B.I.O.S. No. U.5
Lilienthal Gesellschaft Report No. 158, pps. 83-87
28, 29 January, 1943
F. Penzig

Tests made with safety fuel by the Technical Test Station

TZ 900, which is a polymerisate of isobutylene, has the property of breaking up into smaller molecules on heating. Here we get complete decomposition to gaseous isobutylene, which boils at -6°, resembling to a certain extent the familiar fuel gas. This is easily demonstrated by heating TZ 900 in a retort over a bunsen flame, when it changes completely into gas or at least into vaporised Di- or tri-iso-butylene.

In our first attempts to use TZ 900, which is safe against shooting up, as engine fuel, it was our purpose to exploit this property, that is, to supply the engine with a propellant produced in the engine itself by making use of the exhaust heat.

(Fig. 1 - Structure of TZ 900, and its decomposition products)

The plan required that the polymerisate actually was broken down into gas. Fig. 1 shows the structure of isobutylene and its polymers, which one must consider as isobutylene molecules linked together in a chain. Actually, conditions are far from being as simple as this, since for di-iso-butylene there are two, and for tri-iso-butylene actually nine different possible forms of molecule, while nothing exact is known about the structure of the molecules of higher polymers.

To render the viscous TZ 900 serviceable for use as an engine fuel, its long molecule must be split up. The property which this fuel possesses of being converted completely into gas is a special case in the chemistry of hydro-carbons, and is the one possible means of running a spark-ignition engine on a fuel which is proof against shooting-up. All the other known fuels of equal viscosity yield coke or other substances poor in hydrogen when they are heated. These substances, if they get into the engine, impair lubrication. On the other hand TZ in its liquid form has always the properties of a lubricant, so that undecomposed fuel can mix with the lubricating oil without causing damage.

The tests showed, however, that it was impossible to achieve complete decomposition down to gas by thermal decomposition alone. This is impossible in just the same way as it is impossible to demolish a house in such a way that the ruins consist entirely of single bricks. In addition to gas, there were considerable volumes of gasoline-like substances, and these, together with small volumes of substances with still higher boiling points, could not be used as fuel. Fig. 2 shows that decomposition is more thorough the higher the temperature, but that at temperatures above 500° fluid substances still occur along with gas.

(Fig. 2 - Decomposition of TZ 900)

To achieve the most complete break-down possible, even at lower temperatures, we had to use catalysts, such as Fuller's earth, and clay. We also made tests with liquid fuels. The difficulties encountered here were great. Catalytic processes are tied to certain temperature ranges, which cannot be maintained sufficiently exactly. If the temperature is too low, the pores of the catalyst become stopped up. If the temperature became too high, decomposition did not end with isobutylene, the gas decomposing further to form soot and hydrogen. We also had difficulty in separating the gas from the undecomposed substance, with the result that a frothy mixture got into the engine. Also, the enclosing of the gas made it difficult to heat. This last point was very important at the time, as the use of tubes with narrow cross-sections, which would have brought about an improvement, was impossible because the catalyst had to be interchangeable.

Fig. 3 shows how the TZ is delivered through a pump to the decomposer, which

- 2 -

is filled with the catalyst and heated by exhaust gas. After this the liquid components were separated, and the hot gas, then under pressure, was allowed to expand and supplied to the engine.

(Fig. 3 - Installation for decomposing TZ 900 by means of catalysts
The TZ 900 is supplied in a catalyst container heated by the exhaust gases, and the gas delivered to the engine)

The chief defect of the defice in use was the size and consequent clumsiness of the equipment. The maximum load was such that fuel could be supplied only at the rate of ten times the volume of the catalyst per hour. The result was that the dimensions were large, and that the decomposer responded sluggishly to alterations in load. We were compelled to run the whole installation under pressure in order to store up a supply of gas. In spite of this, it remained very awkward to manage, and also somewhat dangerous, owing to the considerable volumes of liquid and of highly heated gas, which was under a pressure of about 10 at. Fig. 4 shows an installation for running a vehicle on TZ 900, which was workable under simple conditions.

We therefore proceeded to decompose the TZ fuel as far as possible, and to inject it in a hot condition. For this purpose the nozzle itself was constructed as a heater, and was installed in such a way that it could be heated by the exhaust gases (Fig. 5). We also tried installing coils of pipes directly after the exhaust valve. These coils led to apertures in the valve seating, through which the heated TZ issued. It was also intended to make use of the high temperature of the exhaust valve seating in the pre-heating process. Similar tests have also been made by Junkers.

All these tests broke down owing to the inadequate nature of the equipment, also largely because the sparking plugs were "oiled-up" in the familiar way by undecomposed fuel, and so misfired. These facts showed that another ignition process is required for safety fuels, and this gave rise to the development of the Ring process.

(Fig. 4 - Arrangement for catalytic decomposition in a motor vehicle)

(Fig. 5 - Hot injection of safety fuel
TZ 900 was decomposed in a nozzle heated by the exhaust gases, and injected)

After this had been more or less settled last year we again undertook tests with TZ on the Ring process. At the same time we did away with hot injection, and re-cooled the more or less thermally decomposed product before injection. In this way, we made it possible to instal a central decomposer for a main engine on the lines laid down by Mücklich.

(Fig. 6 - Arrangement for the decomposing tests
The engine operated on gasoline, and served merely as a heat source for the decomposer)

Fig. 6 shows one of the earliest test installations. The engine, a DB 600l, operated on gasoline, and the corresponding volume of TZ 900 was passed through the decomposer and collected in a cooler. The engine therefore acted only as a heat source for the decomposer. The fuel, pre-heated slightly and also filtered in a tank pump, passed to an intermediate pump, and thence to the actual injection pump. This delivered it, not to the engine, but to a second cooler, to which a gas meter was attached. To protect the injection pump against excessive pressures, a hydraulic control device was provided which disconnected the delivery pump whenever the pressure at the injection pump exceeded 15 at.

For decomposers we used finned heaters as developed by TAL (Holfelder), two of them being arranged one behind the other if they proved to be too small (Fig. 7). The pre-heaters were tube coils made of ordinary injection tubing.

As a finned heater with a length of tubing of 1.8 m. was insufficient to cause a pronounced degree of decomposition, a pre-heating coil of 3 m. length was connected. Fig. 8 shows that with this arrangement up to 50% of the substances obtained boiled at less than 200°, and consisted of up to ⅔ of gas. Better results were obtained with two finned heaters, better still with a decomposer consisting of a coil of tubes 3 m. long. The best results of all were obtained with a pre-heating coil of 3 m. and a decomposing coil of C m. This arrangement made it possible to convert nearly all the material into gasoline-like substances. At the same time the decomposer could easily become choked up because isobutylene, which forms in large quantities, decomposed into soot and hydrogen on coming into contact with the hot walls. This occurred especially when the engine was suddenly stopped with the decomposer hot, and the remaining contents were subjected to a temperature of 600°. Decomposition occurred best at an excess air ratio of 1:1, at which the exhaust gas temperature and the TZ volume are evidently in the optimum relationship to each other. These tests settled the question of the best size for the decomposer.

(Fig. 7 - Heating fins, type T.A.L.
The safety fuel is conducted through a double coil, which is enclosed by a finned sheath)

(Fig. 8 - Decomposition of TZ 900 in different installations
3 m. pre-heaters and 3 m. decomposers are required to bring about satisfactory decomposition)

It should be mentioned that power measurements showed that the power of the engine was only slightly altered by installing the decomposer in the exhaust manifold.

In addition to these tests, we also investigated the knock rating of the decomposition products. In general, olefines have a good knock rating, which can be still further raised by branching. But a characteristic of the unsaturated ones is their high temperature sensitivity and small lead susceptibility. The boost limit curves of Fig. 9 show that in the case of Di-isobutylene there was nevertheless a certain lead effect. The best antiknock values were reached with isobutylene, so we should attempt to make decomposition as complete as possible. As against this, of course, there is greater danger of coking.

For further engine tests we used at first an experimental installation as in Fig. 10, which permitted better observation of the process. The chief feature of the arrangement was a mixing chamber, in which the decomposed substance mixed with the tetra ethyl lead, while at the same time the gas was separated out from the pump circuit.

(Fig. 10 - Decomposer for operating an engine on TZ 900
This complicated installation was mainly for the purpose of observing the liquefaction of the gas under pressure, or its output in the liquid components)

A water-cooling system was also provided for the decomposer, to avoid coking-up of the coils on sudden stopping of the engine. The installation is exceedingly complicated and is merely reproduced as an example of the difficulties encountered in these tests. The decomposer was an arrangement known as a spiral tube decomposer, shown in Fig. 11. The TZ fuel was led through two spiral tubes connected in series. The equipment was fitted up regardless of weight, and the possibility exists of cutting this weight down to a fraction. With these decomposers, the degree of decomposition shown in Fig. 12 was reached. The length of the flow path was 11m., the cross-section was 8 mm.^{2}, as smaller cross-sections proved too sensitive to coking. The times spent in the apparatus were between 17 and 30 secs., according to the rate of delivery required, the speed of flow was between 0.4 and 0.75m/sec. It then appeared that at 500° most of the substances produced boiled at +10°, that is, they mostly consisted of isobutylene. The remainder mostly boil up to 200°, the residue, which are higher boiling, being comparatively small in quantity. Analysis of the gases formed gave, (Fig. 13), apart from isobutylene, small quantities of other olefines, such as butylene and propylene. As always on decomposition, methane occurred, forming, together with butane 10 to 20% of the gas. These two paraffins, as is well known, have a very high knock rating. At higher temperatures hydrogen also occurred, an indication that the gas was decomposed, with consequent separating out of carbon.

The above described test installation possessed many advantages, but was very complicated to handle, and we evolved a simpler lay-out, which was more or less like the first test installation (Fig. 8). It also appeared to be sufficient if the injection pump was set to full delivery, and the delivery pump only was adjusted to the required volume. The pressure in the decomposer was adjusted to such a figure that the gas remained in solution in the cooled products of decomposition. Decomposition could be controlled by a shutter in the exhaust pipe.

The results obtained with an engine operating on TZ were, if not completely satisfactory, at least adequate. The highest power, as Fig. 14 shows, was only slightly less than when operating on gasoline. Consumption is accordingly still higher. The volume of R-fuel injected was 30 mm^3. Unfortunately the temperature of the decomposer was not measured with complete accuracy, so that it is not possible to say to what extent decomposition took place. The fall in exhaust temperature before and after the decomposer was between 60 and 100°, so that we may assume considerable heat absorption by the decomposer.

We will continue these tests, and attempt, by obtaining more accurate measurements to provide reliable data for the dimensions of the heat exchangers. Although we are aware that we have a long way to go before all questions are answered, we are still of the opinion that this work on safety fuel should be carried steadily forward.

(Fig. 11 - Spiral tube decomposer
To accomodate great lengths of tubing, two tubular windings were provided)

(Fig. 12 - Thermal decomposition of TZ 900
At 600° it was possible to achieve almost complete decomposition of TZ 900 into gas or gasoline-like substances)

(Fig. 13 - Composition of the gas obtained by decomposition
The gas consists chiefly of isobutylene, also of paraffins, such as butane and methane. The presence of hydrogen points to decomposition of the gas)

(Fig. 14 - Power and consumption of TZ 900 compared to gasoline
The engine when operated on TZ 900 achieved almost the power of gasoline. The decomposer absorbed a great quantity of heat)

30.1.46.