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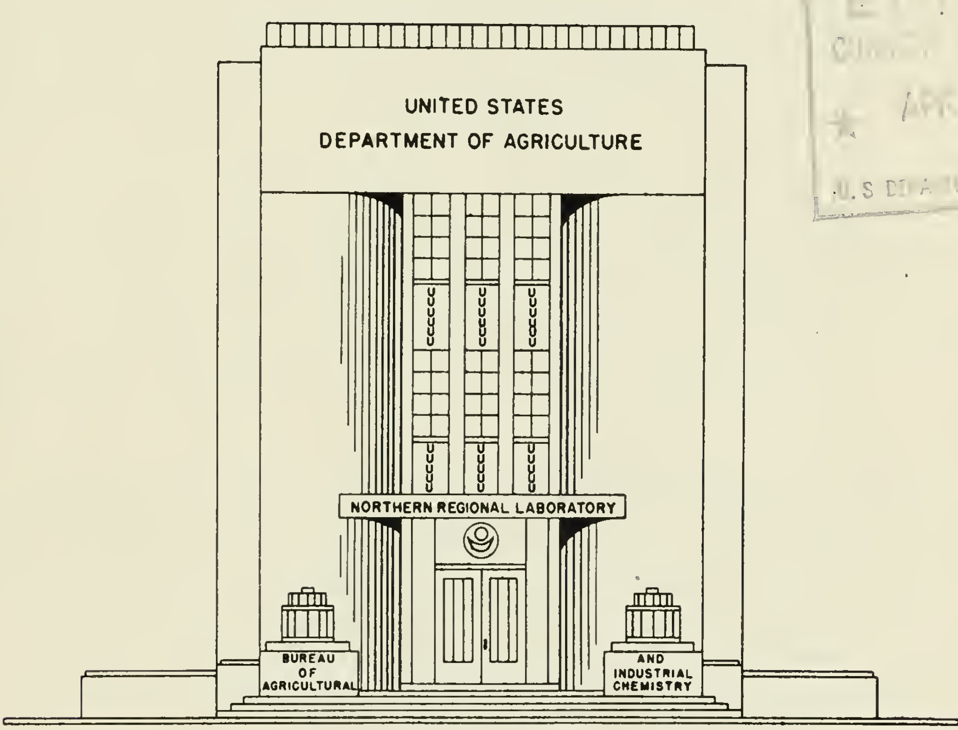
ALCOHOL-WATER INJECTION FOR FARM TRACTORS



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The present trend in automotive engine design is towards higher and higher compression ratios for greater specific power output and more miles per gallon. These engines require higher octane fuels, but commercial gasolines appear to be reaching at least a temporary octane limit and the slight advances which are being made have been costly to the fuel manufacturer.[3]

A relatively recent development is the use of alcohol-water injection for boosting the octane number of gasolines, particularly in engines with compression ratios above those now commonly used. One of the most important potential applications of alcohol-water injection for boosting the octane number of motor fuels is in farm tractor operations. High-compression engines which are now being manufactured for use with liquid petroleum gas (L.P.G.)[4] could operate also with gasoline in combination with alcohol-water injection up to ratios of 8:1.

The Northern Regional Research Laboratory of the Bureau of Agricultural and Industrial Chemistry at Peoria, Illinois has studied the possible use of alcohol-water injection in farm tractors and has conducted successful laboratory and field experiments in which injection was used in a special high-compression farm tractor. After the completion of this work, arrangements were made to carry out field tests under actual farm operating conditions. Under a research contract with the Northern Laboratory, the Department of Agricultural Engineering of the Ohio Agricultural Experiment Station at Columbus arranged and supervised cooperative tests with a number of farmers involving a total of fifty tractors. These tests have now been completed and indicate the possibilities of alcohol-water injection in farm tractor operation. It is the purpose of this bulletin to give information to the farmer how alcohol-water injection can be

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[1] A report of work done under contract with the U.S. Department of Agriculture and authorized by the Research and Marketing Act of 1946. The contract is being supervised by the Northern Regional Research Laboratory of the Bureau of Agricultural and Industrial Chemistry.

[2] One of the Laboratories of the Bureau of Agricultural and Industrial Chemistry, Agricultural Research Administration, U.S. Department of Agriculture.

[3] According to Bureau of Mines National Motor-Gasoline Survey Winter 1951-52 the average octane numbers for regular and premium grade gasoline were 83.1 and 90.0 respectively. (These are the "Research" octane numbers which check most closely the low-speed-range, engine octane-requirement).

[4] L.P.G consists mainly of propane, a hydrocarbon gas. Propane condenses into a liquid under a certain pressure, (its vapor pressure). The required pressure increases with higher temperatures.

applied to farm tractors. No attempt is made to discuss fuels and engines in detail and only the minimum necessary technical background is given in each case.

Tractor Tests With Alcohol-water Injection at Northern Laboratory

Alcohol-water injection is applied only to spark-ignition engines.[5] The compression ratio of present-day spark-ignition tractor engines ranges from approximately 4.1 to almost 7.1 for gasoline and from 8:1 to higher ratios for liquid petroleum gas. Higher compression ratios will give more power for the same displacement and also more work per gallon of fuel. This can be seen diagrammatically in Figures 1 and 2. Figure 1 shows that by raising the compression ratio of a particular standard tractor engine from 5.3:1 to 8:1, with equipment supplied by the manufacturer, an increase of maximum power from 42.3 hp to 54 hp is secured. The high-compression tractor will deliver about 28 percent more power with the same engine displacement. The fact that a considerable saving of fuel can be achieved at the higher compression ratio is shown in Figure 2. For the same power output, selecting for example maximum power at the 5.3:1 ratio, 1.11 gallons of gasoline are saved per hour when the compression ratio is increased to 8:1. Corresponding savings can be obtained at other loads and more equipment can be handled at lower unit cost. At higher compression ratios, therefore, a saving can be accomplished both in fuel and time. High compression changeover should, of course, be made only at the recommendation of the manufacturer, in order to insure satisfactory operation of the tractor.

The manner in which maximum octane requirement (or minimum fuel octane requirement) of the tractor engine varies with compression ratio is shown for three makes of tractor engines in Figure 3. A-1 and A-2 are two tractor engines of the same make but run at different speeds.

These data were obtained with so-called reference fuels (isooctane *n*-heptane blends) in order to eliminate the fuel as a variable. Commercial fuels frequently do not rate as high in tractor engines as reference fuels so that even the best grade (90 octane number) is not likely to give knock-free operation in tractor C though its maximum octane requirement, as shown in Figure 3, is in the neighborhood of 87. All other tractor engines definitely are not satisfied by premium gasoline alone.

Experiments at the Northern Laboratory have indicated that alcohol-water injection could be used at 10:1 compression ratio in a special high-compression engine supplied as a prototype by a large automobile manufacturer; however, injection can also be applied successfully to the lower compression ranges. In other words, injection may be applied to any octane range of fuels, in the technical sense, but this may not always be economical. The low-octane fuels such as distillates and straight-run nonleaded gasoline, may be used in combination with alcohol-water injection. Distillate fuels, selling at prices considerably less than gasoline, can be used in combination with injection in the low-compression

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[5] Some attempts have been made to extend alcohol-water injection to Diesel (compression ignition) engines but the experimental results do not show promise of such general usefulness.

tractors in instances where the distillates alone could result in heavy knock detrimental to engine operation. Straight-run nonleaded gasolines are usually not sold at a price low enough to make up for the cost of installing the injection equipment and the alcohol-water mixture consumed.

There are, however, certain special advantages in using unleaded straight-run fuels with alcohol-water injection, since such a combination gives a sufficiently high octane number for the ordinary compression range, as well as a remarkably clean engine.[6] Engine deposits, as they occur when injection is used, are usually soft and easily removable. Large-scale, practical experiments are now in progress to investigate further the effect of injection on increasing valve life.

Automotive machines are being used by the farmer in increasing numbers. The Bureau of Census estimated recently that on January 1, 1952 there were 4,170,000 tractors, 4,350,000 autos, and 2,410,000 trucks on United States' farms. The use of more efficient engines in farm tractors would result in a marked saving of motor fuel.

A tractor engine ordinarily does not require, for knock-free performance, the full octane value of the gasoline throughout its operating range. Only at, or near, full-throttle does the engine need the full benefit of the antiknock qualities of the fuel. The operating range during which alcohol-water injection should be applied is illustrated for one particular type of tractor by the shaded area in Figure 4. In this case, the gasoline could not supply enough antiknock quality if used alone. Without alcohol-water injection this tractor engine would begin to knock at about 70 percent of full power with this particular gasoline. If the tractor were to operate exclusively at about 60-percent load, a regular gasoline of about 78 octane number might suffice, but this would not only be impractical but would also defeat the advantages of high compression.

Therefore, a fuel is used which will satisfy the engine requirements over most of the part-throttle range, alcohol-water injection will supply the extra octane values, just when needed, for full- or near full-load performance, and the tractor will run smoothly over the whole range. How this can be accomplished technically will be explained later.

Farm Tractor Experiments in the Columbus, Ohio Area

As shown in Figure 4, the octane requirements of an engine increase as the load increases, and with the proper fuel, alcohol-water injection is required only for heavy loads. Therefore, the only way to ascertain the consumption of the alcohol-water mixture and the gasoline is by field tests with the engines under loads encountered in actual situations. To obtain data for a practical analysis of this problem, the Department of Agricultural Engineering of the Ohio Agricultural Experiment Station supervised a field-test program with tractors owned and operated by farmers near Columbus, Ohio, A total of fifty tractors, with compression ratios ranging from 5.3:1 to 8.0:1, were used. Each tractor was taken to the laboratory and equipped with an automatic alcohol-water injector, an hour meter, and, in some cases, high-compression pistons or

[6] Octane numbers of distillate and straight-run nonleaded fuels range from 20 to 60 octanes.

heads. After the injectors were checked for proper functioning by operating the tractor on a belt-load, the tractor was returned to the farmer who used it for normal type of work for one year. The farmer kept detailed records of fuel and mixture consumption and an account of his observations and experiences. A 50:50 specially denatured grain alcohol-water mixture was furnished for use with the injector.

The proper operation of an alcohol-water injector depends upon careful adjustment. It must be set to provide a minimum amount of alcohol and water needed to obtain the required octane gain for a given kind of gasoline at various loads and speeds. As will be shown, four separate adjustments are required to determine the proper settings. Figure 5 illustrates schematically the injector used in the tractor field tests.

In controlling injection, advantage is being taken of the fact that engine load and speed are directly related to the vacuums existing at any one time in the carburetor venturi and the intake manifold. For this purpose the manifold and carburetor venturi are connected to the injector chamber below the diaphragm. The vacuum existing in the injector chamber below the diaphragm depends therefore upon the manifold and venturi vacuums and incidentally on the size of the manifold and venturi orifices. This resulting vacuum determines the position of the injector shut-off or diaphragm valve which permits or prevents injection. When the engine is running, gasoline vapors mixed with air, flow from the carburetor venturi through the manifold to the engine. Alcohol and water vapors do likewise but only under predetermined load and speed conditions. At full-throttle and low-engine speed, the manifold and venturi vacuums are low enough (i.e., almost equal to atmospheric pressure) that, with the help of the injector spring, the diaphragm valve opens and injection occurs. At high-engine speed and wide-open throttle, the venturi vacuum is finally high enough to close the valve even though the manifold vacuum remains low. At part-throttle operation, usually above 7" of mercury, the diaphragm valve will close because the resulting vacuum is again too high. While the manifold and venturi vacuums regulate the time of injection, the fuel jet governs the amount of alcohol-water mixture which passes through the carburetor venturi. Therefore, the rate of injection to an engine under variable load depends upon

(1) Size of the manifold orifice.
(2) Size of the venturi orifice.
(3) Size of the spring.
(4) Fuel jet size.
(5) The load and speed of the engine.

A typical installation is shown in the photograph at the end of the bulletin where the injector is seen mounted close to the carburetor and the tank on top of the hood.

The ABC of Alcohol-Water Injection

The answers to the questions below are based on the extended experience with injection at the Northern Regional Research Laboratory and particularly on the field tests carried out by the Department of Agricultural Engineering, of the Ohio Agricultural Experiment Station. They should point out the possibilities and limitations of alcohol-water injection in farm tractors.

1. Why is alcohol-water injection used?

The maximum effective octane value of a fuel for spark-ignition engines can be increased when an alcohol-water mixture is injected with the base fuel. An increase in the octane value of the fuel permits the use of higher compression ratios which, if incorporated into the engine design, will result in more efficient engines with higher specific power output. Since the maximum octane value is required only under conditions of heavy load the injection of alcohol, which is relatively expensive, is required for heavy loads only. At part-load conditions, the efficiency of a high-compression engine can be realized with no consumption of alcohol (see Figure 4), provided an adequate base fuel is used.

2. How much can the octane value of the base fuel be increase?

Alcohol-water injection can be used to increase the octane value of present gasolines by 8 to 10 numbers and by about 15 numbers for distillate and kerosene.

3. How much can the compression ratio of an engine be increased when alcohol-water injection is used?

With an octane increase of 10 numbers the compression ratio of the basic tractor engine can be increased about 1.5 numbers--for example 5.5 to 7.0, or 6.0 to 7.5. However, this depends to quite an extent on engine make. (See Figure 3)

4. How will such a compression ratio increase affect the gasoline consumption?

The overall gasoline consumption should be from 10 to 15 percent less for the same amount of work done. This is according to laboratory tests and reports by the farmers who used the high-compression engines during the field tests. Gasoline consumption on the basis of gallons per hour, was higher for the field tests but the engines were doing proportionately a greater amount of work in less time.

5. How much alcohol-water mixture will be used?

For a two-three plow tractor the yearly consumption may vary between one and eight percent of the gasoline used, with an average of four percent. This depends upon the engine load. The more the operation is at full-load, the higher will be the total comsumption of the mixture.

In smaller tractors, the average consumption of alcohol-water mixture may be eight percent of the gasoline used. This is due to a greater tendency by the farmers to overload smaller tractors during average operation.

6. What would be the monetary saving on the average 2-3 plow tractor?

The difference in fuel costs between a standard gasoline engine and a high-compression engine with alcohol-water injection will depend upon the cost of the gasoline and the alcohol. With gasoline at 20 cents and alcohol at 75 cents per gallon (bulk prices at Columbus, Ohio) the average fuel saving for the high-compression engine would be $15-20 for each 1,000 gallons of gasoline used. This is based on an assumed 4-percent average alcohol-water mixture consumption.

7. How would the fuel costs of an engine designed to use distillate with alcohol-water injection compare with an engine designed to use gasoline without injection?

The total fuel cost would be about $40 less per 1000 gallons of fuel in favor of the distillate engine, with a 4-percent average alcohol-water mixture consumption.

8. How much could the power be increased by increasing the compression ratio 1.5 numbers?

The power would be increased by 10 to 20 percent, depending upon the engine design. Engine manufacturers are now also increasing the power by increasing the engine speed and displacement, with small increases in compression ratio.

9. Are the present tractors and equipment strong enough mechanically for an increase in compression ratio and power output?

Twenty-five tractors with compression ratios from 6.5:1 to as high as 8:1 were operated for one year with no failures. Six of the engines were completely disassembled after the test period and were found to be in good condition. (Other parts of the tractor were not inspected).

During the severe part of the winter some of the high-compression engines could not be started with the standard battery. Two of the tractors with compression ratios of 8:1, equipped with an additional battery in parallel with the regular one, could be started at any time.

A few cases of bent plow beams and twisted shafts in power-take-off equipment were reported. These can not be considered the fault of the extra engine power, but they illustrate the fact that judgment is required for proper use of more powerful engines.

10. What were the opinions of the farmers who used the high-compression engines?

The increase in power and smoothness of operation was of more importance to them than the saving in fuel. They were able to handle heavier loads, and sometimes to operate in a higher gear ratio with a saving in time. Twenty-three of the twenty-five tractors in which the compression ratio was increased for the test program will continue to be used by the farmers.

11. What were the farmers complaints about the use of alcohol-water injection?

The only complaint mentioned was the handling of the alcohol-water mixture in addition to regular fuel, and this was considered to be a minor objection.

12. Can injection be used to advantage on a tractor with a standard compression ratio?

From an economy standpoint, this probably would not be advantageous. Some farmers reported that the engines ran smoother and had more "lugging" power, similar to operation on a damp or rainy day. The power output of other engines was materially increased, because the carburetors did not permit an adequate adjustment of the air-fuel mixture for maximum power output on gasoline alone. The alcohol thus provided the extra fuel needed in addition to improving the octane number.

An unleaded straight-run gasoline, with injection for extra octane value, can be used in some engines with standard compression ratios. One farmer used this combination satisfactorily during the field test. In comparison with engines using regular gasolines, the combustion chamber and valves of this engine were remarkably clean, which would tend to prolong engine life and satisfactory performance. As mentioned previously, large-scale practical tests are now in progress to investigate this further.

13. Can an injector be purchased which will be satisfactory for my tractor?

Satisfactory alcohol-water injection equipment can be bought today for installation on a tractor. (See Figure 5 for requirements of a good injector). However, the success of injection depends upon the engine compression ratio, the octane value of the base fuel, the octane requirement of the engine, and the adjustment of the injector. Laboratory engine tests are generally required to obtain the correct combination of the above factors. Therefore, the equipment should be approved by the engine manufacturer who will know the type of injection equipment which meets the requirements.

14. Can the alcohol-water mixture be purchased or prepared?

Leaded alcohol-water mixtures containing about 85 percent alcohol and 3 ml. tetraethyl lead are being sold, which are very effective in suppressing knock. Under most farm-tractor operations, experience has shown that it is not necessary to go to such a concentration of alcohol or lead, and that a 50 50 unleaded alcohol-water mixture will suffice. A suitable composition for a mixture is given below:

25 gallons of water
25 gallons of alcohol
0 5 parts of corrosion inhibitor[7] preparation
containing a sulfonated oil (soluble oil)

In preparing the alcohol-water mixture, the corrosion inhibitor is first thoroughly mixed with the water alone (only distilled or reasonably soft water should be used) and this mixture then added to the alcohol. The proportions are not very critical and ordinary care is sufficient for making up the mixture. Cleanliness is however important.

Either grain or wood alcohol may be used interchangeably. Both are equally efficient. Wood alcohol (methanol) is an internal poison and, like leaded gasoline, should not be handled without due care. Ordinary denatured grain alcohol,

[7] For the proper functioning of the injector it is important to keep the injector jet and valve seats free from accidental deposits. In addition to a small filter which should be part of any good injection system a corrosion inhibitor must also be present in the alcohol-water mixture. The presence of water may cause a slight attack on some metals which may be used in the construction of the injector and this must be avoided.

which containing substances that may cause objectionable engine deposits, cannot be used. Only specially denatured grain alcohol can be used in injection mixtures, but the denaturants employed have not yet been approved by the Alcohol Tax Unit for individuals to use in making up their own mixtures. Antifreeze alcohol should never be used.

In general, therefore, it is recommended that alcohol-water mixture not be made up by the individual, but rather that it be purchased whenever possible. As time and need progress the number of suppliers of these mixtures undoubtedly will increase.

15. Can water alone be used?

Water alone has been used for a long time to prevent knock in engines, relatively more so in the past than at present. The use of water alone is strictly limited to conditions where only small octane gains are required. It may have its place, for instance, in certain very hot areas to cool the inlet air, since high temperatures tend to promote knock in engines. Alcohol-water injection would serve the same purpose but would be uneconomical if used only for such limited purpose.

16. Are tractor manufacturers considering new engines or auxiliary equipment for present engines to utilize the principles of injection?

Certainly the best approach for economical and wise use of the principles of alcohol-water injection is through the tractor manufacturer. Apart from the fact that such equipment would be properly designed, the local dealers would handle spare parts, provide necessary maintenance, and probably would market a satisfactory mixture for the injectors.

A few of the tractor manufacturers have expressed an interest in alcohol-water injection. Some have conducted tests of their own and others have been studying the data and performance of tractors which have been using alcohol-water injection. If the manufacturers plan to market such equipment, it may become available in the near future.

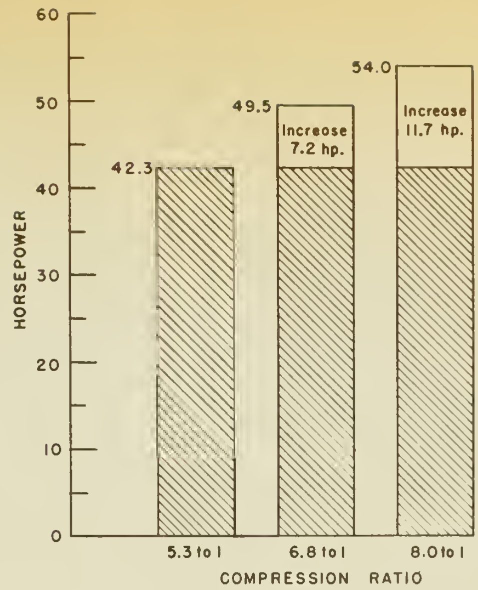

Figure 1 - Increase of brake horsepower by changing the compression ratio of a farm tractor engine.

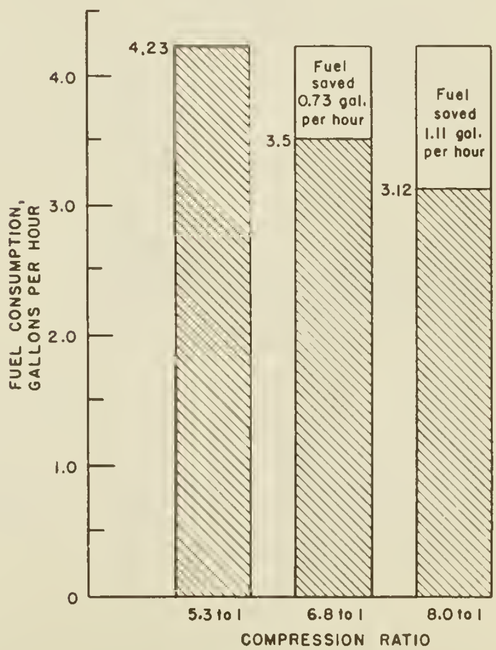

Figure 2 - Fuel saving in the operation of a tractor engine when compression ratio is increased.

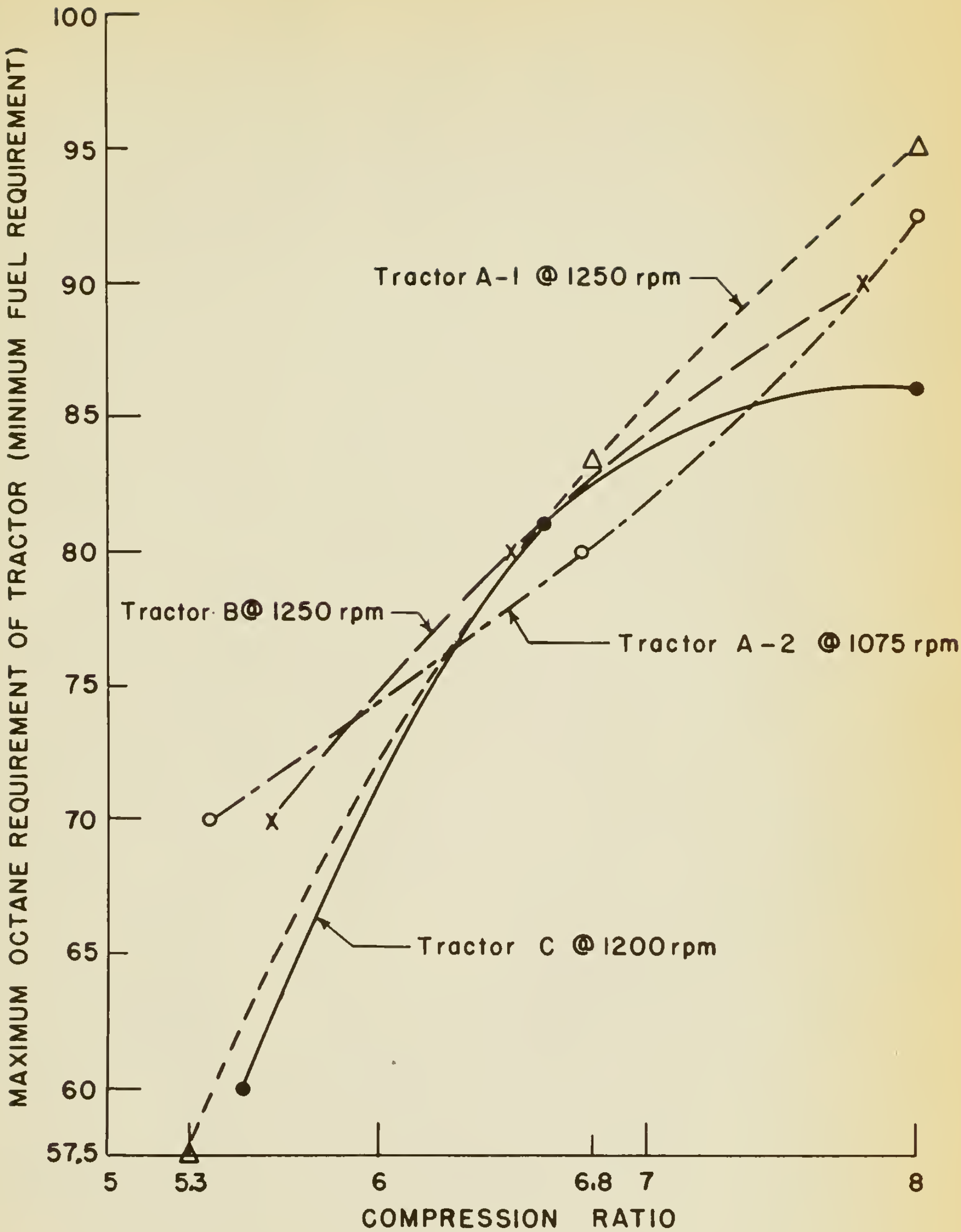

Figure 3 - Change of maximum engine octane requirement (or minimum fuel octane requirement) of three makes of tractors with compression ratio.

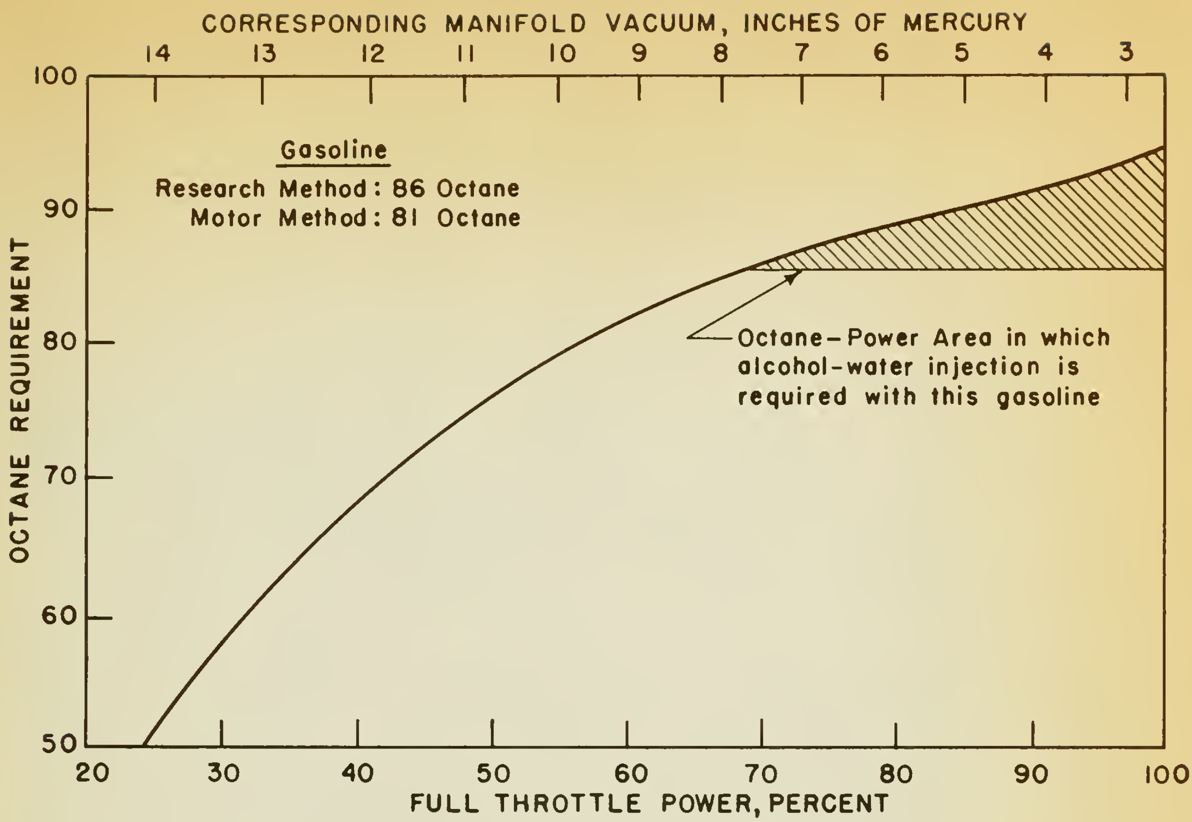

Figure 4 - Octane requirement for trace knock of an 8:1 compression ratio farm tractor for various loads at 1250 r.p.m. and 20° spark advance.

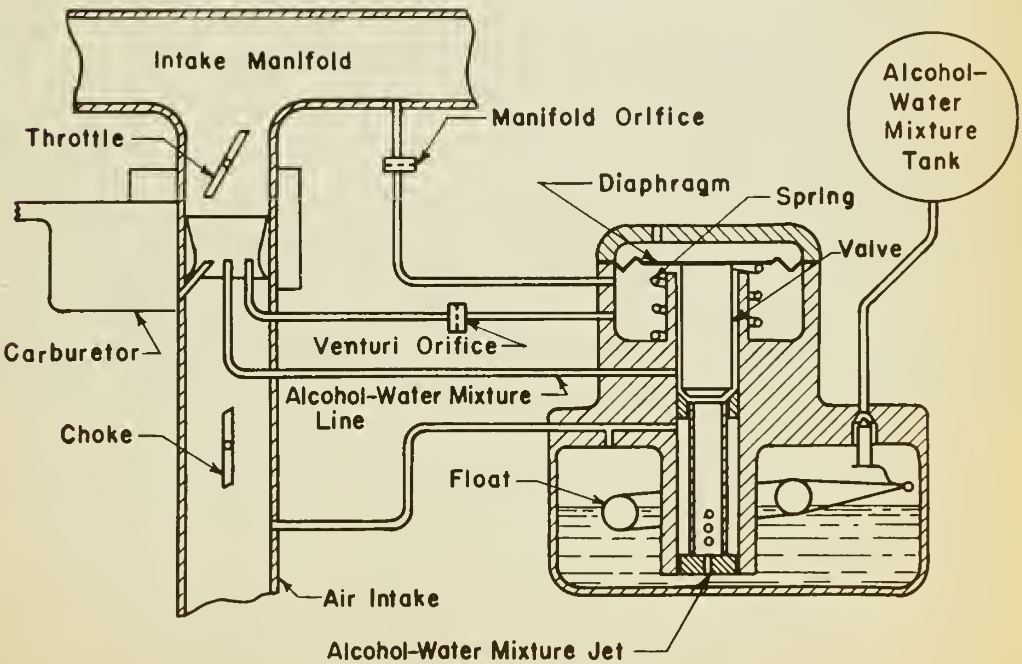

Figure 5 - Schematic digram of an injector for alcohol-water mixtures.

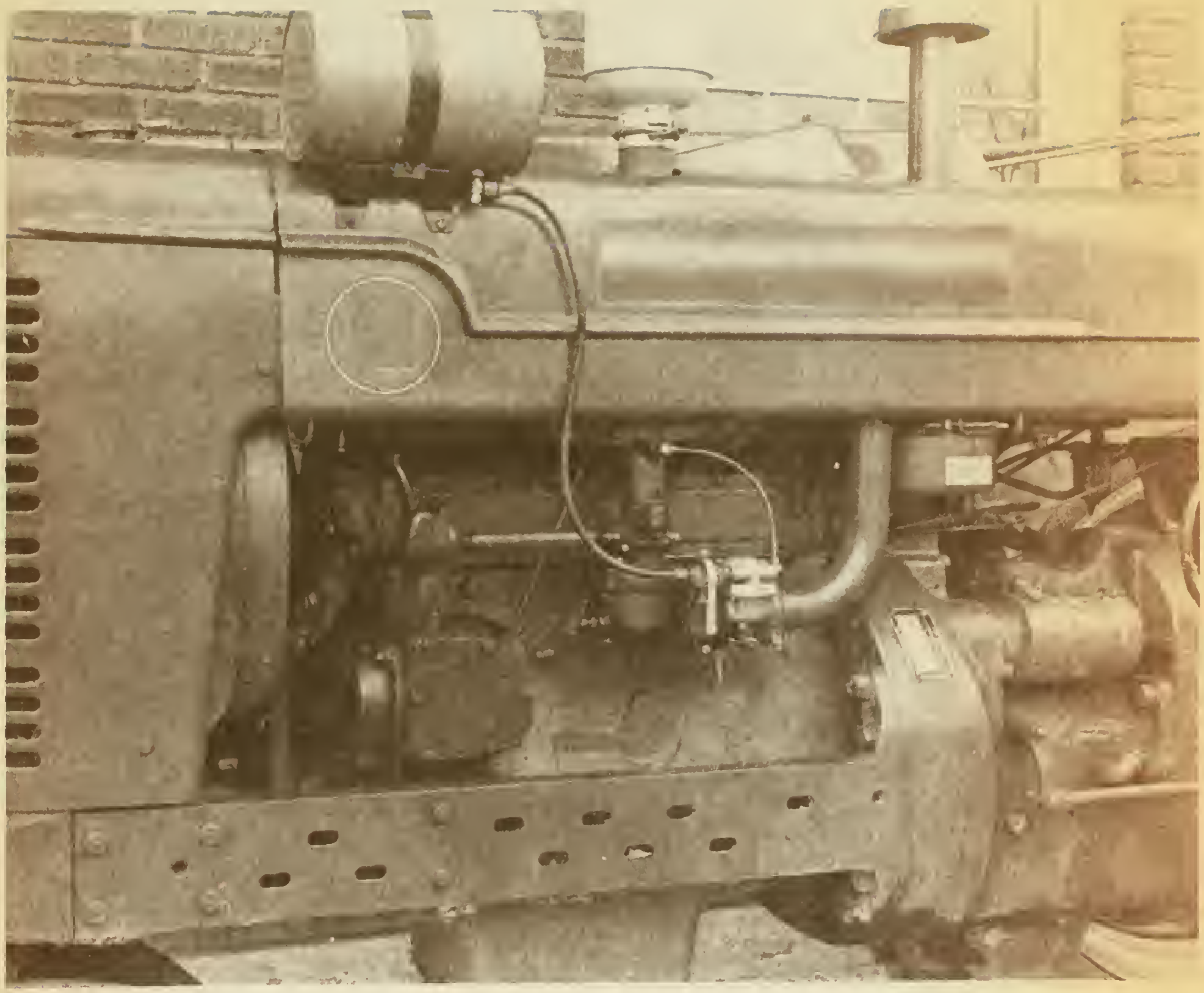

Figure 6 - Typical Injector Installation on Farm Tractor.