Research on Alcohol as Fuel for Military Vehicles

By Major EULOGIO G. GALANG

THE earliest known research on the use of alcohol as motor fuel was conducted in 1915 in the United States. In the Philippines, the earliest known work on this subject was carried on by Dr. A. L. Teodoro of the College of Agriculture, U.P., in Los Baños in 1931. Dr. Teodoro's findings can be summarized as follows:

Engine Behavior — Compared to an engine powered with gasoline, one that is fueled with straight alcohol is difficult to start because of the lower vapor pressure and lower inflammable unit of alcohol. Starting from cold with alcohol is not as fast as in starting with gasoline, but automobile and tractor engines can be started without difficulty. Around Canlubang and Los Baños, where Dr. Teodoro conducted his experiment, the coldest temperature is not less than 60°F. This temperature (60°F) is the critical temperature in cold-starting engines using alcohol as fuel. When the engine is not yet warmed up to maintain a steady running operation, it was found necessary to close the choke partially for a few seconds.

Acceleration — Acceleration with limits is dependent on the distillation curve in the region between 30% and 70%. The lower the position of this region in the curve the better the acceleration. With proper carburetion and relative valve and ignition timing, acceleration is greater when the engine has been warmed up.

It was observed that the operation of automotive engines with alcohol as fuel was smooth at all speeds. The detonations that occur under certain conditions in engines using gasoline were not observed when alcohol was used.

It was also found that an engine that is properly adjusted for the use of alcohol does not overheat more than one in which gasoline is used.

Power — With carburetor and spark set for maximum power, alcohol will enable the engine to deliver more power than gasoline can under the same compression ratio. The cylinder is more easily kept cool when using alcohol so that more power output and efficiency are produced.

Fuel Economy — With the use of Ricardo's variable compression engine, it was shown that for the same compression ratios alcohol shows about 3% greater thermal efficiency than gasoline due to the lower cycle temperature.

Dr. Teodoro found that 1.33 gallons of alcohol could cover the same distance as one gallon of gasoline a vehicle could travel only 17 kms. on one gallon of alcohol, while it could cover 26 kms. with the same measure of gasoline. This means larger fuel orifices in carburetors for alcohol fueled engines.

It was also found that contrary to the belief then prevailing, water in alcohol does not increase the corrosive effect of alcohol fuel and commercial alcohol with certain denaturants have less corrosive effect than gasoline. Corrosion can be overcome with proper adjustment in the carburetor to ensure complete combustion and with the addition of alkaline compounds such as aniline and pyridine.

Scale and Carbon Deposits — Alcohol gave rise to considerably lesses carbon deposits than gasoline. This is due to the fact that alcohol is completely oxidized.

The scales that are found in the tanks, tubes and other fuel lines after prolonged operation with gasoline fuel are made up of iron oxide, dust, rubber particles and cotton linters cemented together with the gummy oxidation product of the gasoline. These scales do not occur when alcohol is used because they are soluble in alcohol.

Furthermore, when alcohol is blended with gasoline or other fuels, gummy or tarry substances are produced. The use of straight alcohol does not produce these substances.

Other Observations — In all the tests conducted by Dr. Teodoro, the viscosity of the crank case oil increased with the use of alcohol as fuel. No oil dilution was also observed unlike when gasoline was used. There was therefore, a little more oil when using alcohol as a fuel, an increase of about 10 per cent more.

As to safety in the use of alcohol, it was found out that fire from alcohol can be extinguished by water, while gasoline flames can not be so put out. The flash point of alcohol (60°C) is higher than that of gasoline (10°C), so that storage of alcohol is much safer.

U. S. GOVERNMENT RESEARCH

In the early months of the last war when the fuel situation became serious for the Allies because of the operations of enemy submarines, the National Bureau of Standards of the United States Government undertook a comprehensive study of the problems involved in the use of alcohol as a motor fuel substitute for gasoline. These investigations were carried out at the request of the Board of Economic Warfare and included studies of the following special problems:

1. Effects of variations in compression ratio;
2. Knock ratios;
3. Power and fuel consumption with standard-type automotive engines;
4. Engine tests of gaseous fuels;
5. Effects of mixture distribution on engine performance;
6. Starting characteristics at low temperature and at altitudes;
7. Fuel pump life, cylinder wear and corrosion; and
8. Vapor lock with blends.

The results of the research can be summarized as follows:

It was found out that engines operating with alcohol as fuel develop from 2% to 4% more power than with the use of gasoline, but require from 60% to 70% more fuel. The amount of fuel needed is inversely proportional to its heat of combustion. Mixture distribution is somewhat less uniform with alcohol than with gasoline. Distribution of highly volatile alcohol fuel is better than those of low-proof alcohols.

It was indicated that a .075-inch jet with an idle tube about 50% larger will give an acceptable performance with 95% alcohol.

A desirable maximum starting time was 15 seconds or 0.250 minute, within which time a start should be made.

The minimum starting temperature of alcohol is slightly higher than gasoline. Starting difficulties were noticeable using 95% ethyl alcohol at 59°F. Starting tests under altitude conditions also showed a further reduction in starting temperature.

Fuel pumps may be operated without failure for 3,500 hours over a period of five months which is equivalent to 200,000 miles operation. This is considered a satisfactory performance, as it exceeds the life of the average automobile.

Cooling effect is approximately 5 times as great with alcohol as with gasoline during similar operations.

Evaporation loss is materially less than when gasoline is used.

The wear with alcohol is about one-half that occasioned by leaded gasoline.

The tests gave no indication of any significant difference in the oil consumption in the use of the two fuels. There was no dilution of the lubricant when alcohol fuel was used, while a dilution of 2% by weight was observed in the use of gasoline.

Unblended 190 proof alcohol (95%) is not subject to vapor lock at any atmospheric temperature. The ether-alcohol blend proved satisfactory for starting at low temperatures.

The relative rate of evaporation, combustion chamber deposits, and crankcase oil dilution is less with the use of alcohol than when operating on gasoline.

The disadvantages of using alcohol as

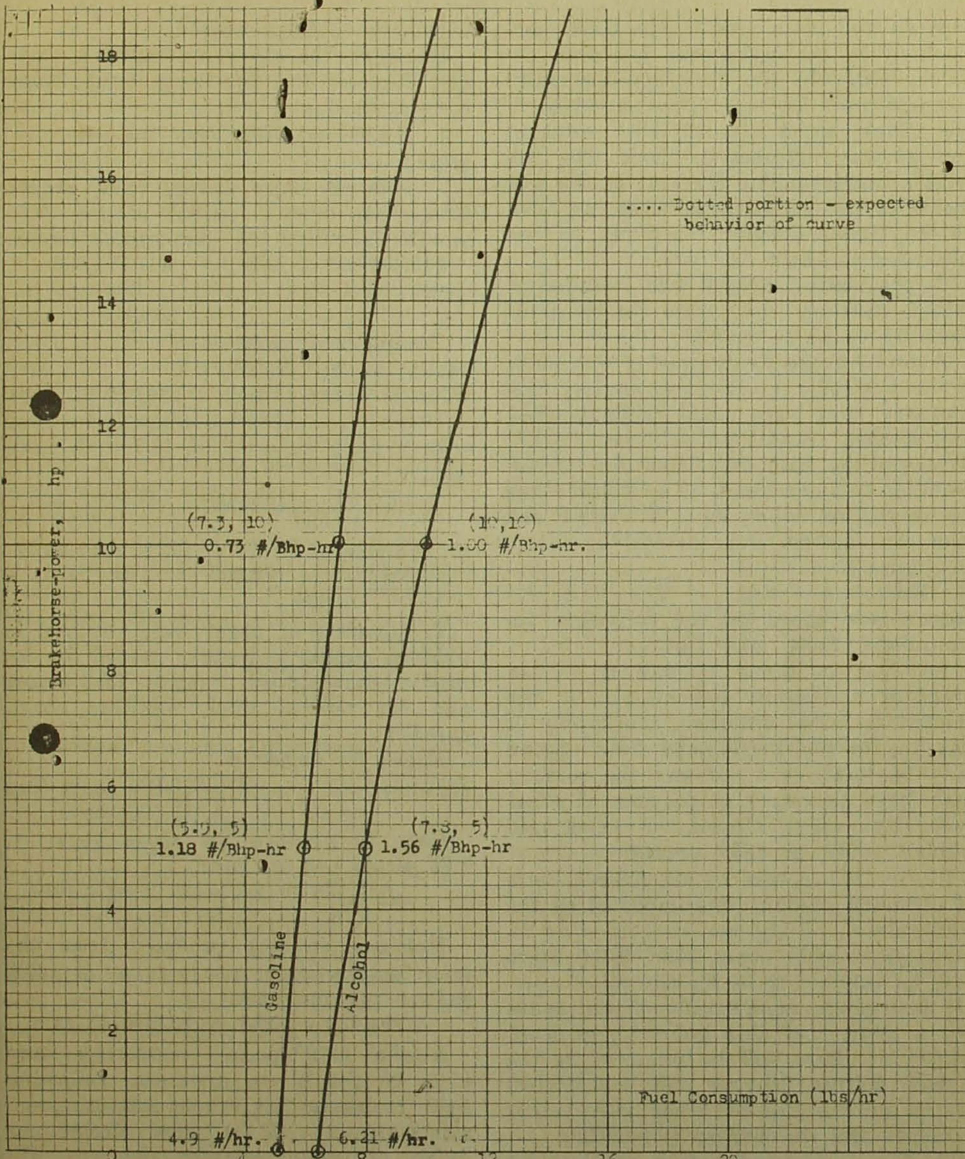

Fig. 1—Fuel consumption using gasoline and alcohol compared graphically.

a motor fuel are that the range of atmospheric temperature of operation is less than when gasoline is used and there is greater consumption of alcohol.

AFP RESEARCH

All the tests conducted here and abroad have shown that alcohol is the best fuel substitute for gasoline. They also indicated that the problems attendant to the use of alcohol can be completely solved by proper adjustments in carburetion and starting.

In the Armed Forces, the Research and Development Division has conducted a research on the use of alcohol as fuel for military vehicles with satisfactory results. The phases of the RDD research may be outlined as follows:

A. *Mechanical Changes in Engines.* — Certain changes had to be made in the engines that were used in the tests, particularly in the carburetor jets and metering rod. In the "low speed circuit" the idle well jet was removed, while in the "high speed circuit" the metering rod jet was increased to about .098 inch with a corresponding increase in the diameter of its tip by using soldering lead. In the "Pump Circuit" the pump jet was increased to about .059 inch.

A pre-heating gadget was installed to insure starting time within the range of from 15 to 20 seconds.

A prony-brake dynamometer was made for a 4-cylinder Le-Roy gas engine. Preliminary runs were made using gasoline and alcohol. Brake Horse Power (BHP) developed by both fuels and the corresponding fuel consumption by volume and by weight wer ecomputed. The BHP and fuel consumption were plotted as shown in Figure 1

B. *Economic Study.* — The RDD research was based on the following assumptions, facts, and figures:

1. That in times of war or in the event of a desirous deterioration in the the international situation, the supply of gasoline to the Philippines from abroad may be totally cut off and the country may have to resort to the use of other fuels like ethyl alcohol, or dematured alcohol (95% or 189° proof).

2. In 1951, a total of 523,828,406 liters of ordinary gasoline was imported by the Philippines. Fifty per cent of this figure, or roughly about 262,000,000 liters may be assumed to be the controlled overall emergency requirement of the country a year. Of this quantity, at least 45,800,000 liters will be required by the Armed Forces, leaving only 216,200,000 liters for the use of other government agencies and the civilian population.

3. This estimated yearly requirement of 262,000,000 lters of gasoline will have to be replaced by at least 445,400,000 liters of denatured alcohol (189° proof), based on a factor equivalent of 1.7 under similar conditions.

4. Alcohol can be produced partly from waste cane molasses from the manufacture of sugar and partly from straight cane juice.

5. The distillation of alcohol will take about ten (10) months. The present capacities of the country's distillery plants will have to be increased.

Based on the above assumptions, facts and figures, the following computation were arrived at:

1. *Additional distillery columns required.* —

Average daily alcohol (189° proof) production over a period of ten (10) months, allowing 5% evaporation losses:

$$\frac{445{,}400{,}000 \times 1.05}{10 \times 30} = \frac{467{,}670{,}000}{300} = 1{,}558{,}900 \text{ G. Ltrs.}$$

Present total daily capacity of all distillery columns in the Islands . 183,000 G. Ltrs.

Number of additional columns required with a daily capacity of 10,000 G. Ltrs. each:

$$\frac{1{,}558{,}900 - 183{,}000}{10{,}000} = 137.6 \text{ or } 138$$

or, columns at 20,000 G. Ltrs. each daily:

$$\frac{1{,}558{,}900 - 183{,}000}{20{,}000} = 69$$

2. Quantity of sugar cane required to produce alcohol and sugar needed for domestic consumption (sugar for export and for reserve stock was not considered):

Sugar for domestic consumption ..... 279,505.505 short tons or 4,015,426 piculs

Cane to produce the above sugar at 1.75 piculs per ton cane:

$$\frac{4{,}015{,}426}{1.75} = 2{,}294{,}529 \text{ metric tons}$$

Molasses (waste) produced from the manufacture of the above sugar at 5.238 gallons per ton cane:

$$2{,}294{,}529 \times 5.238 = 12{,}018{,}743 \text{ gals.}$$

Alcohol (189° proof) recoverable from 90% of the above molasses, (allowing 10% molasses for miscl. domestic consumption), at 1.70 G. Ltrs. alcohol per gallon of waste molasses and with 5% evaporation losses of alcohol:

$$12{,}018{,}743 \times 0.90 \times 1.70 \times 0.95$$
$$= 12{,}018{,}743 \times 1.4535$$
$$= 17{,}469{,}240 \text{ G. Ltrs.}$$

Allowing 2,000,000 G. Ltrs. for medicinal and other uses, only 15,469,240 G. Ltrs. of the above alcohol from molasses will be available for fuel.

Cane needed to supply juice for direct distillation to produce the balance of total alcohol requirement, based on 65 G. Ltrs. alcohol per ton cane:

$$\frac{467{,}670{,}000 - 15{,}469{,}240}{65} = 6{,}956{,}935 \text{ metric tons}$$

Therefore, the total can required to produce the country's requirements of alcohol and sugar will be:

6,956,935 + 2,294,529 = 9,251,464 metric tons

or, allowing 10% for bad crop, the actual cane needed will be:

9,251,464 x 1.10 = 10,176,610 metric tons

3. Additional area to turn into sugar cane plantation to take care of the increase in cane requirement over present production, based on 48 tons per hectare:

$$\frac{10{,}176{,}610}{48} - 189{,}048 = 22{,}965 \text{ ha.}$$

4. Probable Net Income per hectare:

From sugar cane planted purposely for alcohol:

a. *Share basis*:

Assuming an average produce per hectare conceding the present average production and that expected under the same cultivation methods used in pre-war days, the yield per hectare may be placed at:

$$\frac{48 + 80}{2} = 64 \text{ tons}$$

Recoverable alcohol (189° proof), based on cane with an average sucrose content of 12.85%:

65 x 65 = 4160 G. L.

Planter's share:

At 65:35 share basis and @P.20 G. L. the planter would get:

4160 x 0.65 x P.20 = P450.80

Less: Cultivation and harvesting expenses at P4.90 per ton cane, or 64 x P4.90 = 313.60

Net Income per hectare on share basis of 65:35 .... P227.20

Central's share:

Gross income on 64 tons cane:

4160 x 0.35 x P.20 .... P291.20

Less: Distillation and hauling exp., based on average for 1950-51 crop:

4160 x P.077 .... 320.32

Loss per 64 tons cane .... (P 29.12)

Assuming, however, a 50:50 share basis, the planted would get:

4160 x 0.5 x P.20 .... 416.00

Less: Cultivation, harvesting and hauling exp. at P4.90 per ton, or

64 x P4.90 .... 313.60

Net Income/Ha. on a 50:50 share basis P102.40

And the Central would get:

4160 x 0.5 x P.20 .... P416.00

Less: Distillation and hauling exp., based on average for 1950-51 crop:

4160 x P0.077 .... 320.32

Net income on 64 tons cane milled and distilled .... P 95.68

b. *Outright purchase of cane*:

By the central:

Buying planter's can at P6.50/ton, picked up at railroad side:

Cost of cane — 64 x P6.50 .... P416.00

Cost of hauling and distillation of 64 tons cane (yield = 4169 G. L. Alcohol):

4160 x P.077 .... 320.32

Total cost to Central in processing to alcohol 64 tons cane P736.32

Gross income: 4160 x P.20 ... 832.00

Less: Materials and processing exp. 736.32

Net Income/64 tons cane ..... P 95.68

Planter's Side:

Gross income per hectare by selling the 64 tons cane to the Central at P6.50/ton:

64 x P6.50 .... P416.00

Less: Cultivation, harvesting and hauling exp. at P4.90 per ton:

64 x P4.90 .... 313.60

Net Income/ha. P102.40

These figures on the production of sugar may be compared to the production and income from rice production, as follows:

If upland rice, based on the harvest/yr. @ 25-30, or 27.5 cav. palay/Ha. and at P10/cav., the planter would get:

Gross Income — 27.5 x P10 .. P275.00

Less: Cultivation and harvesting exp./ha. 200.00

Net Income/Ha. .... P 75.00

2. If lowland rice, based on two harvest/yr., 35-45 or 40 cav. palay/ha., and at ₱10/cav., the planter get:

Gross income — 40 x ₱10 .... ₱400.00
Less: Cultivation and harvesting exp./Ha. 300.00
Net Income per harvest ...... ₱100.00

or, net income per year:
2 x ₱100 .... ₱200.00
(Note: Most cane fields are upland; hence, income must be based on upland rice for comparison with that of sugar cane.)

C. Extensive test runs were conducted by the RDD in its research and experi-

MURPHY - PMA RUN 30 November 1952

I. ALCOHOL

(1) ROUTE SERIAL	(2) MILES RUN	(3) HOURS RUN	(4) FUEL CONSUMPTION in GALLONS	(5) AVERAGE SPEED MPH	(6) AVERAGE MILEAGE MPG	(7) TEMPERATURE ATMOSPHERIC °F	(8) CHARACTER & TYPE OF ROAD & GRADE	(9) REMARKS
1. Libis-Malolos	29.30	1H-26M	3.00	20.49	9.73	74°-86°	Good Concrete Asphalt	Stop at Cubao, Balintawak, Malanday. Fairly heavy traffic. Idling increase at Malanday.
2. Malolos - San Fernando	18.80	OH-42M	1.75	26.86	10.74	86°-90°	Good Concrete	Traffic very heavy in Apalit & San Fernando Idling needle opened 1/8 turn.
3. San Fernando-Tarlac, Tarlac	34.15	1H-11M	3.00	28.94	11.38	90°-92°	Fairly good Asphalt, concrete, gravel	Partly rolling. Generally down grade. Idling needle open 1/8 turn.
4. Tarlac - Villasis	30.80	OH-57M	2.75	32.21	11.20	92°-94°	Fairly good Concrete Asphalt	Fairly level. Normal traffic.
5. Villasis - Junction	28.95	1H- OM	2.75	28.95	10.53	94°-90°	Fairly good Asphalt & Concrete	Parly rolling. Normal traffic.
6. Junction - P M A	19.90	1H-17M	2.50	15.55	7.96	90°-84°	Fairly good Asphalt & Gravel	Up grade - Normal traffic.
Totals.....	161.90	6H-33M	15.75					

LOADS: Libis - Tarlac, Tarlac .... 635 lbs.
Tarlac - P M A .... 535 lbs.

II. GASOLINE

(1) ROUTE SERIAL	(2) MILES RUN	(3) HOURS RUN	(4) FUEL CONSUMPTION IN GALLONS	(5) AVERAGE SPEED MPH	(6) AVERAGE MILEAGE MPG	(7) TEMPERATURE ATMOSPHERIC °F	(8) CHARACTER & TYPE OF ROAD & GRADE	(9) REMARKS
1. Libis-Malolos	29.30	1H-26M	2.25	20.31	13.00	74°-86°	Good Concrete Asphalt	Stop at Murphy, Cubao Balintawak & Malanday. Fairly heavy traffic. Idling increase at Malanday
2. Malolos - San Fernando	18.80	OH-42M	1.00	26.86	18.80	86°-90°	Good Concrete	Traffic very heavy in Apalit & San Fernando Idling needle open 1/8 turn.
3. San Fernando - Tarlac, Tarlac	34.15	1H-11M	1.25	28.94	27.32	90°-92°	Fairly good Asphalt, concrete, gravel	Partly rolling. Generally down grade. Idling needle open 1/8 turn
4. Tarlac - Villasis	30.80	OH-57M	1.50	31.36	20.53	92°-94°	Fairly good Concrete Asphalt	Fairly level. Normal traffic
5. Villasis - Junction	28.95	1H- OM	1.50	28.95	19.30	94°-90°	Fairly good Asphalt & Concrete	Partly rolling. Normal traffic.
6. Junction - P M A	19.90	1H-17M	2.00	15.51	9.95	90°-84°	Fairly good Asphalt & Gravel	Up grade - Normal traffic
Totals	161.86	6H-33M	9.50					

LOADS:
Libis - Tarlac .... 600 lbs.
Tarlac - PMA .... 530 lbs.

Fig. 2—Alcohol and Gasoline Consumption Compared in Murphy-Baguio test run.

ments. Similar road test runs had been conducted in 1948 with an old standard army jeep using alcohol as fuel, but the results were not satisfactory due to the dilapidated condition of the jeep. It was therefore found necessary to have reconditioned army jeeps for the alcohol experiment and modifications and adjustment of jets had to be made. On 30 November 1952, a road test run was conducted from Camp Murphy to the Philippine Military Academy in Loakan, Baguio. Two jeeps were used, one of which was fueled with 95% ethyl (190° proof) alcohol and the other with V-72 gasoline. The jeeps were with about 600 pounds

BAGUIO - MURPHY RUN 2 December 1952

I. ALCOHOL

(1) ROUTE SERIAL	(2) MILES RUN	(3) HOURS RUN	(4) FUEL CONSUMPTION IN GALLONS	(5) AVERAGE SPEED MPH	(6) AVERAGE MILEAGE MPG	(7) TEMPERATURE ATMOSPHERIC °F	(8) CHARACTER & TYPE OF ROAD & GRADE	(9) REMARKS
1. Baguio MP-Junction	21.10	1H-07M	1.25	18.92	16.89	70°-82°	Good Asphalt & Concrete	Downgrade
2. Junction - Tarlac	59.75	1H-56M	5.25	30.84	11.38	82°-94°	Fairly good Asphalt & Concrete	Partly rolling Normal traffic
3. Tarlac - San Fernando	33.95	OH-55M	3.50	37.00	9.69	94°-93°	Fairly good Asphalt Concrete & gravel	Partly rolling Generally Upgrade Normal traffic
4. San Fernando Malolos	18.75	OH-33M	1.75	34.00	10.71	93°-92°	Good Concrete	Level. Fairly Heavy traffic
5. Malolos - Libis	29.30	1H-02M	2.50	28.44	11.71	92°-91°	Good concrete & asphalt	Heavy traffic up to Bonifacio Monument. Partly rolling.
Totals	162.81	5H-33M	14.25					

Load: 564 lbs.

II. GASOLINE

(1) ROUTE SERIAL	(2) MILES RUN	(3) HOURS RUN	(4) FUEL CONSUMPTION in GALLONS	(5) AVERAGE SPEED MPH	(6) AVERAGE MILEAGE MPG	(7) TEMPERATURE ATMOSPHERIC °F	(8) CHARACTER & TYPE OF ROAD & GRADE	(9) REMARKS
1. M. P. - Junction	21.10	1H-07M	0.75	18.95	28.10	70°-82°	Good Asphalt & Concrete	Downgrade
2. Junction - Tarlac	59.75	1H-56M	2.75	30.91	21.72	82°-94°	Fairly good Asphalt & Concrete	Partly rolling Normal traffic
3. Tarlac - San Fernando	33.95	OH-55M	2.00	37.45	16.97	94°-93°	Fairly good Asphalt, Concrete & Gravel	Partly rolling Generally upgrade Normal traffic
4. San Fernando - Malolos	18.75	OH-33M	1.00	34.00	18.75	93°-92°	Good, Concrete	Level. Fairly Heavy traffic.
5. Malolos - Libis	29.30	1H-02M	1.25	28.34	23.44	92°-91°	Good Concrete & Asphalt	Heavy traffic up to Bonifacio Monument. Partly rolling.
Totals...	162.81	5H-33M	7.75					

LOAD: xxx --- 500 lbs.

Fig. 3—Alcohol and Gasoline Consumption Compared in Baguio-Murphy test run.

payload each, but at Tarlac, Tarlac the payload was reduced to 530 pounds.

Instruments used were a Taylor wet and dry bulb temperature gage and the jeeps' panel instruments like the mileage gage and the temperature gage. A fuel measuring rod divided into 1-gallon interval was devised for approximate reading of fuel consumption. These two jeeps have each a compression ratio of 6.48 to 1.

The route, Murphy-Baguio, was divided into six serials as follows:

(1) Libis-Santolan — Malolos
(2) Malolos — San Fernando
(3) San Fernando — Tarlac, Tarlac
(4) Tarlac — Villasis
(5) Villasis — Junction
(6) Junction — P.M.A.

This was considered necessary as the grade, character and type of road for every serial more or less varies. This will, as was found later, give a better MEAN or AVERAGE mileage and speed when the data were arranged statistically.

At every stop, time, mileage, fuel consumption and atmospheric temperature readings were taken and recorded for both jeeps.

It was observed that both the alcohol-fueled jeep and the gasoline-fueled jeep, climbed the Zig-Zag Road to Baguio with ease on second gear.

While in Baguio, starting in cold tests were conducted at midnight and dawn Temperatures at midnight of 30 November and 1 December 1952 averaged 60°F, while the temperature between 0200 hrs. to 0300 hrs. averaged 57.5°F. Starting without difficulty in alcohol with the preheater gadget was observed.

Ordinary road test runs were also made in and around Baguio. The operation was normal.

The Baguio-Murphy route, was divided into five serials only as the road type from Junction to Tarlac, Tarlac is almost uniform. The serials are as follows:

(1) Baguio — Junction
(2) Junction — Tarlac
(3) Tarlac — San Fernando
(4) San Fernando — Malolos
(5) Malolos — Libis, Santolan.

At every stop, time, mileage, fuel consumption and temperature were also recorded. In this run speed was accelerated. The data and the resulting statistical averages are as shown in Figure 2.

D. Consolidation of Results.

The preliminary comparable road test runs showed that the ratio of alcohol to gasoline consumed averaged 1.77. The U.S. Bureau of Standards tests using finer and better instruments found the ratio to be from 1.6 to 1.7. The slight difference of .07 may be due to inaccuracies of the instruments used. However, the results tallied almost exactly with the results of the tests conducted by the U.S. Bureau of Standards. They showed that more power is developed by alcohol than by gasoline. Moreover, while using alcohol as fuel, cold starting at 57.5°F was not difficult with the preheater gadget. Cooling was also faster in the alcohol-fueled jeep than in the gasoline-fueled vehicle.

With stationary engines using a prony-brake, it was shown that the ratio of alcohol to gasoline at 1/2 load is 1.38. This tallies closely with Teodoro's ratio of 1.33. No appreciable amount of carbon deposits were found in the alcohol jeep. (See Figure 1)

More Extensive Tests Necessary

The results of the preliminary tests conducted by the RDD as well as the results of the extensive tests by the U.S. Bureau of Standards and by Dr. Teodoro point to the necessity for more extensive tests in the use of straight 95% (190% proof) ehtyl alcohol as fuel. A service test employing 50 jeeps would be sufficient.

It is likewise imperative that the study be extended to other types of military vehicles, such as the power wagon, or weapons carrier, 2-1/2 ton truck, staff cars, etc. so that their performance with the use of alcohol may be determined.