TECHNICAL MEMORANDUMS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

No. 224

ENGINES AND FUELS

From La Technique Aeronautique, April 15, 1923.

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Present Difficulties.

The war has greatly increased the use of automobile internal combustion engines, both for trucks and for passenger vehicles. Furthermore, aviation, which before the war was only in its beginnings, has now entered the path of practical accomplishments. All these various uses have naturally resulted in a very great consumption of liquid fuels. On the other hand, the commercial sources of these fuels do not seem to increase. There is even cause to fear that the supply will not keep up with the demand.

The result is a considerable increase in the price and an appreciable falling off in the quality, especially in comparison with prewar fuels. The quality has become so poor that automobilists, not without reason, often complain of the running of their vehicles. There is a tendency to attribute their difficulties to the designing and construction of the vehicles, when it is really due only to the fuels they are compelled to use. This situation has often been made the object of investigation and various remedies have been proposed. It is well, therefore, to consider the present functioning conditions of internal combustion engines.

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Fuels : Solid, Liquid and Gaseous.

Solid fuels cannot be used in automobile and aviation engines. It may be objected that satisfactory tests have been made with gasogens (apparatus for producing gases from solids), but no such device has been found very practical. It adds considerable to the weight of the vehicle and leaves too much to be desired in the matter of cleanliness, for its use to become general. As for aviation, its weight is absolutely prohibitive.

Gaseous fuels are of no more practical use, although they have been proposed by intelligent persons. Assuming a cubic meter of the fuel to contain 15000 calories, the quantity that can be stored in any vehicle will still be small, unless we use very large containers capable of withstanding very high pressures. The use of such containers would be very dangerous and, furthermore, the weight of a container holding 40 liters, for example, would have to be very great in order to withstand the high pressure.

Suppose we wish to carry 30 kg. of fuel, which is a minimum for any vehicle even of small dimensions. If this fuel should have about the same density as the air (1.03 kg. per cu.m), its volume would be about 29 cubic meters, which would have to be subjected to a pressure of about 300 kg. in order not to require a container of over 100 liters capacity. Such a container would be much heavier than its contents and its use would necessitate accessories which would add still more weight. Even if its use should be possible on automobile trucks, it would be extremely difficult on passenger vehicles and absolutely impossible on airplanes.

Liquid fuels offer real advantages. Like gases, they can be stored in containers of any shape, which may be very light, since they only have to withstand the force of gravity. Liquid fuels can be transmitted through light and inexpensive pipes. They are clean and easily handled. They contain a large amount of energy in a small volume. These advantages amply justify the efforts made to procure liquid fuels. Automobiles and airplanes are destined to use liquid fuels for many years to come.

Not all liquid fuels, however, are equally suited for use in existing engines and it is well to call attention to a point of extremely great importance at the present time.

Fuel Delivery.

Different fuels do not all behave the same and hence require special methods for their utilization. In large factories, liquid-fuel engines usually function in a particular manner.

For example, let us take the Diesel engine. The fuel generally used in this type of engine is a petroleum product and is injected into the engine cylinder at the end of the compression stroke. The fuel is injected by means of compressed air. If the mechanism which regulates the quantity of fuel functions properly, each cylinder receives the right amount of fuel for the weight of air admitted. If the fuel is also properly atomized, the combustion will be sufficiently complete.

In automobile engines, the fuel is introduced in an entirely different manner, due to the fact that injection pumps, which give excellent results with engines under a constant or only slightly varying load, are not adapted to automobile engines, which function under greatly varying loads.

An automobile engine passes suddenly from a very small load at low speed to a full load at much higher speed. This occurs just in the period of time required for the machine to speed up, the driver suddenly throwing the control mechanism to the position of full speed and power and then throwing it back suddenly to the position of minimum power.

This manner of operation is not in conformity with the conditions for the successful utilization of the fuel-injection method. We know of no case where it is giving complete satisfaction on high speed engines. For this reason the fuel is introduced with the aid of a mechanism called "carburetor."

Hence, in speaking of fuels for automobile and airplane engines, we must bear in mind this manner of introduction, which, as we shall see, restricts the use of different fuels and requires of them certain qualifications.

Functioning of Automobile Carburetor.

When the engine revolves, it draws air into the cylinders through a pipe connected with the carburetor. The latter consists in part of a tube formed by joining the smaller ends of two conical tubes, thus producing a constriction in which is placed the end of the spraying nozzle. The velocity of the air in this constriction is quite high and causes a negative pressure or suction at the end of the nozzle, thereby causing the fuel to be sprayed into the intake tube, the action being similar to that of a perfume atomizer.

It is important for this spray to offer as large a surface as possible to the air and for the fuel particles to be as small as possible. The air, coming in contact with this spray, carries along a portion of the fuel in the gaseous condition, the larger portion, however, remaining in the form of a mist whose particles will vary in size according to the perfection of the apparatus and the nature of the fuel.

If this mist should enter the cylinders just as it is formed in the carburetor, the functioning of the engine would ordinarily be perfect. Before reaching the cylinders, however, it is obliged to follow the bends of the pipes and to change direction according to which cylinder it is to enter.

The velocity of flow, on the other hand, is subject to quite large variations, especially in the intake manifold. Each cylinder only draws periodically. In a very short time, the flow of gas must pass from a very high velocity to almost zero, producing changes in direction, eddies, etc.

These various phenomena affect the composition of the mixture of air and fuel, the coarser drops tending to collect and form condensation nuclei. The condensed fuel is deposited on the walls, whence it follows the path of least resistance and of least change in direction.

The particles which have not been deposited (but which still have considerable size and consequently a rather large mass with relation to their surface) do not keep pace with the gases and likewise tend to follow the path of least resistance. This results in some cylinders receiving a richer mixture than others.

Heating the Intake Pipes.

In order to remedy this defect, the intake pipes are heated, either by sinking them in the cylinders or by surrounding them with hot-water jackets. The heating thus accomplished diminishes the condensation, though not perfectly. The mixture remains in the pipes for too short a time and the particles of fuel are too large to absorb sufficient heat to vaporize them completely.

Sometimes this difficulty is obviated by heating the air before it enters the carburetor, for example, by causing it to circulate about the exhaust pipe. Thus, the air acquires a higher temperature and the proportion of fuel vaporized is increased. The unvaporized portion of fuel is also heated (or rendered less cold), its viscosity is diminished, it becomes better diffused and the surface area of the particles increases with relation to their weight.

The mixture is improved in both cases, but it is not expedient to heat the air very much before it enters the cylinders, on account of the resulting expansion in volume and consequent diminution in the mass introduced per unit of time, thereby causing a corresponding decrease in engine power.

Vacuum in the Pipes.

From what has been said above (that when the engine is running at a reduced speed, its functioning is improved) it may be remarked that the vacuum in the pipes has increased. If, by some device, the temperature can be kept from falling appreciably, the fuel will vaporize more readily under this reduced pressure, the fuel-charged air will be farher below the saturation point and the mixture will remain more homogeneous.

We see, therefore, that in order to obtain a suitable mixture, it is necessary for the properties of the fuel to answer certain requirements, especially for the vaporization to take place as easily as possible and for the viscosity to be as small as possible.

Practical tests have enabled us to define, at least in part, the qualities answering both requirements. Before proceeding farther, we wish to say, however, that it is not only necessary for the proportions by weight to be correct in each cylinder but also for the mixture to be perfectly homogeneous, in order to secure perfect combustion.

It is readily understood that if the fuel is in the form of large particles in the air at the instant of ignition, the combustion will be slow, with the formation of deposits in the cylinder and the emission 0f smoke through the exhaust pipe. When the particles are smaller and the diffusion is more complete, the combustion will be more rapid and will be completed in the first part of the power stroke.

The points just mentioned are all the more important when the engine under consideration is required to develop more power in proportion to its dimensions.

On high-powered engines, it has been found necessary to have large cylinder orifices, pipes of large diameter and carburetors of large capacity. In order to reduce the losses from the time the fuel enters the carburetor till it enters the cylinders, it is necessary to reduce naturally and simultaneously the suction in the carburetor and intake pipe and consequently the intake velocity, so that the fuel used for such an engine will, even more than for ordinary engines, develop its best qualities.

It is, moreover, in designing aviation engines that the necessity for fuels to answer special requirements has made itself felt most emphatically. Accidents kept occurring with disquieting frequency and without apparent cause, either as regards the materials used, the design or the construction. Constructors made many investigations gradually removing all causes considered capable of causing such accidents, but were finally forced to admit that the initial cause was the qualities of the fuel employed.

Acceptance Conditions of Aviation Fuels.

Chief properties of most common fuels.

Substance	Alcohol	Heptane	Benzene	Cyclohexane
Chemical formula	C_2H_5OH	C_7H_{16}	C_6H_6	C_6H_{12}
Specific gravity at 15°C	0.796	0.704	0.889	0.784
Specific heat at 15°C	0.540	0.502	0.400	0.500

Chief properties of most common fuels, (Cont.).

Substance	Alcohol	Heptane	Benzene	Cyclohexane
Boiling point	78.2	98	80.2	80.9
Heat of vaporization at normal boiling point.	206	74	94.4	85
Heat of combustion	7200	11000	9830	10500
Coef. of viscosity at 20°	0.01192	0.00379	0.00649	0.62
Coef. of viscosity at 80°	--	0.00232	0.00327	0.40
Capillary constant at 20°C	22	--	30 at 12	--

These fuels may be classified as follows:

Alcohol family (methyl and ethyl alcohol);

Benzene " (aromatic hydrocarbons);

Marshgas hydrocarbons (American petroleum);

Hydro-aromatic hydrocarbons.

We might add to this list other hydrocarbons whose composition is intermediate between the ones just mentioned, but they would be of no importance here. The power obtainable from them would differ according to the fuel employed.

The large heat content already mentioned would not determine the power of an engine using either one of them, since this evidently depends on their chemical composition and consequently on the weight of air required for their combustion. The quantity of heat carried away by the water vapor should also be deducted.

From the viewpoint of the heat developed in the engine and the maximum attainable power, it is more important to determine the heat developed by a given quantity of gas.

Alcohol.- It requires 5.921 liters of air to burn a cubic centimeter of alcohol, i.e. to liberate 4.979 calories; or, per liter of air 4.98/5.921 = 0.84 calorie.

Benzene.- It requires 9.581 liters of air to burn one cubic centimeter of benzene, thereby liberating 8.34 calories; or 8.34/9.581 = 0.87 calorie per liter of air.

Gasoline.- It requires 9.101 liters of air to burn one cubic centimeter of gasoline, thereby liberating 7.1 calories; or 7.1/9.101 = 0.785 calorie per liter of air.

Hence the benzene hydrocarbons appear to be the best from this point of view, alcohol coming next. Nevertheless, in order to obtain the same power for the same period of time, 50% more alcohol than gasoline would be required. In order to equalize the cost, the relative prices would have to be 2 for gasoline and about 1.25 for alcohol. These figures are only indicative, since the heat equivalents of different samples vary greatly.

We have added cyclohexane, which is of some importance as will be shown farther on.

Influence of Physical Characteristics.

Density.- Gasoline has the lowest mean density. This is a very important factor, especially as regards the functioning of the spraying nozzles when the engine is picking up.

If the inertia of the liquid column delays the mixing at the moment of picking up, the first cylinder charges will be too poor and may burn so slowly that there will still be flames in the cylinder when the intake valve opens. This causes backfiring into the carburetor, which is often the cause of fire.

This defect may be remedied, either by employing an additional air valve which opens easily, or by the previously mentioned immersed nozzle, which facilitates the prompt emission of the fuel when the engine begins to pick up. From the point of view of the composition of the mixture in the pipe, the density of the gasoline thus indicated cannot be taken as an absolute value, since it is simply the result of the mean densities of the substances constituting the mixture.

Alcohol and benzene have greater densities than gasoline. This is quite a serious disadvantage, especially for benzene, first because of its chemical composition, and secondly, because too great a density increases the difficulty of obtaining a fine enough spray. If, however, the picking-up device is efficacious, the other characteristics may offset the disadvantages due to the density.

Specific heat.- This is lowest for benzene, but only partially offsets the disadvantages due to the greater density of benzene, because the difference between the specific heat of benzene and the other fuels is small. The specific heat of alcohol is higher and, consequently, it would be necessary to heat more strongly the carburetor, designed to run with alcohol, in order to make it absorb a quantity of heat sufficient to vaporize, at least partially, a portion of the liquid.

Boiling point.- Alcohol has the advantage in this respect, but, considering its specific heat, it is nevertheless necessary to heat it more, in order to impart sufficient heat to the carburetor.

Gasoline has a "boiling point" of 98°C. In reality, this is the boiling point of one of its constituents. We will see farther along that gasoline is a mixture of substances which distil at widely varying temperatures.

Benzene and cyclohexane have practically the same boiling point. The specific heat of benzene is lower than that of cyclohexane and yet, as regards its use in engines, the latter is decicedly better. This is due in part, as we have already stated, to their chemical composition and in part to their relative density.

Heat of vaporization and vapor tension.- The greater the amount of heat required for vaporization, the greater the amount of heat to be supplied to the carburetor. The curve of the vapor tensions, in terms of pressure and temperature, is also important. Practically, the lightest constituents of gasoline, other things being equal, have the highest vapor tension. The greater this tension, the greater the percentage of vapor in the mixture.

Viscosity and surface tension.- Viscosity necessitates an increase in the diameter of the conduits, but we must consider also the surface tension opposed to the separation of the liquid into small particles. If the fuel is in an atmosphere whose pressure is quite low and whose temperature is high enough to convert a portion of it into vapor with a vapor tension sufficiently high with relation to the pressure of the medium, this change of condition greatly favors the obtention of a very fine mist by comminution of the drops.

If the fuel is heated, for example, between the float chamber and the jet, the diffusion is greatly improved, the surface tension diminishes quite rapidly as the temperature rises and the more volatile portions evaporate. Moreover, the evaporated portions mechanically facilitate the dispersion of the drops and the mixture is rendered more homogeneous.

Distillation curve.- The "heat of vaporization," "boiling point," "specific heat" and "vapor tension" all come in for consideration and, in order to take account of them in a general way, the official specifications for American gasolines stipulate certain limits in the curve of fractional distillation.

It is important for a portion of the gasoline to evaporate at quite a low temperature, in order to form a sufficiently fine mist in the carburetor. In fact, the vaporization of a portion of the liquid facilitates ignition in the engine and also helps the dissemination of the jet and, consequently, the formation of a sufficiently fine mist.

It is especially important to prevent the furnishing of gasoline containing substances which evaporate at too high a temperature. The most refractory substances in the gasoline should distil below 130°C, in order to give satisfaction in an automobile engine.

Influence of Chemical Composition.

On examining the formulas of the various fuels (alcohol, gasoline and benzene), we find that benzene has the largest proportion of carbon with reference to the hydrogen. Experience has taught us that the richer a fuel is in carbon, the more difficult it is to obtain perfect combustion.

The composition of the mixture of air and benzene must be very carefully controlled, in order to obtain correct combustion and prevent carbon deposits in the cylinders and, on the other hand, the formation of carbon monoxide.

Alcohol and gasoline burn much easier, provided, of course, they are mixed with air in the correct proportions.

Cyclohexane is particularly interesting in this connection. It can be produced by causing benzene to absorb hydrogen. Experiments with this substance, in comparison with an aviation gasoline of good quality, furnish interesting results. We give a few figures below.

These experiments were made on an engine with 8 cylinders of 120 mm bore and 170 mm stroke, the atmospheric conditions being as follows: temperature 23°C, barometric pressure 759 mm.

There were tested on the same day: a gasoline (which we will call "gasoline No.10") with a distillation curve exceeding 145; another gasoline ("gasoline No.20"), whose distillation curve exceeded 130, i.e. similar to the curve accompanying the present article; also cyclohexane. The following results were obtained:

Fuel	Specific gravity	R.P.M.	Wt. raised 1 meter	HP	Fuel consumption Liters per hour	Grams per HP/hr
Gasoline No.10	0.781	1615	109	246	84	268
" " 20	0.700	1630	109	247	90	254
Cyclohexane	0.783	1620	110	250	82	256

It is seen that cyclohexane gives better results than gasoline No. 20, which is the best quality now obtainable. In this connection, we will add the summary of a report made after the examination and testing of a fuel found on a German airplane during the war.

"This fuel has a distillation curve ending at about 135°C, or very near that of the best French gasoline. It contains a number of cyclic hydrocarbons (of the aromatic series), its composition being:

Marshgas hydrocarbons		10%
Cyclic	"	85
Benzene	"	5

In the few tests made with this fuel, the engines functioned especially well, due probably to the presence of the cyclic hydrocarbons. These cyclic hydrocarbons must have been introduced into the fuel either by conversion of benzene hydrocarbons or in some other manner, since it is improbable that fuel of this composition came from the distillation of any natural petroleum."

Observations made during Tests on Aviation Engines.

As already mentioned, a series of systematic investigations were made which justify this conclusion and render it possible to specify the essential characteristics of aviation fuels.

For gasoline from American petroleum (composed of marshgas hydrocarbons), these characteristics have been defined as follows:

Appearance: colorless;

Odor: only that peculiar to pure gasoline, hence no odor of benzene, sulphur compounds, etc.;

Specific gravity: about 0.71 at 15°C;

Acidity: none; must be neutral.

The most important point, aside from purity, is the distillation curve. This point is, in fact, of relatively much greater importance than the specific gravity, because it is always possible to increase the specific gravity of a gasoline that is too light, which may be done for the purpose of disguising very poor gasoline.

Obviously, however, the specific gravity must not vary too much, because it would necessitate new carburetor adjustments and different sized nozzles.

A higher specific gravity does not help the engine to pick up, but just the contrary. For a given distillation curve, however, the specific gravity does not vary greatly. It is essential for fuels to contain some volatile substances evaporating below 100°C. These substances evaporate in the air forming a permanent vapor which will persist until the entrance into the cylinders and will facilitate the priming for the start. On the other hand, the distillation curve must not extend too far into the temperature scale. If it does, the mist formed is not nearly so fine, the particles are coarser and the disadvantages already mentioned are accentuated.

It is also quite worthy of note that the heat equivalent of the fuel passes to the second plane with reference to the curve of distillation. Tests were made with two gasolines, for one of which the distillation curve went to about 135°C and measured 10750 gram-calories with the Malher bomb. Another gasoline, whose distillation curve went to 152, gave 11200 calories, or 450 calories more than the first. The second gasoline did not enable the engine to develop as much power as the first. The following are the figures:

1. An 8-cylinder engine, bore 120 mm, stroke 150 mm, developed 171 HP at 1402 R.P.M., with gasoline at 10750 calories, and a fuel consumption per HP/hr of 246 grams;

2. With gasoline at 11200 calories, the same engine was not able to develop a power of more than 160 HP at 1373 R.P.M. and the fuel consumption had to be carried to 263g per HP/hr.

This proves that a portion of the gasoline was poorly burned, just because some of the cylinders received too much gasoline and others not enough, as a consequence of the lack of homogeneity of the mixture of fuel and air.

The experiments relating to the properties of the gasoline lasted several months, but were all made in comparison with the same standard gasoline. Parallel tests were made the same day on this standard gasoline and the gasoline under investigation, so as to eliminate any errors which might otherwise arise from changes in weather conditions or even in the condition of the engine at the time of the test. In order to execute them, two gasoline tanks were so arranged that, by the simple turn of a three-way cock, the engine could be supplied with either one of the gasolines.

Among the many tests, we will describe one made with a very poor gasoline. An engine similar to the one already mentioned had been compelled by the military authorities to undergo acceptance tests several times. The constructors wished to find out whether it would be possible, however, to make it function properly by increasing the quantity of gasoline burned. By a suitable device the consumption per horsepower had been raised to 350 grams. At 1500 R.P.M. it was impossible to get over 100 HP and, notwithstanding the large quantity of gasoline consumed, the test had to be stopped on account of the erratic functioning, which indicated a bad condition of some of the parts. In fact, on inspecting the engine, it was found that some of the pistons had been injured by the excessively high temperature to which it had been subjected, while others indicated a considerable excess of fuel.

As already mentioned, an arrangement had been consummated which made it possible to supply an engine at will with either one of two fuels. With this arrangement, the engine was started on a gasoline of good quality. It functioned normally, did not vibrate and its power corresponded to the calculations.

The poor gasoline was then turned on and in a few minutes (the time required for displacing the good gasoline already in the carburetor) the engine began to vibrate, the color of the flames changed (dark in some cylinders, short and bright in others) and the functioning kept growing worse, while the engine vibrated violently and lost power. When the good gasoline was now turned on, the vibrations gradually ceased and the engine resumed its normal functioning and power.

In some instances it was possible to improve the functioning (especially in winter) by heating the gasoline just before it entered the carburetor, thus raising its temperature 25 or 30°. Obviously the heating of the gasoline diminished its viscosity, surface tension and also the cooling effect due to the evaporation of a portion of the gasoline, and thus enabled a more perfect diffusion.

In order to remove the defects, the military authorities decided that aviation gasoline should fulfill the following conditions of distillation:

5% below 60°C,
55% " 95° ,
95% " 120° .

The last 30th of the distillate should not have a specific gravity of over 0.75 at 15°C.

The above conditions are fulfilled by the American gasolines most commonly used in France.

Automobile Gasoline.

For automobiles, excepting the first minutes of starting in the morning (especially in winter), the conditions are less exacting. Here, in fact:

1. The neighboring air is heated by radiation from the engine and especially from the exhaust pipes;

2. Before entering the carburetor, the air is considerably heated by coming in contact with the radiator;

3. Warmer fuel is delivered to the sprayer nozzle.

It is well to remember that the heating is much more intense in summer and that, in order to improve the functioning of the engine, it is better to take the air directly from the outside atmosphere. Under the hood, the temperature of the air at the level of the carburetor may easily reach 45 to 50°C on hot summer days.

Lastly, there is usually a greater negative pressure in the cylinders of a running automobile engine than in the intake pipe. Other things being equal, we may therefore accept, for automobiles, fuels whose density curve runs a little higher, e.g. to 135 or 140°C. The latter temperature is a maximum, the mean specific gravity at 15°C being 0.725.

Present Status of the Problem.

Let us examine, on the accompanying curves, the gasolines offered for automobiles. They may be classified in three categories:

1. "Extra" gasoline.- Very dear and practically unobtainable;

2. "Tourist" gasoline.- Best now obtainable;

3. Heavy gasoline.- The engines are well adapted for using such a fuel, though the efficiency is not especially high.

On examining the curve for the "extra" gasoline, we find that it approaches the conditions enumerated above for aviation gasoline. Though slightly less volatile, this gasoline is still very good. The curve for "tourist" gasoline is bad, though its mean density is not so high as the above.

We will now consider its distillation curve. At 100°C only 26% distils. This is hardly half what distils with the first gasoline. It contains substances which distil only at about 170°C, the temperature of the radiator water being about 80°C. Obviously carburetion becomes very difficult. Such a fuel is bound to give trouble, especially with a cold engine. If we attempt to burn the last portions of the distillate from this gasoline, we find that it will ignite only after considerable heating and that it burns with difficulty.

As to the third fuel, it is almost petroleum. It frequently contains benzene in appreciable proportions. We have found 8% of substances eliminatable by nitration. These were probably added to improve the curve of distillation.

These three gasolines, obtained from one of the best firms, were all distilled recently and therefore fairly represent those now on the market.

Conclusions.

Evidently engines run with these fuels, but the complaints heard are justified.

By intense heating, it is possible to burn a heavy fuel, but the power is diminished, the engine carbonizes more rapidly and the consumption of fuel increases. There is also danger of accidents to the valves and spark plugs, if the engine is designed for a high efficiency relative to the charge.

It seems probable that gasolines will not improve. In fact, the countries producing them employ gasolines perhaps even poorer than we use in France. This is simply due to the fact that the consumption of gasolines has become so great that the production of the oil wells is becoming insufficient. In order to increase the production of the light oils, it has become necessary to raise the final temperature of the fractional distillation.

The new industry therefore finds itself facing a difficult problem. If the quality of the gasolines does not improve but grows poorer, constructors, automobilists and all those interested must unite their efforts. Constructors must evidently invent new devices for the practical utilization of less volatile fuels. It is, in fact, possible to make a suitable mixture in the carburetor with a heavy fuel, but this is only one phase of the problem. The mixture must pass from the carburetor into the intake pipes, where its equilibrium is maintained with difficulty. In the cylinder itself, during the phases of intake and compression, homogeneity cannot always be maintained. This justifies the construction of the industrial engine employing heavy oils, which are injected at the end of the compression stroke. This difficulty in the cylinder can be partially remedied, however, by various devices. The intake pipes present the greatest difficulties, the mixing being only begun in the carburetor. The mixture must assume its final form during its passage through the intake pipes. This problem is a very difficult one.

It will be necessary to investigate with four or six cylinders (8 and 12 cylinders being only multiples) the essential conditions for producing a mixture containing the highest percentage of vaporized liquid, the rest being in the form of an invisible mist.

For intake pipes of different shapes, it is important to obtain the pressure curves for the characteristic points, in order to determine their influence on the state of the mixture. Thus we can determine the best shapes and the ratios of the lengths of the straight parts to the diameters with relation to the speed and the number of cylinders.

The different methods of heating must be compared: the separate heating of the fuel, air and walls and also simultaneous heating.

The requisite number of carburetors for relieving the successive suction stresses and for supplying widely separated points in the intake pipes must be determined, as also any correction necessitated by the addition of special substances to the principal fuel for facilitating the formation of the mixture and for rendering it stable. The curves of the distribution mechanism should also be studied.

After making this investigation (while taking account of the fuels likely to be used, which will also be the objects of investigations concerning their physical and chemical characteristics), there will be occasion to examine substitutes for the carburetor in its present form, without its being necessary, however, to adopt the Deisel type.

The problem is to form in each cylinder a homogeneous mixture of fuel and air sufficiently stable to maintain this condition until ignited. The mixture must remain correct as to mean proportions and homogeneity, whatever the density of the charge, i.e. whatever power is required of the engine.

The task will be long and difficult, especially as the present tendency is to require engines to be light and economical. The difficulties are just so many more reasons for discussing the subject frankly.

It is still more important to consider seriously the means for assuring France an economical supply of good fuel.

French Fuel.

There has been much said about a national (French) fuel and many persons see in this only the employment of alcohol. To us this seems to beg the question.

A national fuel should enable us to keep up and improve the construction of engines. The utilizable heat of mixture of fuel and air should be equal to that obtainable with the best foreign fuel. The quantity of fuel available on French continental soil should enable us to dispense with foreign fuel, since, in the event of war, the sea may be more or less closed to traffic, thereby rendering colonial supplies precarious.

There is danger that the production of alcohol by distillation of vegetable products may be insufficient, although doubtless large. It may be objected that it is possible to obtain alcohol by synthesis, but alcohol has one rather great disadvantage, especially in aviation. For the same number of calories, alcohol requires much larger tanks than gasoline; consequently more space and more weight.

Aside from alcohol, France has a little benzene and quite a large quantity of shale oil. It is therefore advisable to utilize first and to the best advantage all these resources (separately insufficient) in order to enable us to dispense with foreign fuels. There are still other solutions, proposed by French chemists which may be the reason we do not know about them.

Professor Sabathier has shown us how to convert heavy oils into light oils (See catalysis in Sabathier's organic chemistry), a method which consists in modifying the process of cracking by completing it with the hydrogenation of the products. This transformation, however, is only partial. It suffices, in fact, to cause the distillation curve from a maximum of 180 to 135, for example.

It is known how to convert acetylene into benzene and the above-mentioned scientist of Toulouse shows us how benzene may be converted into cyclohexane by a very good method, the latter substance being, as we have already seen, a fuel of the first order. The oils of shale and coal and the naphthalines can also undergo certain modifications, as indicated by the same Professor, and thus furnish a considerable quantity of light fuel.

Another scientist, Mr. Mailhe, who has worked much with Prof. Sabathier, has just shown us, in a report of the Academy of Sciences, that vegetable oils can be converted into aromatic hydrocarbons, concluding as follows.

"This catalytic process makes it possible to start with a vegetable oil in the preparation of gasoline and petroleum of a mixed nature, capable of being used as a fuel. They are soluble in alcohol in any proportion."

It seems that animal oils (fish oils, for example), are also capable of being converted.

Lastly, coal itself can be much better utilized. By destructive distillation, coal yields combustible gases utilizable in stationary engines and a number of substances which (from benzene to tar) can either be used directly or can be converted into substances utilizable in an engine.

At a recent fuel convention, Prof. Sabathier made special mention of the conversion of naphthaline into a new substance "tetraline" capable of figuring in the list of utilizable fuels.

These results, which were obtained by the personal efforts of a few scientists, can, with much greater facilities, be considerably enlarged and may open up unsuspected vistas.

Mixed Fuels.

It is quite probable that we shall be obliged to adopt a mixture of different substances, in order to produce a French fuel in sufficient quantity to provide for the increasing use of internal combustion engines.

The adoption of such a mixture will demand a very thorough investigation, in order that its composition and characteristics may always be the same. It is therefore desirable to define the limits within which the proportions must come, but, if this is somewhat difficult in order to assure the uniformity of composition, the mixture may, on the other hand, offer certain advantages.

It is known that benzene, toluene and the alcohols enable a higher degree of compression than the gasolines obtained from the aromatic petroleums. The mixture may therefore be made in such proportions as to increase the compression, but it is, of course, desirable to adopt proportions in accord with the possibilities of production of each constituent and also, to a certain extent, in accord with the results of very carefully conducted tests on aviation engines.

Furthermore, fuels for internal combustion engines comprise two classes:

a) Fuels for automobile engines or heavy loads;

b) Fuels for aviation engines.

The latter have a different composition and can be more expensive.

It does not come within the scope of this article to determine the best mixtures. This would, moreover, be decidedly premature, since the study of fuel proddution has thus far hardly been attempted in the domain of scientific research. Only after having determined, from the commercial point of view, the quantity of the principal substances capable of entering into the mixture, can we proceed to the above-mentioned tests. Only after the completion of these tests, which will necessarily be many and consequently of long duration, will it be possible to adopt definite mixtures. It seemed advisable, however, to call attention to the possibility of these mixtures and to the advantages and disadvantages involved in their use.

Sources of Energy.

There is one more point which should receive attention, namely the quantity of energy required for the manufacture of fuels. Whether produced by distillation or catalyssis or by any other chemical or physical reaction, their conversion necessitates an outlay of energy, so that it is desirable, while seeking methods of conversion, to seek also to determine the quantity of energy required to accomplish the transformations and to utilize, in so far as possible, the forces nature puts at our disposal, by employing preferably, of course, those which are not already utilized and are being wasted, such, for example, as the forces produced by waterfalls, rivers, winds and tides or the energy obtained from the atmosphere in the form of electricity.

The source of energy must, in fact, be very prolific, considering the large quantity of fuel required. There must be sufficient energy to leave no cause for uneasiness as regards any possible increase in the use of internal combustion engines, an increase which may be very rapid in the event of war.

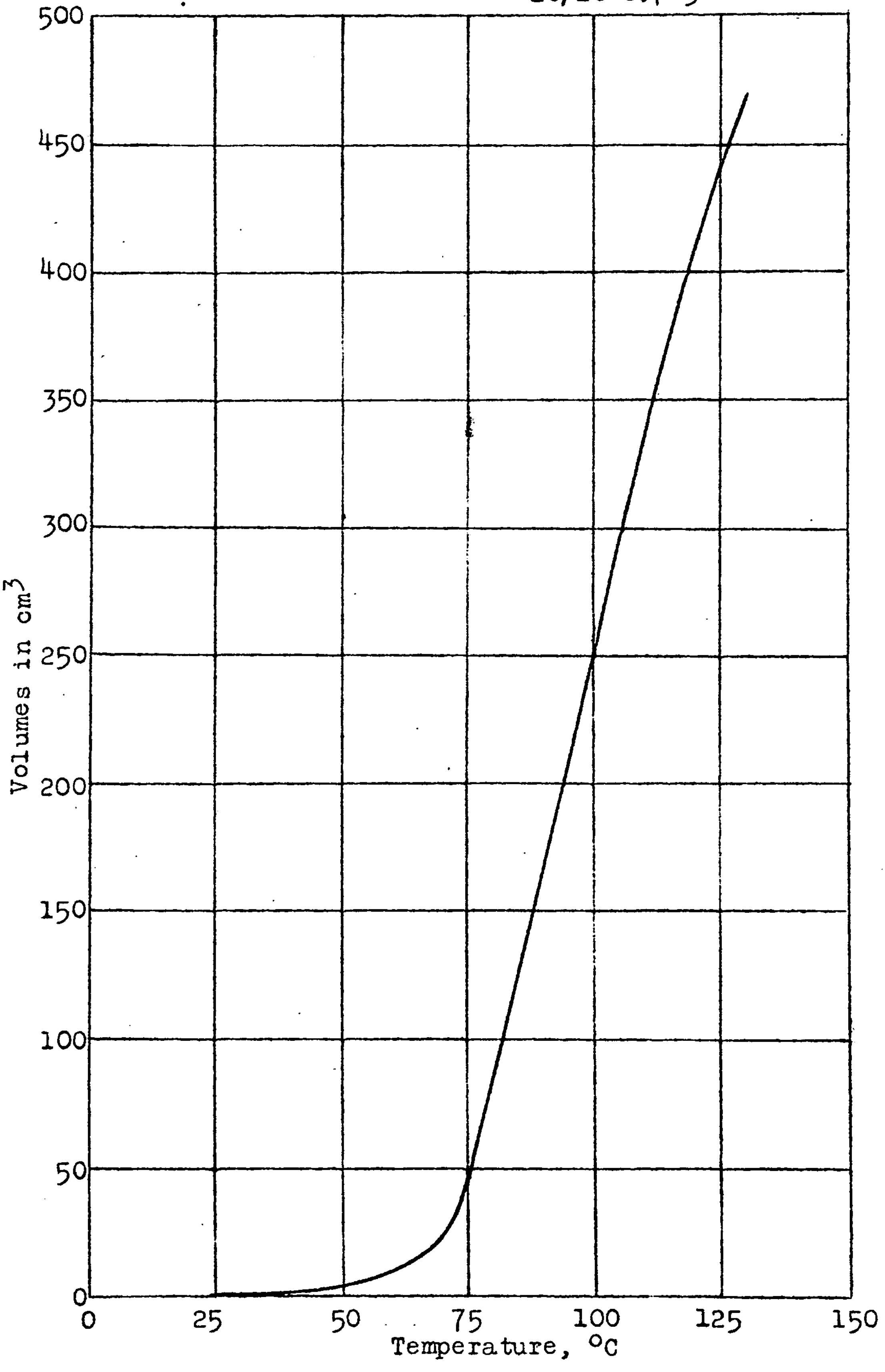
If we assume, for instance, that the quantity of energy required for the various transformations is equal to 20% of the energy contained in the fuel in its final form, it amounts to 200,000 HP on the basis of an annual production of 600,000,000 liters (158,500,000 gallons).

It is therefore advisable to coordinate the efforts in both directions, for, however fine the chemical method of production might be, it would become burdensome in proportion as the final cost of the product should exceed the cost of the imported article. It would then be very difficult to carry out such a proposition, since it would conflict with an economical law.

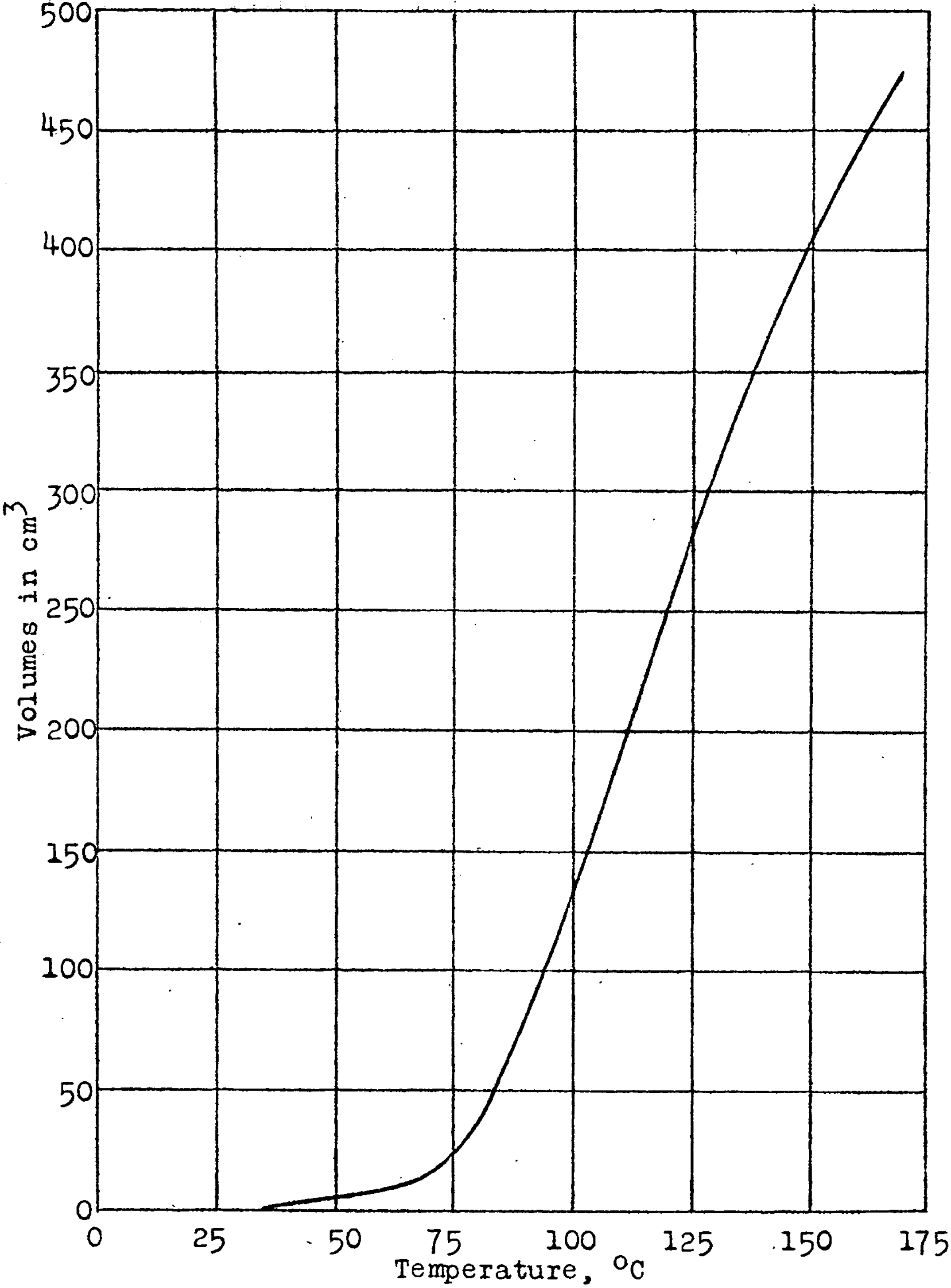
We must therefore escape from the present situation as soon as possible. Constructors of automobile or aviation engines must seek to adapt their engines to the use of heavy fuels, with a high boiling point. Scientists and engineers must seek sources of energy to put at the disposal of chemists. Chemists must study the reactions necessary for producing the required substances. Lastly, the Government and every one interested in the development of the manufacture and use of internal combustion engines in France must furnish material and financial aid.

Translated by
National Advisory Committee
for Aeronautics.

Test No. 404
"Extra" gasoline
Specific gravity at 15°C: 0.722
20/20 0.745



Test No. 406
"Tourist" gasoline
Specific gravity at 15°C: 0.716
20/20 0.765



Test No. 1106
Heavy gasoline
Specific gravity at 15°C: 0.750
20/20 0.792
8% Aromatic hydrocarbons