of 118 gm/min when the oil temperature is increased from -12°C to 15°C;
   c. From 78 to 20 percent at a snow feed rate of 118 gm/min when the oil is removed from the air cleaner.

3. The quantity of snow collected in the air cleaner is not a function of the snow feed rate, quantity of snow fed, oil-reservoir temperature (under 15°C), or the quantity of oil in the reservoir, but is a constant value (1250-1300 gm of snow in the quarter-section cleaner). The use of water-soluble reservoir fluids presumably increases this value.

4. The problem of blockage of the air cleaner by snow could be solved by denying entry of the snow to the air cleaner, by such methods as precleaners (separators) upstream of the air cleaner, heat additions, or use of a snorkel-type air intake.

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February 3, 1953. After 36 miles of operation on the snow road with dry oil reservoirs in the air cleaners and using induction air from the engine compartment, approximately one quart of water was found in each filter after vehicle had been placed in warm storage.

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