950R73055

WORKING PAPER

No. 19
Aug. 1973

UNITED STATES · ENVIRONMENTAL PROTECTION AGENCY

COLD REGIONS
AUTOMOTIVE EMISSIONS

U. S. ENVIRONMENTAL PROTECTION AGENCY
ARCTIC ENVIRONMENTAL RESEARCH LABORATORY
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COLD REGIONS AUTOMOTIVE EMISSIONS

This report is the result of the combined effort
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Working Paper No. 19

August 1973

This paper presents results of investigations which are to some extent limited or incomplete. Therefore, conclusions or recommendations--expressed or implied--are tentative. Mention of commercial products and/or trade names does not constitute endorsement.

ERRATA

"COLD REGIONS AUTOMOTIVE EMISSIONS"

page 1 line 7	reads carbon dioxide (CO)..... should read carbon monoxide (CO).....
page 18 Fig. 7	vertical axes reads 40, 60, 70, 70, 80..... should read 40, 50, 60, 70, 80.....
page 22 & 23	The CO emissions are calculated as $\frac{\text{lit}}{\text{min}}$ CO They should be listed as $\frac{\text{centilit}}{\text{min}}$ CO

ABSTRACT

Cold Regions Automotive Emissions

In Fairbanks, Alaska, during February and March 1973, the emissions of 631 vehicles were analyzed at idle and adjustments were made to reduce CO and HC emitted. It was found that proper adjustment of in-use vehicles could result in approximately 34% reduction in CO and a 12% reduction in HC produced at idle. Emission levels of propane and gasoline and diesel fueled vehicles were measured and compared. Various pollution control devices are discussed and considered for cold weather use and conclusions are drawn. Ice Fog is considered as it relates to CO emission control.

ACKNOWLEDGEMENTS

For their invaluable assistance to this project, we acknowledge the following individuals with sincere thanks: Mr. John Sweet, Environmental Conservation Manager, Alaska District, Atlantic Richfield Company, for securing necessary test equipment; Mr. Richard F. Basset, Retail representative of Standard Oil of California, Western Operation, Inc., for providing a site to test the vehicles of the general public; the personnel of the GSA Motor Pool, State Highway Department Motor Pool, Yellow Cab Company, and Municipal Utilities System Motor Pool for their cooperation in testing fleet vehicles, and the citizens of Fairbanks for their overwhelming response and cooperation in testing vehicles for the general public.

In addition, we wish to express a special thank you to Dr. Fred L. Voelz of Atlantic Richfield's Harvey Technical Center for technical guidance, analytical assistance and general support during the Vehicle Emissions Analysis Program.

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I. INTRODUCTION

A. Background

Alaska is the largest, most sparely populated, least industrialized state in the nation. Yet its major interior city, Fairbanks, stands as one of the great environmental ironies in this country today. This city with an area-wide population of only 44,000 has air pollution levels which rival, and surpass, those of New York and Los Angeles. The air quality of the Fairbanks area is degraded mainly by three types of pollutants. These are carbon ~~dioxide~~ monoxide (CO), ice fog and dust particulates. The toxic health effects of CO have been well documented.[1,2] Records have shown Fairbanks to have one of the most acute CO problems of all American cities. This paper deals with this pollutant. Ice fog air pollution is unique to regions with extremely cold climates. The nature of ice fog has been well defined.[3] The main objection to this cold weather phenomenon is that it severely restricts visibility under abnormally difficult driving conditions (-30°F or less). Ice fog often occurs simultaneously with high ambient CO levels. However, high CO levels occur much more frequently than ice fog. Therefore, ice fog is discussed here only with respect to its interrelationship with methods to control CO emissions. The other pollutant, dust particulate, will not be considered in this report.

Studies show[4] that over 80% of the CO present in the low level ambient air of the Fairbanks area is produced by the internal combustion engine in motor vehicles. The conclusion here is simple: if air quality is to improve in Fairbanks, CO contributions from the automobile must be greatly reduced. The procedure for reducing these emissions is where the dilemma facing Fairbanks clearly reveals itself.

In Fairbanks, motor vehicles must perform the routines of daily operation at temperatures from -50°F in winter to +95°F in summer. No other city in the United States experiences such temperature extremes. Fairbanks is located in a natural bowl surrounded on three sides by hills and has little wind. Arctic winter conditions cuase some of the most extreme thermal inversions in the world; these inversions trap stagnant air and pollutants. These environmental differences drastically change the character of motor vehicle utilization compared to cities in the southern 48 states. It is these differences which make it difficult to directly apply solutions to the Fairbanks situation which have proved successful outside of cold regions.

Fairbanks must then look inward to solve its unique problems. The research necessary to find solutions must be done considering that uniqueness. This report is a part of such a research effort.

B. Scope

Due to the severity of vehicle-emitted CO in the Fairbanks area and the non-availability of research data pertaining to such emission in other areas with cold climates, the Department of Environmental Services of the Fairbanks North Star Borough initiated a research program to be known as the Vehicle Emissions Analysis Program (VEAP). This report presents the results of that program as well as other cold region emissions information obtained by the investigators.

In this project, the Fairbanks North Star Borough was assisted by: the Atlantic Richfield Company (ARCO), which supplied necessary instrumentation, personnel to instruct in its operation, and data interpretation; Arctic Environmental Research Laboratory, Environmental Protection Agency (EPA) and the Institute of Arctic Environmental Engineering (IAEE)* of the University of Alaska who supplied engineering and technical personnel for both acquisition and reduction of the data obtained.

*Now part of the Geophysical Institute of the University of Alaska.

As originally conceived, VEAP would be modeled after the Atlantic Richfield Company's Clean Air Caravan Program which had been carried out in several cities in the lower 48 states.[5] The field testing was planned to run for a period of four weeks during February and early March 1973, a time when the average temperature is in the neighborhood of 0°F. Emissions from private and governmental fleet vehicles as well as those of the general public were to be tested. The program was originally outlined as follows:

Part I: Fleet vehicles only at hot idle (idling after engine warm-up)

Measure: RPM
% CO
Parts per million (ppm) HC
Total gas flow at constant RPM
Exhaust gas temperature

Also check effect of air inject into exhaust manifold pollution control device (limited mainly to 68, 69, and 73 model years).

Time requirement using two men: 3/4-1 hour/vehicle; or 8-10 vehicles/day.

With one extra man, Orsat Analysis for carbon dioxide (CO_2) and oxygen (O_2) could also be accomplished.

Assuming the fleets have 40-50 vehicles each, then run tests as follows:

1st week - GSA Motor Pool
2nd week - State Highway Dept. Motor Pool
3rd week - Propane fueled fleet (Yellow Cab)

Total: 120-150 fleet vehicles

Part II: General Public Vehicles (Voluntary) - 4th week.

Measure: RPM
% CO
HC

Check effect of proper idle mix screw adjustment (only if mechanic is available).

30-60 vehicles/day x 5 days = 150-300 vehicles total.

While all of the tests set forth in the original plan were not accomplished, (see VEAP Program) the total number of vehicles tested far exceeded the early estimates.

It was thought that the accomplishment of this project would provide some of the information necessary for governmental organizations to plan realistic strategies to improve air quality in the Fairbanks area. It would also provide an opportunity for a critical assessment, from an engineering standpoint, of the physical problems associated with the operation of motor vehicle emission control systems in cold regions.

This report is limited to discussing the problem of reducing CO emissions from internal combustion motor vehicles in cold regions as it relates to the vehicles themselves. Other methods for reducing CO, such as, replacement of private vehicles with mass transit, electric (battery) powered vehicles, streamlining traffic patterns, and limiting vehicle miles traveled are not considered here. However, all of those measures represent viable solutions or partial solutions to the CO problem. Specifically, this study has concentrated on gasoline engines of United States manufacture, some of foreign manufacture, propane fueled engines and diesels.

II. VEHICLE EMISSIONS ANALYSIS PROGRAM

A. General

The VEAP testing was done during the period of February 6 to March 3, 1973. The air temperatures experienced during that period are shown in Table 1. As previously mentioned, not all of the data were acquired as called for by the original plan:

1. Total gas flow measurement at constant RPM was not made on any vehicles.
2. Exhaust gas temperature was not measured.
3. Orsat analysis on fleet vehicles was not made, but oxygen (O_2) was measured for all vehicles.

At the end of the testing program, emissions from over 600 vehicles had been analyzed.

B. Equipment and Procedure

Exhaust gas concentrations of CO and hydrocarbons (HC, measured as hexane) were measured for each vehicle using an Olson-Horiba, nondispersive infrared analyzer. Exhaust system leaks or air pump operation was checked with a Teledyne O_2 meter. Engine speed was measured in RPM with a clip-on (high tension leads) type induction tachometer. Positive crankcase ventilation (PCV) valves were checked when necessary with a manometer. Figure 1 is a schematic of the test set up. The following describes the test procedure carried out on each vehicle.

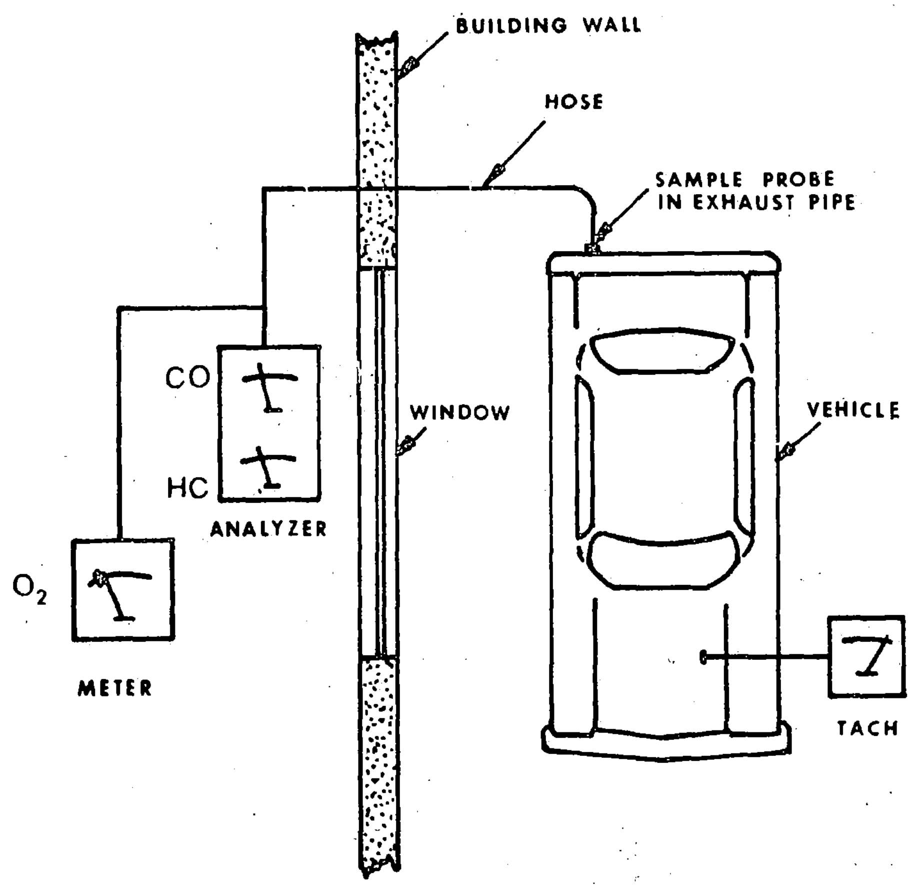
1. A vehicle with the engine running at normal operating temperature was driven into position. The emission sampling probe was placed in the exhaust pipe and the tachometer was connected. The idle speed, model year, manufacturer, mileage, engine type, and displacement, if readily available for the vehicle, were recorded.

TABLE 1

Temperature in Fairbanks, Ak., from February 6 to March 3, 1973

8:00 a.m. --- 5:00 p.m.

	DATE	MAXIMUM TEMPERATURE	MINIMUM TEMPERATURE	MEAN
Feb.	6	9	-10	- 2
	7	10	- 6	1
	8	10	-12	- 2
	9	0	-18	-11
	10	11	-24	-10
	11	10	-26	-10
	12	0	-15	- 8
	13	0	-17	- 8
	14	- 1	-25	-14
	15	- 5	-13	- 8
	16	2	-16	- 7
	17	- 1	-17	- 9
	18	11	-19	- 2
	19	35	- 8	19
	20	34	20	25
	21	28	11	18
	22	29	13	21
	23	18	- 6	8
	24	22	- 1	12
	25	21	-15	7
	26	21	-17	4
	27	13	-18	2
	28	12	3	8
March	1	9	- 2	4
	2	4	- 7	- 2
	3	2	-16	- 5



TEST SETUP

FIGURE 1

2. The condition of the PCV (Positive Crankcase Ventilation) valve was then checked for vacuum by plugging it with the thumb. Those that failed this test were more carefully checked with a dry type manometer.

3. With the transmission in neutral, the engine speed was increased to 2500 ±100 RPM and the steady state CO and HC emissions were recorded. The engine speed was then returned to idle.

4. The steady state CO and HC levels were recorded at idle.

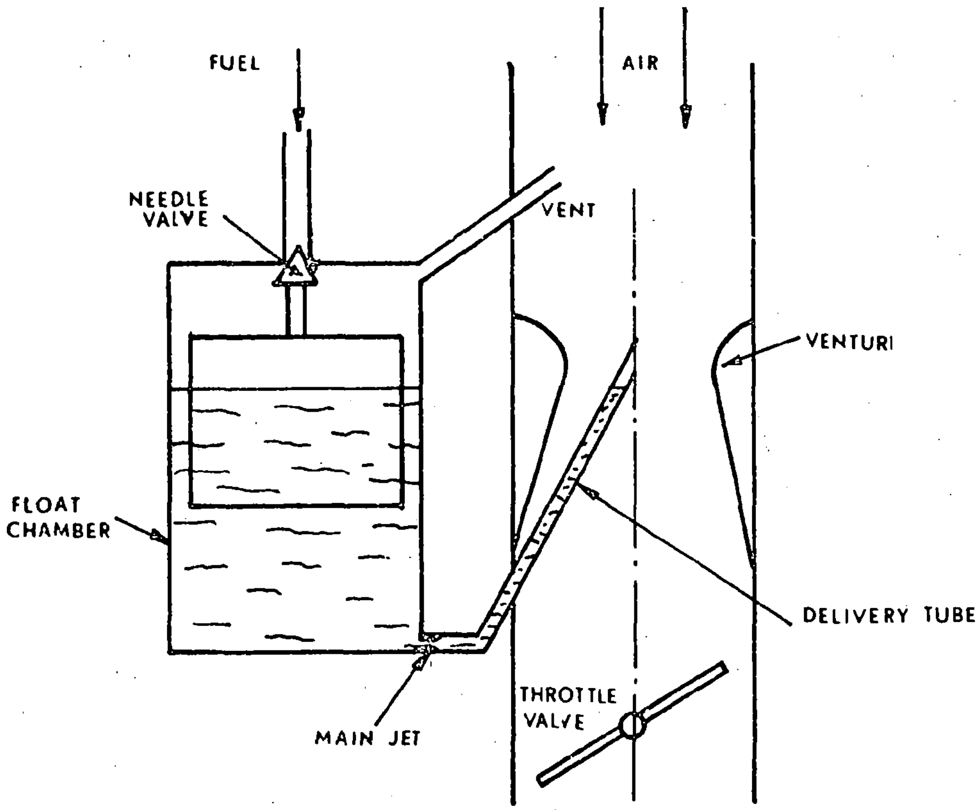
5. Carburetor adjustments were made if appropriate.

C. Discussion of Procedure

For a full understanding of the significance of each part in the procedure, a short discussion of the function of the internal combustion engine carburetor is necessary.

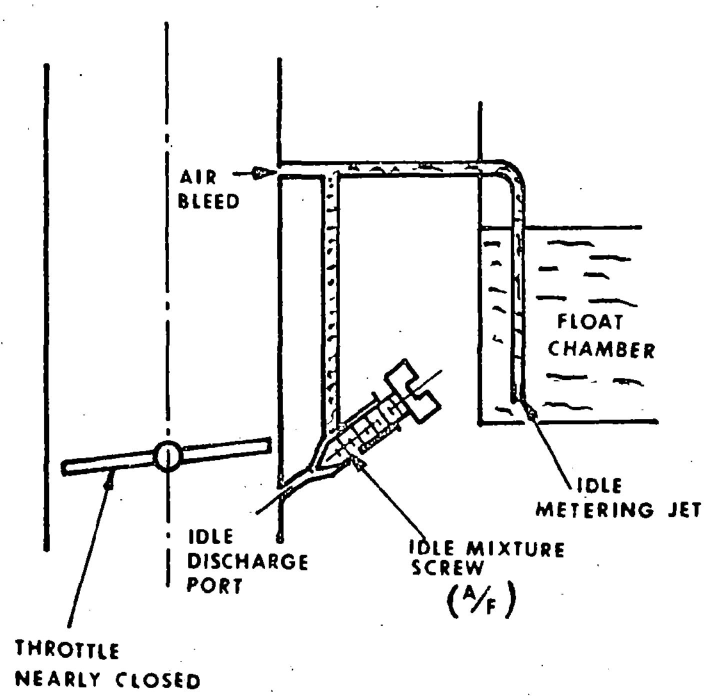
Ninety-five percent of the vehicles tested during this program were powered by internal combustion engines using gasoline as fuel and the conventional carburetor to meter fuel to the engine. It is the function of the carburetor to properly mix fuel and air for introduction into the combustion chamber (cylinders) to sustain efficient combustion throughout the speed and power band of the engine. To accomplish this, the modern carburetor is divided into two major systems, the main metering system and the idle system.

The main metering system is the system by which the carburetor operates while the engine is running at speeds above idle and/or under load. A simplified schematic of this system is shown in Fig. 2. Under these conditions, air flows are high and the resulting pressure drop in the venturi (barrel) draws fuel up the delivery tube spilling it into the barrel where it mixes with the air and continues to the intake manifold. The amount of fuel delivered to the barrel is metered by the main jet. This restricting orifice is fixed in size



SIMPLE CARBURETOR MAIN METERING SYSTEM

FIGURE 2



SIMPLE CARBURETOR IDLE SYSTEM

FIGURE 3

dependent on specific engine parameters such as, displacement, duty cycle, etc. If the main metering system is functioning properly and if the intake manifold is flow balanced, the combustion in the cylinders is very efficient and the resulting CO and HC emissions are low (<2% CO and <200 ppm HC). The 2500 RPM no-load test verifies the condition of this system and detects any gross malfunctions which could not be compensated for if adjustments are required to the idle system. If the 2500 RPM CO concentration was above approximately 4%, then the vehicle's air filter and choke were examined. If they appeared to be restricting air flow, the 2500 RPM test was again run with air filter removed and/or choke held open to demonstrate any differences to the motorist. Other diagnostic information can be revealed by the emission levels of this test but will not be covered in this report.

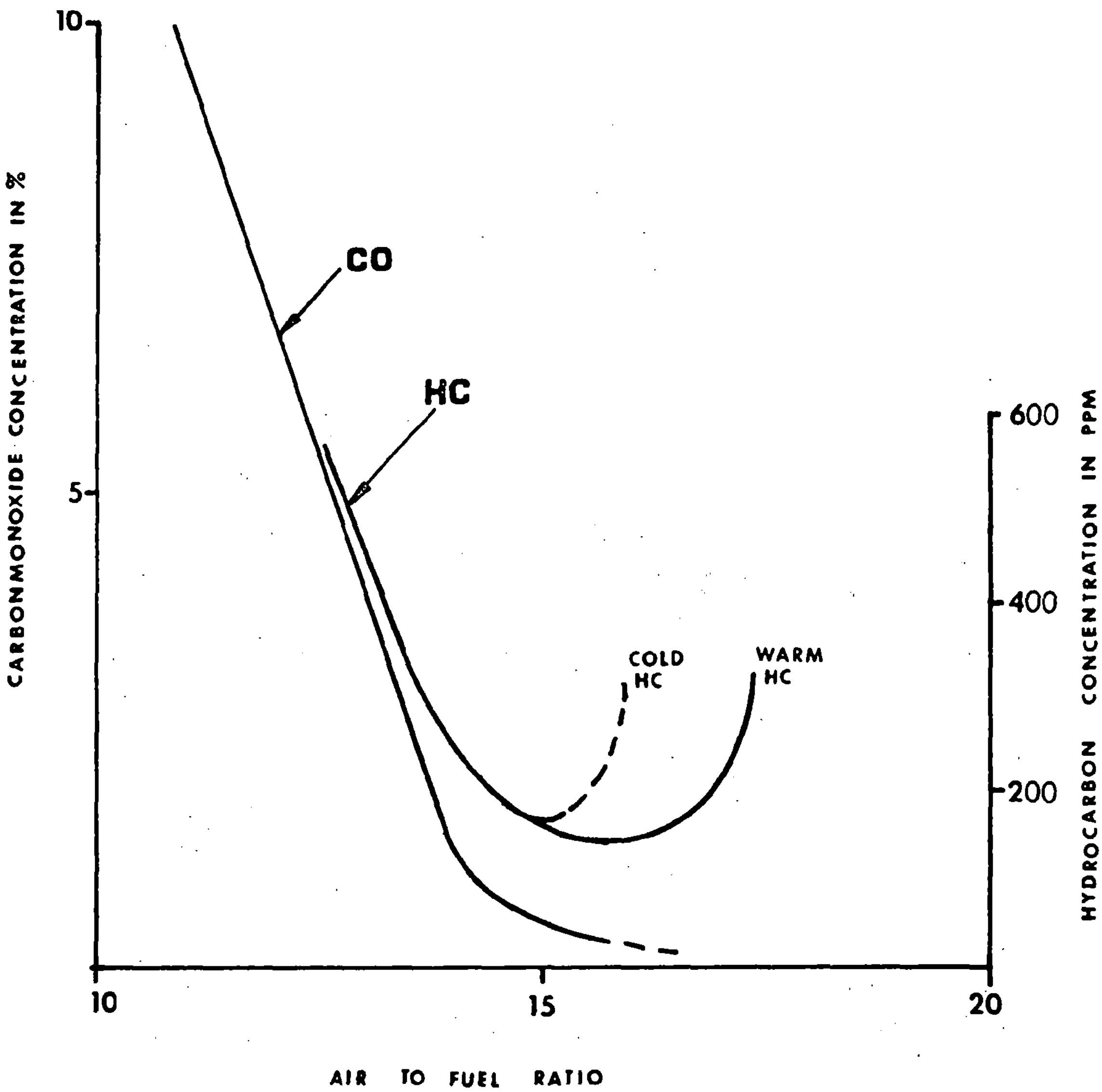
The second carburetor function is the idle system. See Fig. 3. When the engine is not operating under load, an idle system is required because air flow through the venturi is too small to create the pressure drop necessary to draw fuel from the delivery tube of the main metering system. At idle, a relatively rich mixture (low air to fuel ratio) is metered to the engine to keep it running at low speeds (idling). Combustion at idle is normally less efficient than under steady-state load, thus emission levels of CO and HC are expected to be high during idle. However, unlike the main metering system, the idle system is equipped with a fuel-air mixture control valve which is adjustable (idle mix screw). The main point of the VEAP study was to obtain these idle emission levels and to find what improvements could be made in the emission at idle by adjustment to the carburetor idle mix screw. When the vehicle's emissions of CO and HC were recorded at idle, the levels were compared with the limits used the Atlantic Richfield Company's Clean Air Caravan.[5] These approximate limits were:

Pre-1968 model year	3.5 to 5% CO
1968-1969 model year	2.0 to 3% CO
1970 & newer models	1.0 to 1.5% CO

If the CO emissions were above these limits, the idle mix screw was adjusted with the owner's consent to bring it within the limits. In some cases, satisfactory adjustment could not be made due to other engine problems not associated with the carburetion system. However, in the majority of cases, proper adjustment was easily made.

D. Theory of Idle Emission Adjustments

The curves of Figure 4 show the typical response of a spark-ignition internal combustion engine to adjustment of the air-fuel ratio (A/F) with the idle mix screw. Beginning at the left, it is clearly seen that CO concentration decreases as the A/F increases (leaning out). This is because combustion is more efficient when more air is made available for the reaction. The HC curve follows a similar course, however, a point is reached where the HC concentration begins to increase while CO continues to decrease. This response is caused by what is normally called misfire. For proper ignition by the spark plug, the fuel must be vaporized in the intake air. As the A/F is increased, a point is finally reached when the mixture is simply too lean to ignite and thus is passed through the system to show up as an increased HC emission. Since vaporization is necessary, the temperature of the intake air is important. The colder the air in the intake manifold the less easily the fuel vaporizes. As a result, misfire occurs at a lower A/F (richer mixture) with colder intake air (Cold HC curve). Other research has found, in general, lower temperatures produce higher emissions.[10,11] Therefore, the optimum idle adjustment (A/F) is that at which CO and HC are at their relative minimums.



EXHAUST GAS EMISSIONS CURVE

FIGURE 4

E. Results

The data summary for the VEAP study is presented on Table 2. Figure 5 compares the population of model year of the vehicles tested in the VEAP study to those in which the total number of vehicles in the Fairbanks area are considered. A computer solution was used to obtain the reduction in CO and HC emission which would be statistically possible for the total Fairbanks vehicle population based on the results of the VEAP study. For this weighted average, 400 vehicles of the general public from the VEAP study were considered. The vehicles which were not adjusted or could not be adjusted to gain any improvement in emissions were averaged along with vehicles to which adjustments were made. The following results were obtained:

Possible reduction at idle		Vehicle distribution used
CO	HC	
35%	12%	R. L. Polk
33%	12%	GCA Report[7]

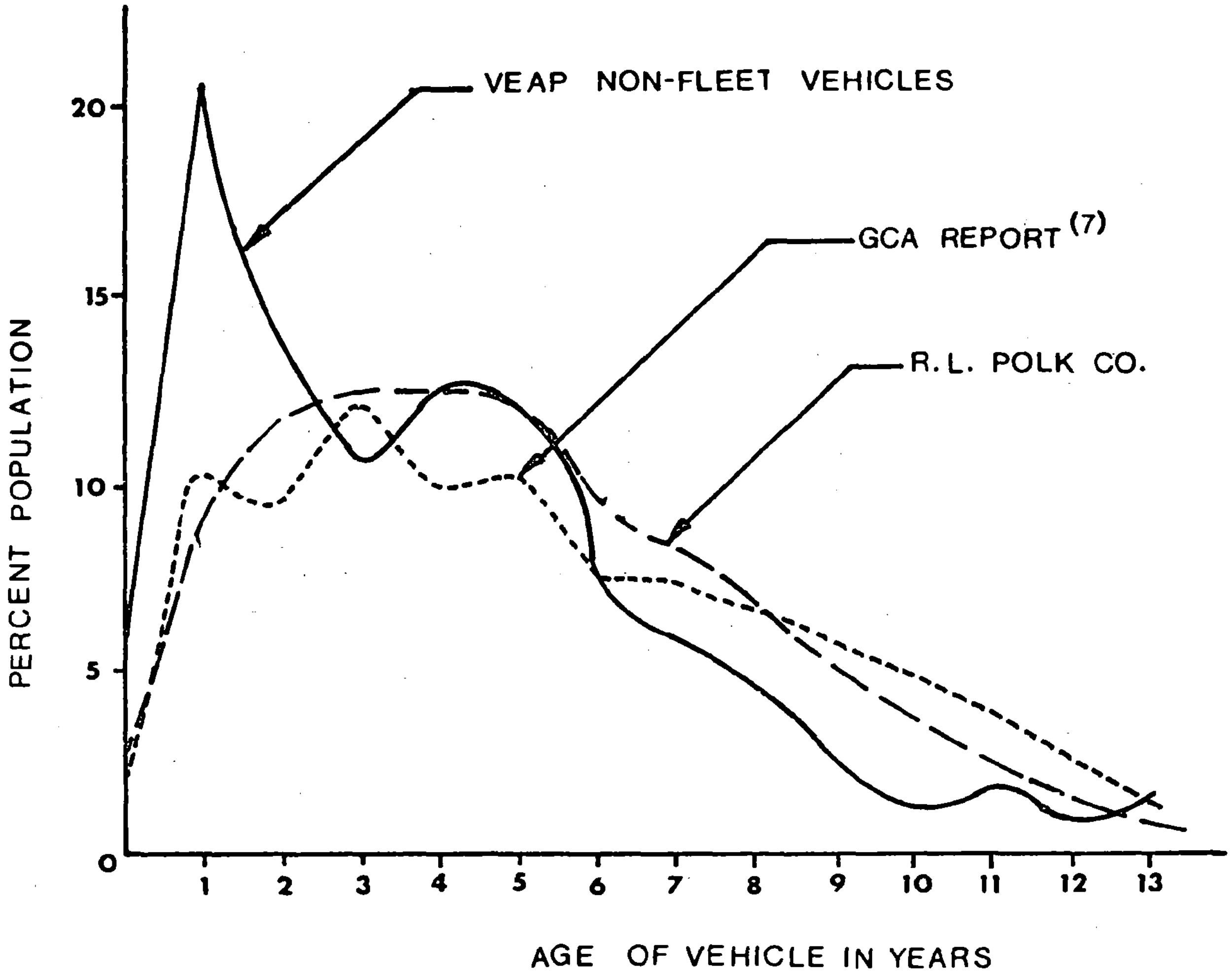
The VEAP data for domestic manufactured vehicles are plotted in Figures 6 and 7. These curves of vehicle population vs. exhaust CO concentration allow one to determine the percentage of a model year grouping that has CO emissions above a specific concentration. Figure 6 shows that the newer models are designed to run leaner (higher A/F) than the older model vehicles; i.e., to produce a lower exhaust CO concentration. In comparing these curves with similar curves (for the same model years) from the "lower 48" Atlantic Richfield Company's Clean Air Caravan,[8] it was found that the VEAP pre-68 models (for population greater than 10%) emitted a lower CO level; i.e., they were idling leaner. The authors thought that, due to the 1967 flood, the VEAP pre-68 group may be more skewed toward the newer vehicles. Lower air temperatures

TABLE 2

VEAP DATA SUMMARY

Sample	Number Vehic. Tested	Before Adjustment Avg. % CO Idle	Before Adjustment Avg. % CO 2500	Before Adjustment Avg. ppm HC* Idle	Before Adjustment Avg. ppm HC* 2500	Number Vehic. Adj.	After Adjustment Avg. % CO Idle	After Adjustment Avg. ppm HC Idle	% Drop in % CO of Vehic. Adjusted
All Vehicles Tested	631	3.4	1.3	350	220	258	2.0	320	38.9
Gasoline Vehicles	599	3.5	1.3	350	230	243	2.1	320	38.2
Diesel Vehicles	10	0.1	0.4						
Propane Vehicles	22	2.4	0.2	650	80	15	0.8	670	64.5
All Domestic Vehicles	564	3.4	1.2	360	230	239	2.0	330	40.4
All Foreign Vehicles	67	3.2	1.7	250	150	19	2.6	210	24.6
All Fleet Vehicles	196	2.9	1.0	250	150	70	1.4	270	42.2
Domestic Non-Fleet Vehicles	369	3.7	1.3	420	270	170	2.2	350	39.7
Pre-1968 Domestic Gasoline	113	4.5	2.1	560	340	49	3.2	460	31.4
1968-69 Domestic Gasoline	141	4.2	1.5	420	340	62	2.3	400	38.4
1970-73 Domestic Gasoline	266	2.7	0.8	250	130	105	1.4	240	46.7
GSA Fleet Vehicles	74	3.2	1.4	300	210	31	1.7	220	43.1
State Highway Fleet Vehicles	61	3.0	1.0	210	140	25	1.5	300	58.1
MUS Fleet Vehicles	43	2.5	0.9	200	100		NO ADJUSTMENT		

* As Hexane, except for Diesel and Propane Fueled Vehicles.



AGE DISTRIBUTION COMPARISON CURVE

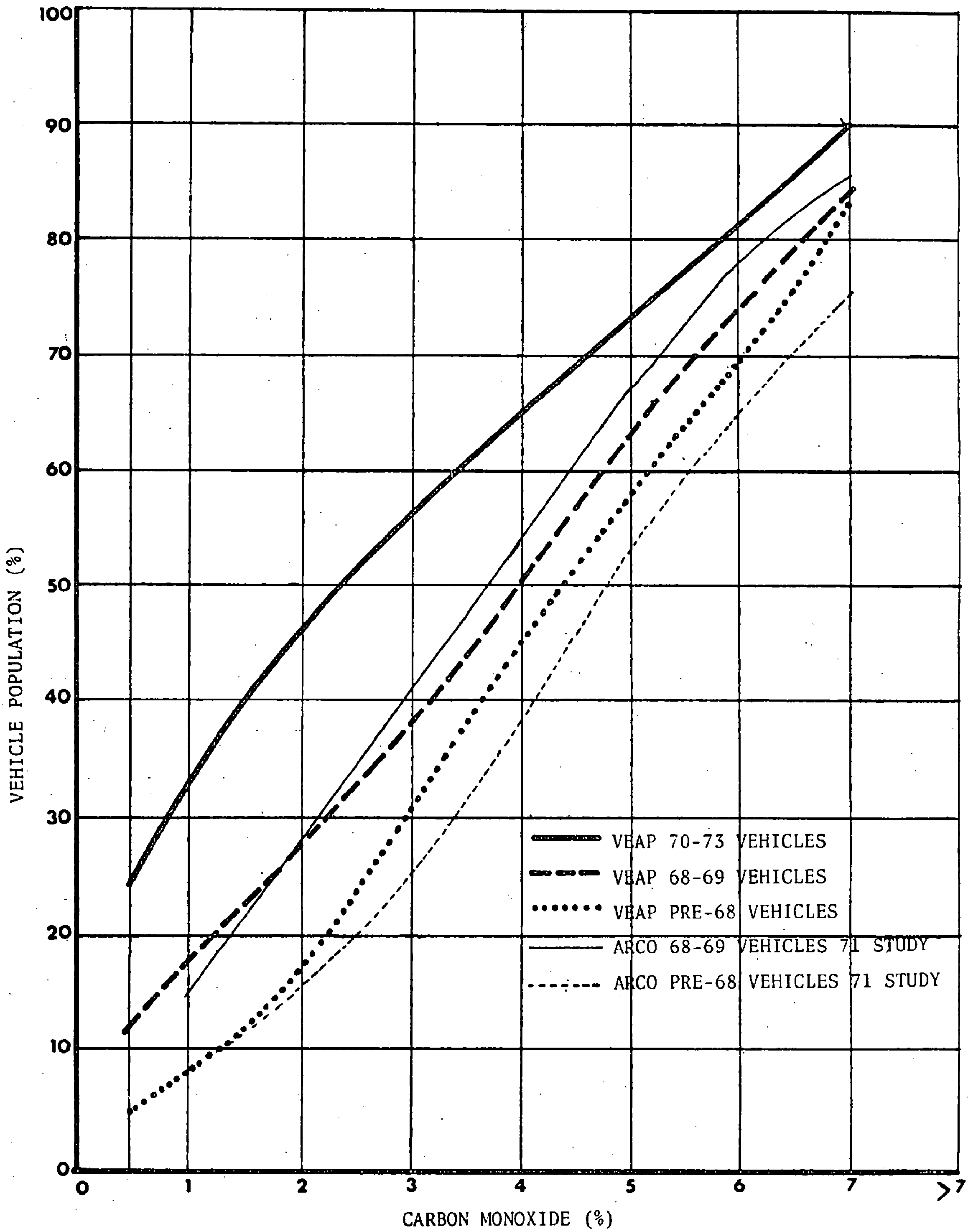
FIGURE 5

in Alaska may be another reason for the lean mixtures. Carburetors are volumetric devices which will pass about the same volume, but more mass, at lower temperatures (higher air mass per unit volume at lower temperatures) thus increasing the A/F.

The 68-69 model year data are about comparable (a little richer) to the Atlantic Richfield Company's (1971) data. Some 68-69 models had limited air preheat in the carburetor air scoop which heats the combustion air effectively lowering A/F. At 2500 RPM (Figure 8) both the pre-68 and the 68-69 models were leaner than those in the Atlantic Richfield Company's 1971 study. Apparently at the higher air intake velocities, the air preheat (on 68-69 models) was insufficient to keep the mixture rich (less air mass).

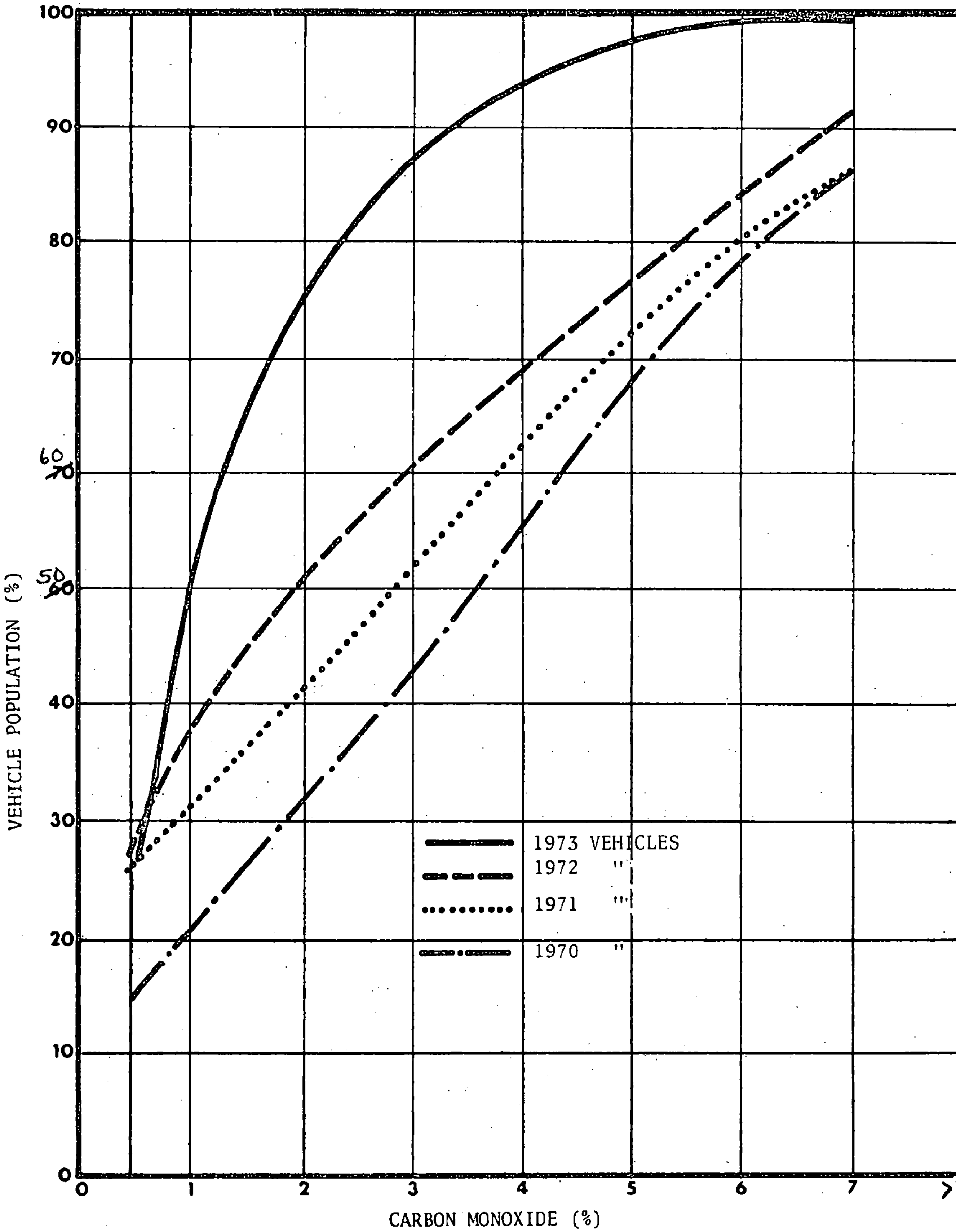
The VEAP study included 1970 to 1973 model vehicles which prevented direct compairson with the 1971 Atlantic Richfield study. The effect of temperature upon air-to-fuel ratios (leanness) is almost negated for a warmed-up 1970 or newer engine because there is a more positive control of combustion air temperature (~100°F) in the air filter assembly. In the 75% population at idle for 1973s (VEAP 1973), the CO concentration was 2% (Figure 7) while it was approximately 4% for 1971s (Atlantic Richfield Company study, Figure 1 of Reference 8). For the same age (73s in 1973 and 71s in 1971), the 73s were putting out one half as much CO as were the 71s. In the VEAP study approximately 40% of the 73s and none of the 71s were fitted with pollution control devices commonly known as air pumps which may account for the reduced CO emission from the 73s. A more detailed discussion of these devices is presented in Part III, however, some discussion is presented at this point to more clearly analyze the VEAP data.

The air pump system injects fresh air behind each engine exhaust valve. Injected air at this point causes unburned hydrocarbons and CO to burn in the exhaust manifold instead of passing to the atmosphere through the exhaust system.



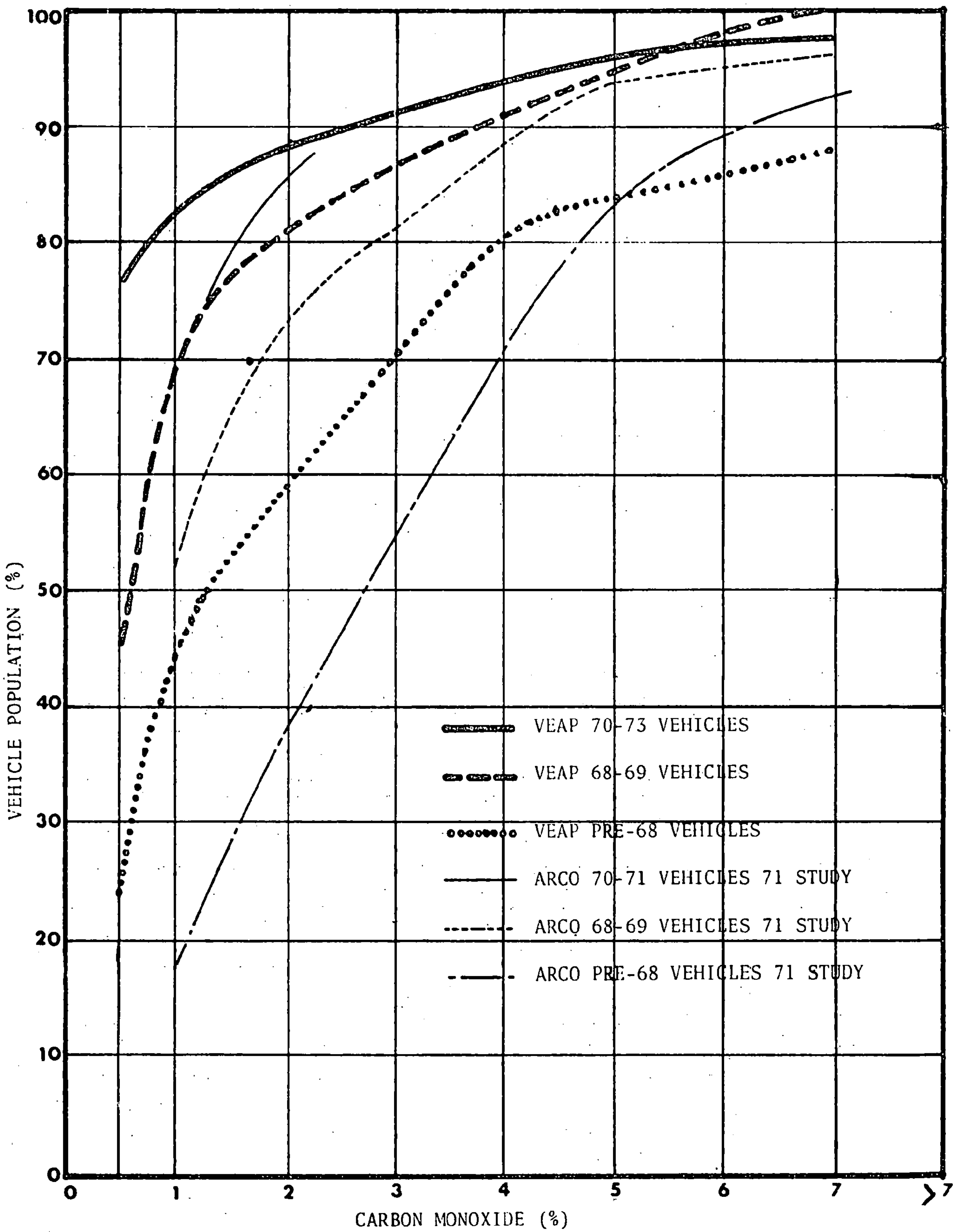
CO EMISSIONS vs POPULATION @ IDLE

FIGURE 6



CO EMISSIONS vs POPULATION @ IDLE

FIGURE 7



CO EMISSION vs POPULATION @ 2500 RPM

FIGURE 8

Gases from the air pumps also tend to dilute the exhaust contaminants. Therefore, to compare vehicles with and without air pumps, one must convert to a common dilution value. Zero percent oxygen (no dilution) was selected. For the 73s with air pumps, the idle and 2500 RPM CO levels were 0.7 ±0.1% and 0.14 ±0.05%. Without air pumps, the respective levels were 2.0 ±0.1% CO (1 ±0.1% CO after adjustment) and 0.33 ±0.05% CO. The injected air oxidized (converted to CO_2) 1.3% and 0.2% CO at idle and 2500 RPM, respectively. An after-adjustment comparison cannot be made since no 1973 air pump vehicles were adjusted.

F. Direct Comparison of Emissions

Here direct comparisons are made between the different engine types used in the vehicles tested. Some conclusions are drawn relating to the desirability of one type over another, based on the emission levels recorded in this study.

1. Gasoline fueled engines vs. Propane fueled engines.

The idle CO emissions for the propane fueled vehicles before adjustment was slightly lower than the gasoline fueled 1970-1973s, 2.4% vs. 2.7% respectively. Most of the propane engines were comparable to the gasoline engines; that is, typical eight-cylinder engines of domestic manufacture with idle speeds of approximately 550 RPM. However, at 2500 RPM, the propane engines produced only about 1/3 as much CO as the gasoline engines. To further assess this considerably more desirable CO emission characteristic, it would be necessary to make further comparisons with the engines under load and transient operation. Unfortunately such comparisons were beyond the scope of this project.

At idle, the only propane vehicles adjusted were those of the Yellow Cab fleet. The propane carburetor manufacturer recommended an idle mixture setting which would produce an exhaust CO concentration of 0.25 to 1.0%. The propane suppliers representative therefore set the vehicles to produce about 0.7% CO concentration. On the day this was done, the outside air temperature was approximately -20°F. After adjustment, the propane vehicles appeared very favorably compared to the gasoline vehicles.

Idle CO Avg. after Adjustment	
69-72 Propane	0.8%
70-73 Gasoline	1.4%

However, within a week after the adjustments were made, the fleet mechanic indicated that the engines were misfiring at idle, and he had readjusted them to an emission setting of 3.0% CO. No follow up was possible on these vehicles to determine the CO at the time of the misfiring or whether the misfire was due to "too lean" operation.

Propane is widely reputed to be a clean burning fuel and is advertised as such. However, on the basis of the VEAP study, no clear evidence was revealed which showed propane to be generally more favorable than gasoline from an idle emission standpoint. To solve this question, a much more detailed field testing program in a Fairbanks or similar climate is necessary. Propane does show a slightly unfavorable ice fog characteristic, which is detailed in Part III.

2. Foreign vs. Domestic Manufacture.

In the previous discussion, it was sufficient to compare CO emission on a percent basis since the engines were of equal displacement. But when comparing small displacement foreign engines to the larger displacement engines of U.S. manufacturer, it becomes necessary to use a mass or volumetric comparison. A good approximation to obtain the amount of CO emitted is as follows.

Intake manifold vacuum in (atm) x
engine displacement in (liters) x
engine speed $\frac{\text{RPM}}{2}(\text{min}^{-1})$ x
CO concentration (%) = CO $(\frac{\text{liters}}{\text{min}})$ at 1 atm.

assuming: moles of combustables = moles combustion products; moles of fuel are insignificant compared to the moles of air; 100% volumetric efficiency.

In making comparisons of the VEAP data, average engine displacements are used with the assumption that:

U.S. mfg. average displacement = 300 cu. in. (4.9 liters)

Foreign mfg. average displacement = 1600 c.c. (1.6 liters)

Both engines operate at approximately 16-19" Hg manifold vacuum (17" used) but the smaller foreign engines idle at approximately 900 RPM compared to 550 RPM for the U.S. engines. Therefore, calculating the relative emissions from the data summary for all foreign and domestic vehicles at idle before adjustment yields:

Foreign: $(\frac{30-17}{30}\ \text{Atm})(1.6\ \text{lit.})(\frac{900}{2}\ \text{RPM})(3.2\%\ \text{CO}) = 1000\ \overset{\text{cent.}}{\frac{\text{lit}}{\text{min}}}\ \text{CO}.$

Domestic: $(\frac{30-17}{30}\ \text{Atm})(4.9\ \text{lit.})(\frac{550}{2}\ \text{RPM})(3.4\%\ \text{CO}) = 2000\ \overset{\text{cent.}}{\frac{\text{lit}}{\text{min}}}\ \text{CO}.$

This comparison shows that as received the average foreign manufactured vehicle emitted about 1/2 as much CO as the domestic vehicles at idle. This, of course, is mainly due to the smaller engine size. The results which were obtained in this study compare very well with the findings of the U.S. Public Health Service[2] when in 1967 that organization reported that CO levels from imported compact cars were only 46% as high as emission levels produced by the standard size domestic vehicles.

No after-adjustment comparison can accurately be made since manufacturer CO emissions criteria were lacking for many foreign vehicles.

3. Domestic Gasoline vs. Diesel vs. Propane.

Here the total volumetric CO emissions for the three engine types are compared as received at idle. Using the same method as the previous comparison, the average diesel powered passenger car had an average displacement of 2.1 liters and idled at 600-700 RPM with negligible manifold vacuum. Thus:

Diesel: $(1 \text{ Atm})(2.1 \text{ liters})(\frac{650}{2} \text{ RPM})(0.1\% \text{ CO}) = 70 \frac{\text{lit}}{\text{min}} \text{ CO}.$

1970-1973 Domestic Gasoline:

$$(\frac{30-17}{30} \text{ Atm})(4.9 \text{ lit.})(\frac{550}{2} \text{ RPM})(2.7\% \text{ CO}) = 1600 \frac{\text{lit}}{\text{min}} \text{ CO}.$$

Propane: $(\frac{30-17}{30} \text{ Atm})(4.9 \text{ lit.})(\frac{550}{2} \text{ RPM})(2.4\% \text{ CO}) = 1400 \frac{\text{lit}}{\text{min}} \text{ CO}.$

As received at idle, the propane and diesel emitted 88% and 4%, respectively, as much CO as the 1970-73 domestic gasoline engines. For low CO emissions at idle, there is no contest--the diesels are definitely superior. Even after adjustment, the spark ignition engines cannot compete with the diesel at idle. This statement should not be taken to mean that if all of the vehicles were converted to diesel the Fairbanks air pollution problem would disappear. For diesels, CO emissions do increase at higher speed, as is seen in Table 2. Also, diesels can be relatively high emitters with respect to the heavier HC and aldehydes (smoke and odor). The levels of HC and aldehydes at present are not very high in the Fairbanks area, but a total vehicle population of diesels possible could result in an increase of these levels. The most conclusive statement which can be drawn from this comparison is: if a significant amount of the Fairbanks vehicle population was diesel powered, a proportional drop in ambient CO levels would be experienced. However, a careful study would be required to find the limits of diesel population which could be tolerated without dangerously increasing other forms of air pollution. Ice fog emission comparisons are made in Part III.

G. Emission Testing Cycle

As the previous sections indicate, the VEAP study and the analysis of the data were mainly concerned with CO emissions at idle. Since the highest ambient CO levels occur in winter in the Fairbanks area when driving conditions are difficult and traffic is moving slowly, idle emissions are very significant. But CO emissions at idle contribute only part of the total ambient CO produced by motor vehicles in the city. While the percentage contribution at idle is expected to be considerable, to date no sophisticated attempt has been made to accurately obtain this information.

The present method for making a total evaluation of vehicle emissions is by the use of a driving cycle.[18,19] A driving cycle is basically the average automobile trip. It consists of: startup, idle, acceleration, deceleration, and cruise at different rates. There are several established cycles, EPA, CVS-1 and CVS-3, HEW cycle, and the California cycle. All differ slightly but most are applicable for driving conditions in the "lower 48." In cycle testing, emissions are measured for each of the driving modes and an overall average emission is obtained. Unfortunately, none of these cycles would apply to the winter driving conditions experienced in Fairbanks. For example, the CVS cycle begins with startup of a vehicle that has been left standing for 12 hours at +60 to +86°F. After idling for 20 seconds, the vehicle is driven on a dynamometer to simulate a typical trip in which periods of cruising at speeds about 50 mph are experienced. In comparison, a typical winter driving cycle in Fairbanks might well begin with a vehicle being started without preheat after it has stood for

12 hours at -10°F. After 2 to 15 minutes of idle, it is then driven in traffic where the maximum speed reached is 30 to 40 mph and averages about 10 to 20 mph. Of course, this is speculation based on the authors' experience. However, the point is simply this: before any firm statements are made relating to the total levels of vehicle produced CO emissions in the Fairbanks area, a typical Fairbanks cycle must be established and vehicles must be evaluated. The VEAP Program has only been a beginning and does not include such total emission considerations.

III. EMISSION CONTROL METHODS

A. General

In this section, a variety of CO control techniques are considered as they relate specifically to climates similar to that found in Fairbanks. The techniques discussed cover a wide range of possibilities. Some are well established methods well proven with long histories of adequate service; some are in the experimental stages of development while others are theoretically attractive but have not been proven to be feasible, even in the experimental stage. It is important to remember that CO is produced as a result of poor combustion efficiency. The internal combustion engine, by its very nature, is a thermodynamic energy converter which attains a relatively high termal efficiency at the expense of combustion efficiency in normal application. In other words, there are practical limits to which CO emissions from existing motor vehicles can be reduced in any environment. It would be the logical conclusion of a comprehensive research effort to establish such limits for cold regions. This report does not go that far; rather it only discusses briefly the methods which must be much more painstakingly considered if such limits are to be defined.

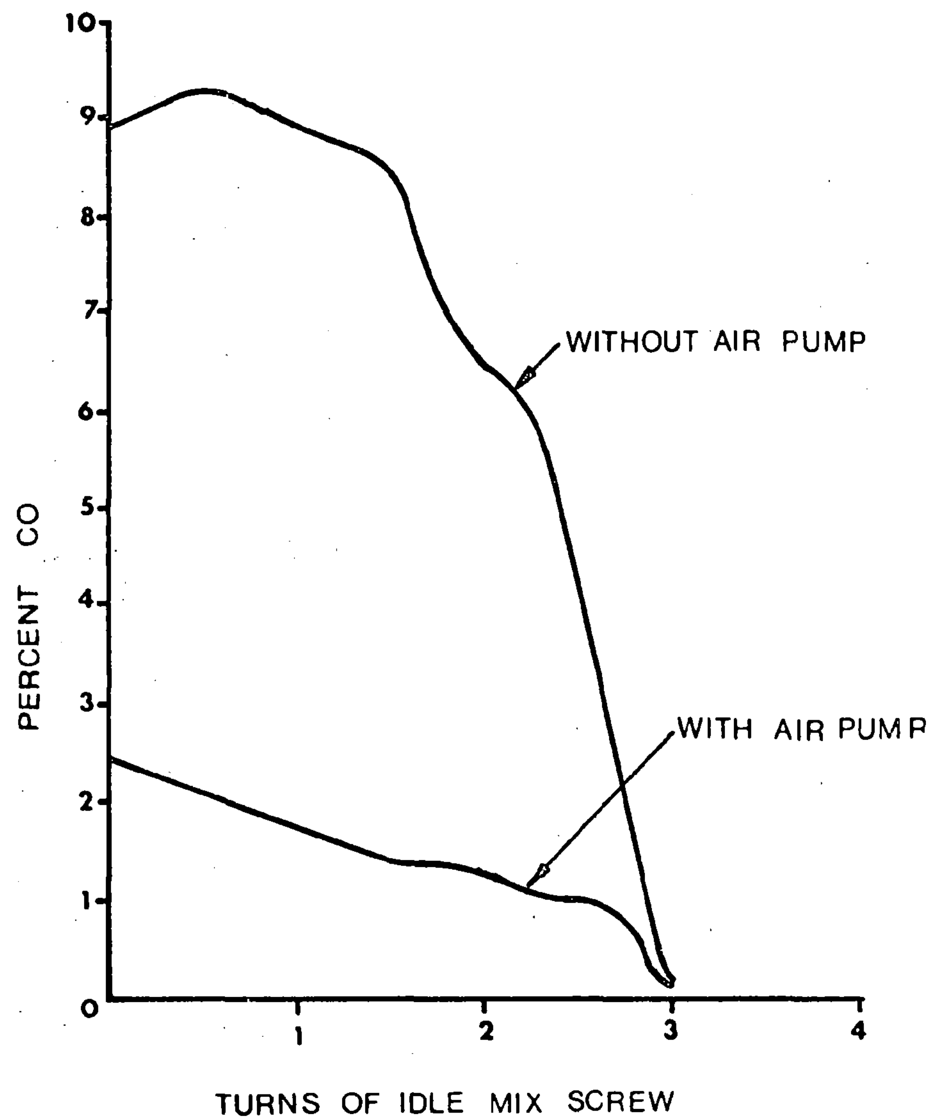
As noted earlier, CO emissions from internal combustion engines are basically an excess fuel problem; i.e., too rich A/F mixture. The solution is, of course, to add extra air (oxygen, O_2) to burn the CO. The air can be added through leaner carburetion or injected into the exhaust system where the CO can burn outside of the cylinder before it can be emitted to the ambient air. Operation with a rich A/F mixture and air injection to allow burning of the CO in the exhaust system gets around the lean mixture operation problem but uses fuel to heat the exhaust system rather than powering the vehicle. The two major exhaust treatment systems which thus far appear to be the most promising are catalytic converters and air injection systems.

B. Air Injection System (Air Pumps)

The air injection system which is in routine use is commonly known as the air pump. With the air pump system, the exhaust port and manifold acts as a thermal reactor or combustion chamber to burn CO and HC. The air pump, which is about the size of the alternator, is located near the front of the engine and is powered by a fan belt. It pumps (injects) fresh air behind each engine exhaust valve. Injected air at this point causes unburned hydrocarbons and CO to burn in the exhaust manifold because of the high gas temperature instead of passing to the atmosphere through the exhaust system. Exhaust gas temperatures downstream of the manifold are too low for efficient CO oxidation (to CO_2) without the use of a catalyst to speed up the reaction. The air injection rate is about 20-30% of the carburetor air flow.

Air pumps were part of the emission controls installed in 1966-67 on California manufactured Ford, GM, and AMC vehicles. Some newer models were also equipped. Approximately 4-5% of the pre-68 and post-69 and 10% of the 68-69 VEAP vehicles had air pumps. Air pump performance at idle on a 1968 six cylinder GM engine is shown in Figure 9, a plot of percentage CO with and without air pumps vs. number of turns of the idle mixture screw. For both curves the CO values have been corrected to 0% O_2 to account (correct) for exhaust dilution caused by the air pump. Larger, insulated exhaust manifold(s) (thermal reactors) should perform more efficiently than the units presently in use.

Lower ambient air temperature (say -40°F) should have little effect upon air pump system performance. VEAP data tend to confirm this. For example, assume 1000°F exhaust temperature before mixing (air injection). Mixture temperature will be $\frac{1.0(1000) + 0.25(-40)}{1.25} = 790°F$. Theoretical mixture temperature for Figure 9 was $800^{\pm}$°F. Combustion of the CO and HC will raise that



CO EMISSIONS VS TURNS OF IDLE MIX SCREW
FOR A GM 250 6-CYL 1968 VEHICLE
CO VALUES ARE CORRECTED TO 0% O_2

FIGURE 9

temperature by 50° to 400°F. During deceleration, the air pump's output is dumped into the atmosphere to prevent backfiring of the very rich mixture at the exhaust port. New (1973) GM vehicles can be ordered with air pumps for less than $20 [16] For retrofit purposes, the U.S. EPA[13] reported installation costs of approximately $375 and that no developers were interested in retrofit application. Addition of an air pump to a vehicle should not greatly affect a mass ice fog emission. However, some additional water vapor will be produced as a result of more complete combustion of HC. There is a slight penalty in gas mileage and an increase in exhaust volume (apparent ice fog volume) by about 25%. Apparent ice fog is a term which refers to the increased plume volume which is visible at the tail pipe which would tend to increase the hazard of following a vehicle during an ice fog episode.

Air pumps do seem to be ideally suited for use in cold climates to help reduce CO emissions mainly because of their good service record and low maintenance requirements as well as their relative insensitivity to carburetor maladjustment. Their increase in apparent ice fog, however, could prove to be a very significant factor in their acceptability.

C. Catalytic Converters

Catalytic converters have been in use for many years to reduce the CO emission of internal combustion engines which operate indoors; i.e., lift trucks and mining machinery. Very good results have been obtained in these applications especially with propane fueled engines. They are, however, relatively new to the auto industry when being considered for general use. While they are commercially available for automobiles, they have seen only limited use in the lower 48 states. To the knowledge of the authors, no record of their performance in cold regions is available.

The catalytic converter is usually a canister containing an oxidizing catalyst, which is mounted integrally within a vehicle's exhaust system. The converter is smaller than a muffler and is usually mounted next to the exhaust manifold for heat conservation. The catalyst, which may be a noble metal, speeds the oxidation of HC and CO and allows it to occur at temperatures lower than with air pumps. For example, a portable "Coleman[RT]" catalytic (platinum-asbestos) heater operates on the catalytic converter principle.

Catalytic converters will theoretically require an air pump if a vehicle's carburetor can be adjusted to give an A/F richer than 14.3. However, from the present testing being carried out by the California State Air Resources Control Board, it appeared that as a practical matter some form of air injection is required in all cases for the most efficient operation.

The catalyst must reach a certain activation temperature before significant conversion (50% of the CO to CO_2) can take place.[17] With usage and deterioration, that temperature can increase, allowing excessive emissions during low temperature operation.

In climates such as those found in Fairbanks, two potential problems with catalytic converter operation can be expected:

1. Activation temperature:

   During cold weather startup it may take a considerable length of time for the catalyst bed to reach activation temperature. If this time should prove excessive, the value of the device to reduce CO will be minimized since CO will be emitted throughout the catalyst warm up period. This problem could perhaps be solved by preheating the catalyst with an electric resistance heater before cold start up.

2. Catalyst overheat:

The second potential problem occurs after the catalyst activation temperature has been reached during a cold start situation. Due to the relatively small thermal mass of the catalyst as compared with the engine block and manifolds, activation temperature can be expected to be reached long before the carburetor choke has opened. This would result in extremely high exhaust concentration of combustables (CO and HC). Oxidation of these unusually high concentrations within the catalytic converter could result in temperatures high enough to destroy the catalyst. It is possible that this problem could be overcome by use of special chokes and intake manifold quick heating devices.

Another more general restriction associated with catalytic converters is that not all fuels are acceptable for use. Lead and phosphorus compounds in gasoline, for example, may tend to poison the catalyst (destroy catalytic activity). Lower-48 retrofit installation costs for catalytic converters were estimated (1972) to cost from $143 to $175.[13] There is no cost estimate available for Alaska. Addition of a catalytic converter to a vehicle should affect ice fog emissions in a manner similar to the air pump.

In summary, regarding the catalytic converter as an emission control device for cold climates; there is insufficient information at this time to make any conclusive statements.

D. Lean Mixture Operation

There is, of course, another more basic method to reduce CO emission. This is through lean air/fuel carburetion. This method is discussed to some extent in Section II and will be elaborated upon here.

The major advantage of lean mixture operation for CO control is that more of the CO and HC is used to increase mileage rather than exhaust temperature as with exhaust treatment devices. Lean mixture means an A/F greater than or equal to 14. Most of the post-1970 models were designed to run with lean mixture carburetors.

To obtain lean mixture operation without one of the newer carburetors, a method called intake manifold air bleed can be considered. In this system air for combustion is injected below the carburetor. An air control valve is used which increases the A/F by metering air to the intake manifold in response to manifold vacuum. This system would be applicable only as a retrofit item on pre-1968 vehicles. Again, however, as with other control devices, cold climate consideration must be made. At low temperature, as seen in Part II (Figures 6 and 7) pre-68 vehicles without intake air preheat tend to run leaner than those found in the Lower 48. If this is in fact due to the increased air densities occurring at low temperature, the air bleed system could result in overly lean mixtures during winter months. This will tend to cause reduced drivability, an increase in HC emissions and perhaps valve burning as a result of the higher cylinder head temperatures. Such devices at this time exist only in the experimental stage. To the knowledge of the authors no certified air bleed to intake manifold systems are commercially available.

In the Fairbanks area gasoline fueled vehicles could run leaner if lean misfire could be eliminated. Misfiring due to lack of sufficient fuel vaporization caused by cold intake manifolds can be corrected by one of two methods: (1) adjust (ream out) carburetor jets to give a richer mixture; i.e., lower A/F or (2) insulate intake manifold and heat if necessary to provide more fuel vaporization. (See warm HC curve, Figure 2) The latter method is preferred since it is less costly; it will provide better mileage, reduce CO emissions, and prevent carbon coating of plugs and head(s). On some "hot" engines (crowded under hood volume) the insulation may have to be removed for summer use. On inline engines (where the manifolds hang on the side) heat may be cross-fed from the exhaust to intake manifold by enclosing both in a metal shroud.

If the mixture is too lean, valve burning problems may occur which would lead to high emissions and repair bills.

Higher idle speeds and leaner mixtures increase the tendency of spark ignition engines to diesel. Dieseling is when a spark-ignition engine continues to run after the ignition has been turned off. On most post-67 vehicles, idle stop solenoids are attached to the carburetor to allow the throttle plate to close when the ignition is switched off, thus preventing dieseling. Many of the VEAP vehicles had the solenoid improperly adjusted or completely missing.

If lean mixture operation increases mileage by about say 5% then the ice fog emission (both mass and volume) will be reduced about 5%.

Lean mixture operation does appear to be an effective CO emissions control method if the proper steps are followed to insure efficient cold weather operation.

E. Summary Comparison

Table 3 summarizes the salient points of the three major CO control methods. The % CO reduction listed in Table 3 should be interpreted with caution; i.e., addition of an air pump to a vehicle with lean mixture carburetion will not reduce the CO emission by 100%. The exhaust treatment devices (air pump and/or converter) are more efficient percentagewise, when there is more CO in the exhaust to treat. For example, from Fig. 9, at three turns out (idle mix screw), the air pump removed 80% of the exhaust CO. But at 1.25 turns out, the reduction was only about 60%.

Table 3

MAJOR CO CONTROL SUMMARY COMPARISON[13][16][19]

	Lean Mixture	Air Pump	Catalytic Converter
% CO Reduction	50±	Up to 50±**	60±
Installed Cost			
Retrofit	\$20-70	\$200-400	\$150-200
with new vehicle	Std. Equip.	\$20 (GM)	> \$20 ?
Expected life miles	Same as engine	Same as engine	50,000±
Expected supplies cost/miles	< \$10 / 50,000	< \$10 / 50,000	\$20 ± (catalyst) / 25,000
Special fuel	None	None	Non-lead
Fuel Economy	Increased	Slight Decrease	Slight Decrease
Temperature Sensitivity	Warm intake manifold may be required.	None	Has to be above activation temperature but below fusion temperature.
Ice Fog	Decrease	Increase	Increase
Other Considerations	Dieseling and valve burning with improper adjustment.	In common use since 1966.	Not in common automotive use.

* Compared to vehicle without that respective control method[13].

** For pre-1970 models.

F. Inspection and Maintenance Programs

Many of the newer vehicles have emission control devices which upon malfunction cause higher emission levels than on similar (earlier manufacture) vehicles without the devices. For example, a plugged PCV valve could more than double the idle CO emission.

Gaseous fuel carburetors are designed to operate at a high A/F ratio, to reduce CO emission. But, as shown before, they could easily be maladjusted to triple the idle CO emissions.

To insure efficient pollution control device operation, an emissions inspection program is necessary. Such a program combined with mandatory repair would detect and correct the harmful emission producing malfunctions. The New Jersey Department of Environmental Protection instituted an inspection (at idle) program in 1972 and has arrived at the following conclusions:[12]

1. With proper training and equipment, the automotive service industry can tune vehicles for low emissions at reasonable cost.
2. Periodic vehicle emission inspections and maintenance can significantly reduce CO emissions in urban areas.

Excessive CO emission is caused by too low an Air/Fuel ratio (A/F) which is basically a carburetion problem. Rebuilding faulty carburetors will not necessarily solve the problem. In rebuilding, metering rods, jets, and springs are not always replaced. In any inspection and maintenance (I & M) program, bench flow testing (for correct A/F) would be requisite for all replacement (rebuilt) carburetors, followed by proper adjustment once installed.

G. Fuel Volatility

Winter gasolines that are more volatile will allow leaner mixture surge-free operation. Propane or natural gas, for example, are extremely volatile, allowing surge-free operation at an A/F of 14.5 or more.

The winter gasolines sold in the Fairbanks area are the same as those supplied in the northern tier of the Lower 48 states. Blending propane or butane with gasoline will increase its volatility but might also increase vapor-locking tendencies. Depending upon relative amounts of propane or butane and gasoline, the mixture will begin to boil (Vapor Pressure ≥14.7 psia) at -45°F for 100% propane to +100°F for 100% gasoline; therefore, enriched gasoline (in a conventional gas tank) cannot be stored in a heated garage. Proper blending and usage is required to reduce the combustion and container explosion hazard.

H. Cold Start

One cold start to warmup a vehicle may emit much more CO than several minutes of warm idling. Wendell, et al.[14] have stated:

> "Unfortunately, the effectiveness of proposed emission control devices to reduce emissions from vehicles is not as effective on cold start emissions as on emissions from automobiles at normal running temperature. Thus, cold emissions from post-1974 cars will become increasingly significant. In particular, 90% of the CO and 80% of the HC will be emitted during the first 2 minutes."
>
> [of the Federal CVS cycle]

Cold start emission levels are expected to last for more than two minutes during sub-arctic driving conditions. To get sufficient fuel vapor for combustion with a cold intake manifold, a vehicle must be choked to a very rich mixture; A/F down to 1 in some cases. At low temperatures, an A/F (liquid) ratio of 1 to 1 may be required to get an Air to Vapor (fuel) ratio of, say, 10 to 1.

Cold start emission levels could be greatly reduced if the intake manifold were heated to normal operating temperature before or immediately after starting. General Motors Co. (GM)[15] is developing a quick-heat manifold early fuel evaporation (EFE) device which is coupled with a rapid release choke. GM has reported that this system has eliminated up to 90% of the CO produced during the cold starting of 1972 engines [1972 HEW schedule, first cycle].

Cold start emissions need to be more quantitatively defined for cold climate regions. A present practical alternative (to cold starts) would be to electrically heat the intake manifold before starting. If the manifold were warm enough, there would be little need of a choke for starting an otherwise cold vehicle. In cold climates, electric heaters are routinely used to heat engine blocks before starting. These electric antifreeze heaters supply some heat to the intake manifolds, especially on engines where the manifold sits between the heads. Insulating the manifold would raise its temperature and require less electricity for easier starts.

Circulating (tank type) heaters are more susceptible to circulation restriction than are direct immersion heaters. In use, ethylene glycol-water (50-50 to 60-40) solutions tend to sludge out (ice formation) at temperatures below -40°F. Sometimes this sludge will plug the 1/4" I.D. suction line to tank type heaters. In-block (immersion) heaters do not have the low temperature circulation problem. Therefore, they should be more reliable. Propylene glycol-water solutions should have a much lower sludging temperature.

I. Fuel Economy

Besides reducing CO levels in the Fairbanks area, an I & M program would save the operator of a "high emitter" considerable cost in terms of fuel expenses if he were required to reduce his vehicle's CO emission. For example, consider a late model vehicle that is emitting 6% CO (many VEAP vehicles were higher) at both idle and high speed. Referring to Fig. 4, that would mean that he was operating at an A/F of 12/1. A late model vehicle should easily operate at a CO level of 1% for an A/F of 14/1. Calculating:

A/F = 12/1, as 1# of fuel is used for every 12+1=13#

Air + Fuel, or F/A+F = 1/13.

Likewise, for A/F = 14/1, F/A+F = 1/15#.

Converting the A/F = 12/1 to an (A + F) = 15# basis,

$$\frac{1}{13}\ \frac{15/13}{15/13} = \frac{1.15}{15}\ \frac{\#F}{\#(A+F)}.$$

Therefore, adjusting a vehicle from 6% to 1% CO will save $\frac{0.15}{1.15} \times 100 =$ 13% in fuel costs under steady state driving conditions. For the owner of one high emitter who spends $10/week for gasoline, this should save him about $68 per year which should more than pay for the adjustment. The annual saving would be over $100 for a vehicle that was adjusted down from 8% to 1% CO. The increased mileage comes from burning the CO and HC that would be present in the exhaust at the lower A/F.

J. Ice Fog

Ice fog generated by motor vehicles is of course the result of combustion produced water vapor emissions. According to Benson,[3] automobiles are a minor contributor to the total ice fog in the Fairbanks area. On an overall basis, this may be true. But it is the vehicle-produced ice fog which lingers above road surfaces, blocks visibility of traffic signals, other vehicles and pedestrians and, in general, creates the extremely hazardous driving conditions which are the main objections to ice fog.

Newer vehicles, due to poorer fuel economy, emit more water vapor resulting in more ice fog than older vehicles. For example, a vehicle that gets 10 miles per gallon puts out about twice as much (mass and volume) water vapor as a vehicle that gets 20 miles per gallon.

If the exhaust gas water vapor were condensed out (by means of a heat exchanger) before exiting, there would be negligible water vapor, hence no ice fog, emission from vehicles. However, to date, no practical equipment has been developed to do this effectively.

After making a few basic assumptions, one can estimate the ice fog (H_2O) emissions from different fuels used in internal combustion engines. The fuels are diesel (fuel oil), gasoline, and propane.

Assumptions: (1) 26 miles per gallon for a 2 liter diesel passenger vehicle.

(2) In switching from fuel oil to gasoline or propane in equal weight vehicles, the motive energy requirement (Btu/mile) will be unchanged.

Summers[20] stated that, in general, diesel engines are 37% and automotive gasoline engines are 25% thermally efficient. The compression ratio is not changed by converting from gasoline to propane; therefore, 25% efficiency will be used with propane.

The heating value of most hydrocarbons (fuel oil, gasoline, and propane) is about the same (20,000 Btu/lb.); therefore, their mileage per pound of fuel will be proportional to efficiencies and will be the same for gasoline and propane. The densities of fuel oil, gasoline, and propane are 6.8, 6.1 and 4.2 pounds per gallon respectively.

Using 26 mile/gal. diesel yields:

$$\frac{6.1}{6.8}(26)\frac{25}{37} = 15.8 \text{ mile/gallon} \quad \text{or}$$

$$15.8/6.1 = 2.59 \text{ mile/pound of gasoline.}$$

Propane would then yield:

$$2.59(4.2) = 10.9 \text{ mile/gallon.}$$

Union Oil Company of California and API data lists arctic fuel oil as 13.7 weight % hydrogen. Henein[19] states a carbon to hydrogen mass ratio of 6:1 to 6.8:1 for commercial gasoline. A ratio of 6.5:1, which is 13.3 weight % hydrogen will be used. Propane is 18 weight % hydrogen.

In all the fuels, hydrogen is assumed to burn completely forming nine pounds of water per pound of hydrogen.

After calculating the water emission from combustion (pounds H_2O per gallon of fuel) the ice fog emission based on mileage can be tabulated as in Table 4.

Table 4

ICE FOG (H_2O) EMISSION BASED ON MILEAGE

Fuel	Mileage		Emissions	
	mi/gal	mi/lb.fuel	lb.H_2O/gal	lb.H_2O/mi
Diesel (fuel oil)	26	--	8.3	0.32
Gasoline	16	2.9	7.3	0.46
Propane	11	2.9	6.9	0.63

Diesel (fuel oil) emits less water vapor because of its higher thermal efficiency; i.e., more miles per gallon.

Water vapor emission (ice fog) based upon other mileages can be estimated by simple conversion. For example, if a vehicle is yielding 10 miles per gallon of gasoline, then its ice fog (H_2O) emission will be 0.46 (16/10) ~ 0.74 pounds per mile.

When considering any environmental problem, it is very important to carefully consider how a change in one area will affect another area. Throughout this section, methods of CO reduction have been considered with respect to how they might influence the production of ice fog in the Fairbanks area. Some

CO controls would reduce vehicle-produced ice fog, while others would increase it. The important point is that in advocating any one pollution control system over another, caution should be exercised to insure that levels of other forms of pollution are not unduly increased.

IV. SUMMARY

Perhaps it can be said that this report has raised more questions than it has answered. Well it might, for as is usually the case when one tries to become educated in a complex subject, the initial conclusion is that to do a proper job, further education is needed. This report has considered in broad terms the problems associated with the control of vehicle produced CO and, to some extent, ice fog in regions with cold climates. This area has shown itself to be complex.

Basically, the approach has been to evaluate the emissions of vehicles as they exist in the Fairbanks area and find out what can be done to lower emissions by simple adjustments. Then from the data obtained, differences in vehicles were assessed from an emissions control standpoint. However, when this was attempted, the conclusions were found to be weak because of a lack of necessary information. Next, systems and methods to further reduce existing emissions were considered, but again, the lack of practical field evaluated information forestalled the desired, firm conclusions. What then has this report accomplished?

This report has outlined the problems faced in cold-regions vehicle emission control, surveyed the problem on the most practical level, and pointed to ways in which the problem might be solved.

It remains to be seen, of course, exactly how the technological, social, and economic problems will be solved. But research must continue if we are to live in an acceptable environment with our existing vehicles, while we wait for industry to develop cleaner running equipment.

V. CONCLUSIONS AND RECOMMENDATIONS

1) As received at idle, the propane fueled vehicles tested emitted 88% and diesel vehicles emitted 4% as much carbon monoxide as the average (300 cu. in. V-8) domestic gasoline fueled vehicle.

2) As received at idle, the average foreign manufactured vehicle emitted about 1/2 as much CO as the average domestic vehicle. This is due to the smaller engines used in foreign vehicles.

3) Proper adjustment of the carburetor idle mixture screw produced a 44% reduction in CO emissions at idle for the 1963 to 1973 domestic vehicles tested.

4) If all of the motor vehicles in the Fairbanks area were adjusted for leaner idle operation without requiring high emitters to have major engine repair to lower their emissions, an overall reduction of about 34% in idle-produced CO could be realized. This does not consider vehicle-produced CO emitted by vehicles while under load.

5) Some form of Inspection and Maintenance program is necessary to insure proper adjustment of carburetion systems and pollution control devices if a serious effort is to be made to lower vehicle-produced air pollution levels.

6) Pre-1968 vehicles without intake air preheat tend to idle leaner in cold climates due to the higher density of the air.

7) During cold weather operation, many of the newer vehicles with leaner carburetion systems tend to misfire when manufacturer's recommended CO emission levels are obtained, probably due to incomplete vaporization of the fuel. Insulating and/or heating the intake manifold would considerably help to eliminate this problem.

8) Most of the pollution control equipment and methods presently in standard use on motor vehicles are helpful in reducing CO emissions in cold climates. However, they are not always as effective as they would be in warmer climates. In addition, some of the low CO emission devices and engine types such as air pumps and propane fuel tend to increase the production of real and apparent ice fog. These trade-offs must be kept in perspective when advocating any one CO control method.

9) Diesel-powered vehicles are low emitters of both CO and ice fog but may be relatively high in heavy HC and aldehydes which are not presently at problem levels in the Fairbanks area.

10) There is a severe lack of information available relating to the operation of and control of emission from motor vehicles in cold climates while the background research necessary to make sound knowledgeable decisions relating to vehicle emissions control in more temperate zones is extensive.

VI. RESEARCH NEEDS

This report raises questions about arctic effectiveness of proposed conventional auto emission control devices and suggests alternate techniques which may reduce pollution while providing better driveability. Concentrated investigation in the following areas is necessary to provide rational, effective and economic criteria for controlling automotive emissions in cold climates.

1) A cold regions vehicle emission test cycle must be developed which would be representative of urban driving habits under arctic winter conditions to properly assess the total emissions of a vehicle, at idle, under load, and during acceleration and deceleration.

2) A thorough field evaluation of all existing vehicle emission control measures must be made with careful, quantitative consideration given to the cause and effect relationship between individual pollutant levels which might result when the level of one is changed. These tests should be carried out using the driving cycle of Item 1.

3) Studies are needed to develop and test techniques, such as heating intake manifolds, etc., which are not specifically pollution control methods but which would increase the efficiency of cold weather vehicle operation and thus aid in pollution control.

4) Fuel research is necessary to develop blends more specifically adaptable to cold weather use. Optimum mixtures of propane or butane and gasoline and the determination of safe handling procedures and carburetion requirements might well be part of such an effort.

5) Immediate attention should be paid to the development of methods to control vehicle-produced water vapor which results in the extremely hazardous pollutant known as ice fog.

6) Any future vehicles manufactured and distributed in cold regions by the automotive industry should be thoroughly evaluated for both acceptable emission levels and satisfactory operation in those regions. This is most important to insure customer protection.

VII. REFERENCES

1. National Academy of Engineering, "Effects of Chronic Exposure to Low Levels of Carbon Monoxide on Human Health, Behavior, and Performance." Washington, D.C., 1969.

2. U.S. HEW, PHS "Air Quality Criteria for Carbon Monoxide." AP-62, March 1970.

3. Benson, C.S., "Ice Fog: Low Temperature Air Pollution Defined with Fairbanks, Alaska, as type locality", U.S. Army, Cold Regions Research and Engineering Laboratory (CRREL) Research Report 121 (1965).

4. State of Alaska, Air Quality Control Plan, Vol. 2, (Appendix), Department of Environmental Conservation, 1972.

5. Voelz, F.L., et al., "Survey of Nationwide Automobile-Exhaust Emissions and PCV Systems Conditions - Summer 1970", Atlantic Richfield Company, Presented at National Combined Fuels and Lubricants, Powerplant and Truck Meetings, St. Louis, Mo., October 26-29, 1971.

6. Kruse, R.E., and D.M. Hill, "Exhaust Emissions from Compact Cars", National Center for Air Pollution Control, PHS, USHEW, SAE Trans., Vol. 76, Paper 670688, (1967).

7. GCA Corp., (US EPA Report) Transportation Controls to Reduce Motor Vehicle Emissions in Fairbanks, Alaska. February, 1973.

8. Voelz, F.L., "Exhaust Emission Levels of In-Service Vehicles - Comparison of 1970 and 1971 Surveys", Presented at National Automobile Engineering Meeting, Detroit, Mich., May 22-26, 1972. SAE Paper 720498, 12 pp.

9. Michael, B.R., "Low Ambient Temperature Emission Testing, A Preliminary Report", EPA Testing and Evaluation Branch, Ann Arbor, Mich., Feb. 1973.

10. Personal communication, Al Gullon. May 14, 1973. Acting Chief, Mobile Source Emission Division, Environmental Protection Service, Environment, Canada.

11. New York, City of, Annual Report of the Bureau of Motor Vehicle Pollution Control, Department of Air Resources, "Emission Factors - The Effects of Cold Temperature on Exhaust Emissions". (Paragraph B-1 of the Report and Table 54, "Cold Weather Tests").

12. Andreatch, A.J., J.C. Elston, and R.W. Lahey, "New Jersey REPAIR Project: Tune-up at Idle", Journal of the Air Pollution Control Association, 21: 757-763, December 1971.

13. Control Strategies for In-Use Vehicles, U.S. EPA, Office of Air and Water Programs, Mobile Source Pollution Control Program, Washington, D.C. 20460 November 1972.

14. Wendell, R.E., J.E. Norco, and K.G. Croke, "Emission Prediction and Control Strategy: Evaluation of Pollution from Transportation Systems", Journal of the Air Pollution Control Association, 23:91-97, Feb. 1973.

15. Callahan, J.M., "GM's 'Hottest' Automotive Emission Elimination", Auto Indust., 147:(4) 25=28, August 1972.

16. Personal communication, Fred Coleman, Fairbanks Chevrolet Dealer, May 14, 1973.

17. Horowitz, J., "Inspection and Maintenance for Reducing Automobile Emissions, Effectiveness and Cost", Journal of the Air Pollution Control Association, 23:273-276, April 1973.

18. U.S. EPA, "New Motor Vehicles and New Motor Vehicle Engines", Federal Register 37:24250-24320, November 1972.

19. Henein, N.A., and D.J. Patterson, Emission from Combustion Engines and their Control, Ann Arbor, Ann Arbor Science Publishers Inc., June 1972, 355 pp.

20. Summers, C.M., "The Conversion of Energy", Scientific American, Vol. 224:(3), September 1971.