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# Modification of CFR Test Engine Unit to Determine Octane Numbers of Pure Alcohols and Gasoline-Alcohol Blends

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ABSTRACT

The CFR test engine unit was modified by the use of a variable fuel needle jet, instead of the carburetor main jet of standard size (ASTM research and motor method), as well as by an additional heating system for the air/fuel mixture pre-heating device (ASTM motor method). This enables octane ratings of pure alcohols and gasoline-alcohol blends without changing engine operating conditions as specified by ASTM. The applicability of the newly developed supplementary devices was verified and found appropriate by the members of a FAM Task Group, organized within the German Institute for Standardization (DIN).

PROBLEMS WHEN RATING OCTANES OF ALCOHOLS

For the determination of the knock characteristics of motor gasolines in terms of research and motor octane numbers, the Waukesha single-cylinder CFR (Co-operative Fuel Research) engine unit as specified by the American Society for Testing and Materials (ASTM) is utilized world-wide. However, the equipment of this test engine unit is insufficient when octane ratings of pure alcohols or gasoline-alcohol blends are to be performed. This is due to the higher latent heat of vaporization of the alcohols, which cause a strong cooling-down of the air/fuel mixture in the engine inlet manifold compared to conventional fuels. Thus, octane ratings by the ASTM motor method cannot be conducted at the specified mixture temperature level of 149°C. Furthermore, the heating values of the alcohols are lower in comparison to conventional fuels. Therefore the adjustment of the air/fuel ratio for maximum knock intensity is difficult for both research and motor method engine units, because the ASTM carburetor is furnished with a calibrated

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main jet adapted to conventional fuels, which limits the fuel flowrate to a lower range than needed for alcohols. Fig. 1 illustrates parts of the CFR engine unit, which are affected by the special properties of alcohols and which do not permit octane ratings as specified by ASTM (mixture heater/motor method), and where a more complicated rating is implied (carburetor main jet/motor and research method).

These facts were the reason for the FAM Task Group, (organized within the German Institute of Standardization (DIN) and competent for octane rating methods) to modify the engine parts as shown in Fig. 1 in a manner that octane number determinations of pure alcohols, as well as blends are possible under the specified engine operation conditions.

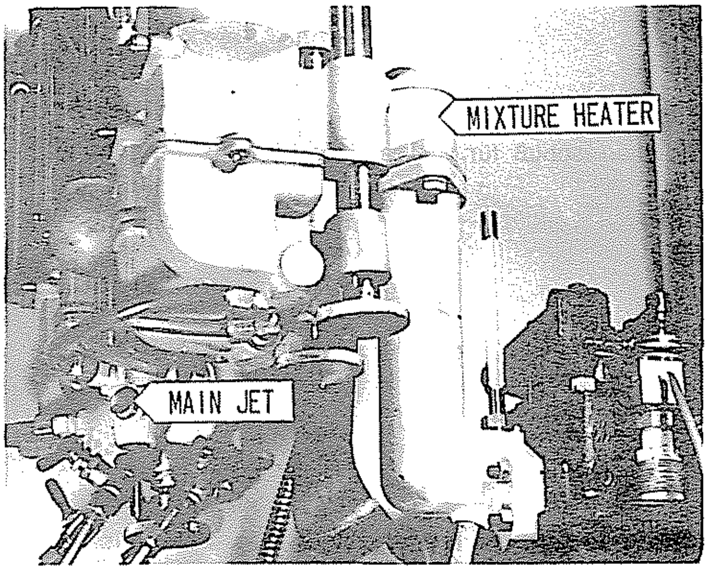


Fig. 1 - Problem areas of the CFR engine unit

## PROBLEM SOLUTION

CARBURETOR MAIN JET - Test specification for both research and motor octane number determinations (RON and MON) require air/fuel ratio adjustments for maximum knock intensity by raising or lowering the fuel level in the carburetor, whereby the main jet of standard size defines the corresponding fuel flowrate. However, the higher fuel consumption with alcohols against conventional fuels cannot be handled by this fixed nozzle. Thus, for octane ratings of alcohol and blends a special jet adaption for the air/fuel ratio adjustments on the engines is needed.

In order to avoid such a complicated jet adaption, it was considered to replace the standard main jet with a variable type, which allows air/fuel adjustments for maximum knock intensity, independent from the different flowrates of all fuels. Fig. 2 and Fig. 3 show the variable needle jet developed for the RON and MON engine unit for this purpose. It

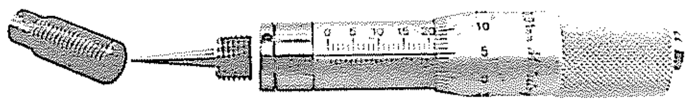

Fig. 2 - Variable needle jet

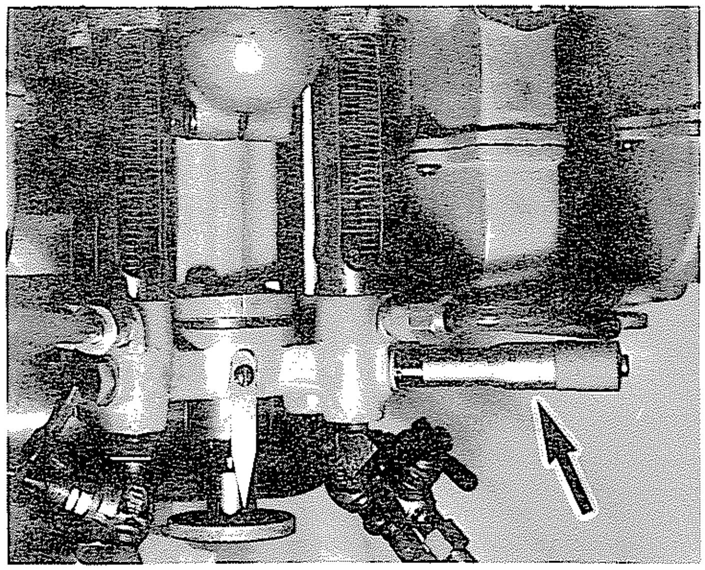

Fig. 3 - Carburetor with variable needle jet

was ensured, that fuel flowrate variations at constant fuel level in the carburetor has the same effect as of raising or lowering the fuel level with calibrated jets of the standard procedure. Thus, the problem has been solved.

FUEL MIXTURE HEATER - The heating capacity of the standard heater element is not sufficient to compensate for the mixture cooling caused by alcohols' latent heat of vaporization, so that the mixture temperature level specified to 149°C (300°F) cannot be met. To achieve this, an increase of the heating capacity is necessary. The full utilization of the 1000 Watt capacity available by the standard heater element is not possible since this resulted in an overheating of the blades, and hot spots are causing the methanol to ignite occasionally before reaching the combustion chamber as observed in some engines. The installation of additional heater blades or blades otherwise shaped inside the heater manifold to supply more heat without hot spot formation is impossible due to the given manifold design and moreover would influence the octane ratings. The only alternative for providing the heat needed for alcohols was by an external supply i.e. from the outside through the heater manifold wall. Therefore a heating device was developed which can be tightly fitted around the manifold housing (see Fig. 4 and Fig. 5).

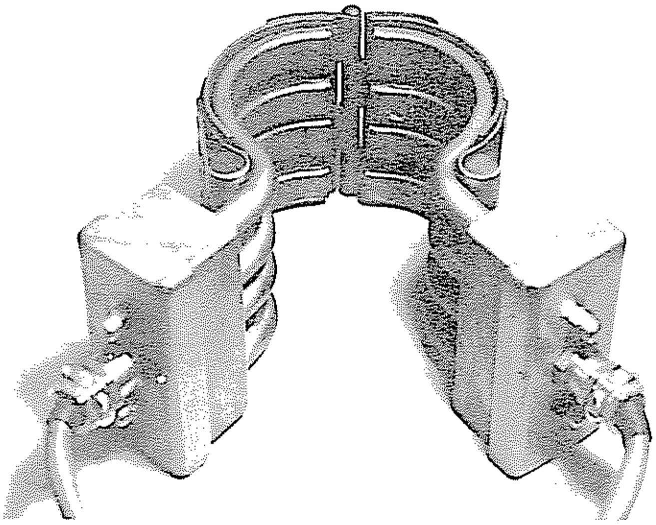

Fig. 4 - Additional heating device

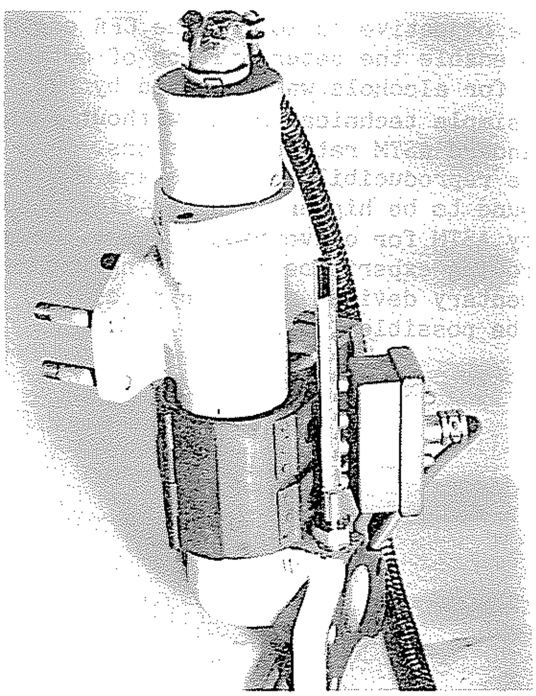

Fig. 5 - Mixture heater with additional heating device

The capacity of this additional heating device was defined to 800 Watt so that the maximum heat demand can always be covered. The total amount of heat necessary for alcohols is produced by two separate independent heating systems: the standard and the additional one. Both heaters are operated on separate power units regulated manually. In order to avoid a possible influence on MON determination resulting from the use of more heat than conventional fuels would need, the power of the standard heating element has to be adjusted to 700 Watt. Fig. 6 shows the MON unit completely furnished with the supplementary devices, variable needle jet, additional heater and the two electrical power units. Naturally the RON engine needs only the needle jet owing to the absence of the necessity to pre-heat the mixture.

RESULTS OF OCTANE NUMBER RATINGS

The applicability of the new additional heating devices and variable needle jet has been tested by all member laboratories of the FAM Task Group. The fuels rated for RON and MON are shown in Table 1. The individual as well as the average results for the tested fuels no. 1 to no. 8 are shown in Fig. A-1 (pure alcohols) and Fig. A-2 (blends). For RON and MON the average figures obtained for

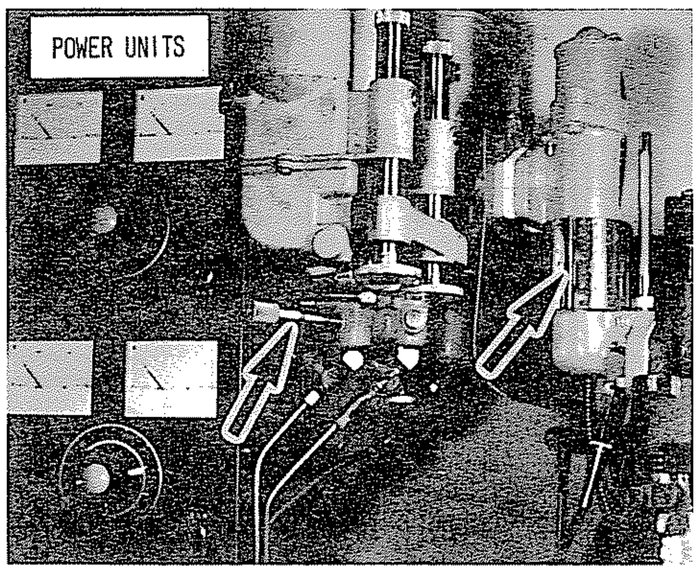


Fig. 6 - MON engine unit completely modified

Table 1 - Octane Rating Fuels

| Number | Fuel |
|---|---|
| 1 | Methanol |
| 2 | Ethanol |
| 3 | Isobutanol |
| 4 | 50 vol.% No. 1 / 50 vol.% No. 8 |
| 5 | 15 vol.% No. 1 / 85 vol.% No. 8 |
| 6 | 50 vol.% No. 2 / 50 vol.% No. 8 |
| 7 | 50 vol.% No. 3 / 50 vol.% No. 8 |
| 8 | Conventional Fuel (Premium) |

Table 2 - Results of Octane Ratings of Pure Alcohols (Average Values)

| | RON | MON |
|---|---|---|
| No. 1 Methanol | 108.7 | 88.6 |
| No. 2 Ethanol | 108.6 | 89.7 |
| No. 3 Isobutanol | 106.3 | 90.4 |

pure alcohols are given in Table 2.

RON and MON as a function of alcohol contents in the conventional base fuel no. 8 (premium grade) are given in Fig. A-3. The RON diagram indicates that the blending octane values for methanol are higher than the laboratory octane results or about equivalent for ethanol and isobutanol respectively. Regarding MON the blending values were found to be almost equivalent (methanol) or lower (ethanol, isobutanol) than the corresponding laboratory octane numbers. However, these results cannot be generalized because usually blending values are depending strongly on hydrocarbon composition as well as on octane number level.

PRECISION OF THE OCTANE NUMBER RATINGS

Values for the reproducibility of the RON and MON determinations are also outlined in the Fig. A-1 and Fig. A-2 for all fuels tested. In Fig. 7 the precision of the RON results on pure alcohols and blends are shown. The comparison with the accepted limits for conventional fuels by ASTM indicate that the scatter between the laboratories was wider, but the reproducibility data obtained follows the same trend as the ASTM accepted limits, which demonstrates the higher the RON level the higher the level of error for reproducibility. This is also valid for the MON ratings where also the accepted limits for conventional fuels were exceeded (Fig. 8).

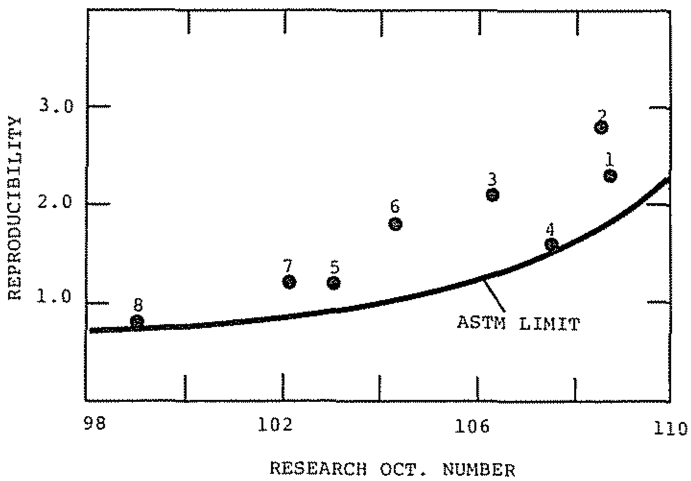


Fig. 7 - RON rating precision of pure alcohols and gasoline-alcohol blends

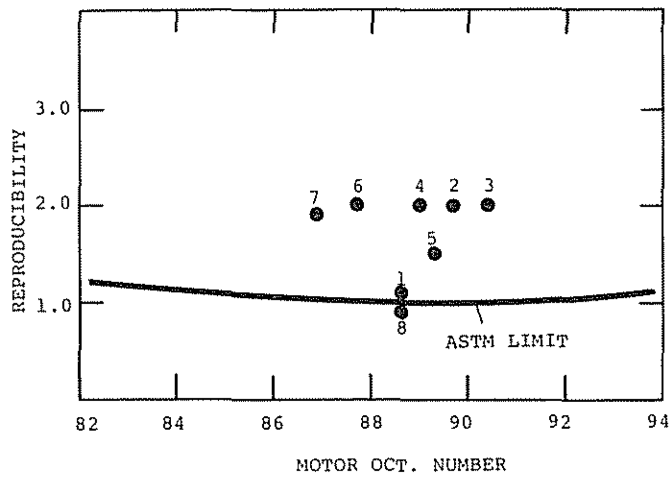


Fig. 8 - MON rating precision of pure alcohols and gasoline-alcohol blends

CONCLUSIONS

The objective to modify the CFR engine unit to enable the determination of octane numbers for alcohols was achieved by relatively simple technical means without changing the standard ASTM rating conditions.

The reproducibility of RON and MON ratings were found to be higher than the limits specified by ASTM for conventional fuels. However, with growing experience in handling the new supplementary devices a higher precision should be possible.

OCTANE RATINGS OF PURE ALCOHOLS

| Lab. Code | Sample No. 1 Methanol | | Sample No. 2 Ethanol | | Sample No. 3 Isobutanol | |
|---|---|---|---|---|---|---|
| | RON | MON | RON | MON | RON | MON |
| 3 | 110.0 | 88.0 | 109.6 | 88.8 | 106.9 | 89.3 |
| 8 | 108.4 | 88.7 | 108.2 | 89.8 | 106.1 | 90.3 |
| 12 | 108.1 | 88.9 | 108.5 | 89.7 | 106.4 | 90.8 |
| 13 | 108.6 | 88.0 | 107.8 | 89.3 | 106.4 | 90.0 |
| 14 | 109.1 | 88.6 | 110.7 | 89.0 | 108.1 | 90.0 |
| 15 | 109.1 | 88.5 | 108.4 | 88.0 | 106.6 | 89.1 |
| 17 | 108.8 | 88.8 | 108.5 | 89.5 | 105.6 | 90.5 |
| 26 | 108.3 | 88.5 | 108.0 | 90.4 | 105.6 | 91.2 |
| 27 | 108.7 | 88.3 | 109.5 | 89.8 | 106.6 | 90.5 |
| 30 | 108.1 | 88.4 | 109.4 | 89.6 | - | 90.3 |
| 32 | 110.9 | 89.3 | 109.9 | 90.0 | 107.2 | 91.1 |
| 35 | 108.4 | 88.8 | 108.1 | 89.8 | 106.1 | 90.1 |
| 45 | 108.3 | 88.9 | 107.0 | 90.7 | 105.6 | 91.3 |
| 48 | 107.6 | - | 107.6 | - | 106.0 | - |
| 54 | 108.9 | 88.3 | 109.0 | 89.5 | 106.3 | 90.0 |
| 79 | 108.4 | 88.7 | 108.0 | 90.5 | 106.0 | 91.5 |
| 110 | 108.2 | 89.1 | 108.0 | 90.2 | 105.2 | 89.9 |
| Average | 108.7 | 88.6 | 108.6 | 89.7 | 106.3 | 90.4 |
| Reproducibility | 2.3 | 1.1 | 2.8 | 2.0 | 2.1 | 2.0 |

Fig. A-1

OCTANE RATINGS OF GASOLINE-ALCOHOL BLENDS

| Lab. Code | Sample No. 4<br>50 % No. 1 / 50 % No. 8<br>RON | <br><br>MON | Sample No. 5<br>15 % No. 1 / 85 % No. 8<br>RON | <br><br>MON | Sample No. 6<br>50 % No. 2 / 50 % No. 8<br>RON | <br><br>MON | Sample No. 7<br>50 % No. 3 / 50 % No. 8<br>RON | <br><br>MON | Sample No. 8<br>Conventinal Fuel<br>RON | <br><br>MON |
|---|---|---|---|---|---|---|---|---|---|---|
| 3 | 108.7 | 88.1 | 102.9 | 88.9 | 104.8 | 87.2 | 102.4 | 85.8 | 99.0 | 88.8 |
| 8 | 107.5 | 89.3 | 102.9 | 89.1 | 104.1 | 87.4 | 102.1 | 86.2 | 98.9 | 88.5 |
| 12 | 107.9 | 89.0 | 103.0 | 89.4 | 105.0 | 87.6 | 102.0 | 87.3 | 99.1 | 88.9 |
| 13 | 107.4 | 88.6 | 103.1 | 88.9 | 103.7 | 87.2 | 102.3 | 86.8 | 99.0 | 88.8 |
| 14 | 107.2 | 88.9 | 102.6 | 90.0 | 105.4 | 87.0 | 102.6 | 87.0 | 99.1 | 88.9 |
| 15 | - | 87.2 | 103.9 | 88.4 | 104.4 | 86.0 | 101.9 | 86.1 | 99.3 | 88.7 |
| 17 | 107.6 | 89.0 | 103.0 | 89.0 | 103.4 | 87.1 | 101.6 | 86.0 | 99.0 | 88.2 |
| 26 | 106.6 | 89.1 | 102.3 | 89.7 | 103.9 | 87.8 | 101.6 | 86.8 | 98.8 | 88.3 |
| 27 | 106.9 | 88.7 | 103.3 | 89.5 | 104.3 | 88.2 | 102.3 | 87.3 | 98.6 | 89.0 |
| 30 | 108.1 | 89.2 | 103.9 | 89.2 | 104.5 | 88.5 | 102.6 | 87.9 | 99.3 | 88.5 |
| 32 | 108.3 | 89.6 | 102.8 | 89.5 | 105.5 | 88.1 | 102.6 | 87.0 | 98.6 | 88.9 |
| 35 | 107.4 | 89.6 | 102.8 | 89.2 | 104.4 | 88.3 | 102.8 | 87.3 | 98.9 | 88.5 |
| 45 | 107.0 | 89.5 | 102.5 | 90.1 | 103.6 | 88.2 | 101.8 | 87.4 | 98.7 | 88.6 |
| 48 | 107.3 | - | 102.9 | - | 104.0 | - | 101.7 | - | 99.0 | - |
| 54 | 107.5 | 88.5 | 102.9 | 88.6 | 104.8 | 87.4 | 102.5 | 86.4 | 98.9 | 88.7 |
| 79 | 107.5 | 90.1 | 102.8 | 90.0 | 103.9 | 88.4 | 102.0 | 87.9 | 98.8 | 88.9 |
| 110 | 107.2 | 89.4 | 102.7 | 89.0 | 103.9 | 88.2 | 101.6 | 86.5 | 99.7 | 88.0 |
| Average | 107.5 | 89.0 | 103.0 | 89.3 | 104.3 | 87.7 | 102.1 | 86.9 | 99.0 | 88.6 |
| Reproducibility | 1.6 | 2.0 | 1.2 | 1.5 | 1.8 | 2.0 | 1.2 | 1.9 | 0.8 | 0.9 |

Fig. A-2

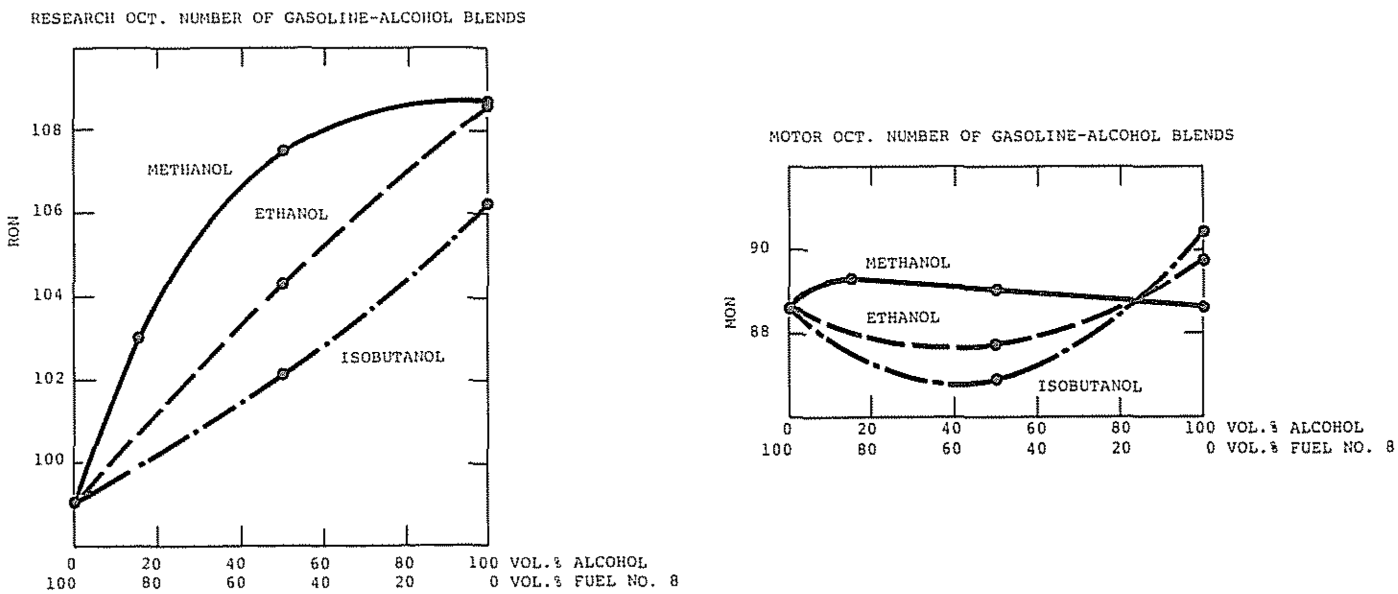


Fig. A-3

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