

# THE KINETIC INTERPRETATION OF THE NEW "MAN-M" PROCEDURE

By

G. SITKEI

Department of Agricultural Machinery, Polytechnical University, Budapest

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Presented by Prof. Dr. I. RÁZSÓ

## Introduction

The MAN firm of Nürnberg in 1954 put a new motor on the market which differs essentially in regard to mixture formation from the usual mixture formation systems used up till then. The motor worked smoothly, without forming smoke and moreover had a good specific consumption. Not being sensitive to the quality of the fuel, it was possible to use fuels of various fractions.

Great interest was shown towards this new kind of mixture formation all over the world, not only because of the indisputable advantages of the new procedure, but even more because of its new basic idea which differs fundamentally from the principles of the habitual mixture-formations.

The inventor of the new mixture-formation procedure, S. MEURER, had made the essence of his procedure known in several periodicals (MTZ, ATZ, SAE-Journal) and had moreover given the kinetic interpretation of that new reaction [1].

Regarding this interpretation, there were, however, various doubts, which were also mentioned by PISCHINGER [4] but without explaining his own point of view. An endeavour is made to sum up the description of combustion in Diesel engines and within its scope the kinetic interpretation of the "M"-procedure, — according to the present standpoint of science.

### 1 §. The process of mixture-formation in the MAN-M motor

In regard to mixture-formation the MAN-M motor is a direct-injection piston-chamber engine. On injection, the greater part of the fuel (about 95%) gets on the wall of the chamber forming a very thin film. The fuel particles which are separated from the jet (about 5%) go directly into the air, mixing with it. These drops burn, after gasifying accordingly the mechanism of ordinary diesel combustion and the generated combustion-products ignite — according to MEURER — the rest of the fuel.

Because of the masking, the admission valve produces a vertical axis air swirl in the cylinder, which guarantees the gradually evaporating fuel, from the walls, mixing with the air.

The temperature of the piston chamber wall is about  $300^{\circ}\text{C}$ . After the ignition the intensive flame radiation accelerates the process of evaporation insuring thereby the course of combustion.

Fig. 1 illustrates schematically the evaporation and combustion process. It can be observed that in case of the M-process the evaporation of fuel during the ignition lag is very little and this results in a small pressure rise.

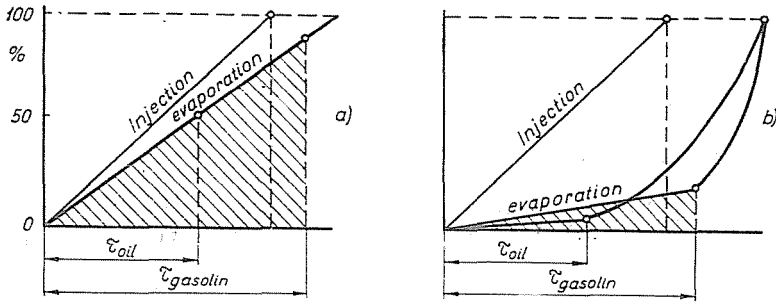


Fig. 1. Mixture formation in an ordinary engine (a) and Mixture formation in a „MAN-M” Diesel engine

The mixing of the fuel gradually evaporating from the wall with fresh air is aided by the “thermic admixture” caused by swirl motion [4]. The combustion products and the burning particles travel — because their specif-

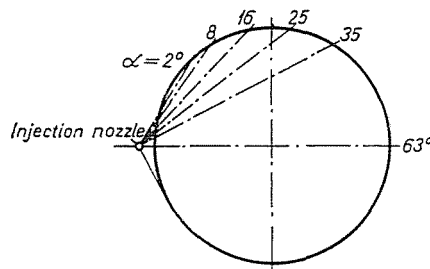


Fig. 2. Scheme of spraying on cylinder wall

ic weight is less than that of air — towards the center of the combustion space, while fresh air travels from there outwards. This is proved by immediate photographs. Hereby the supply of fresh air for the fuel is ensured which later evaporates.

Regarding the mass-velocity of the combustion the experiments of PISCHINGER [4] can now be regarded. The fuel has been brought on the wall from various angles (Fig. 2) hereby also changing the quantity of the fuel brought to the wall. The pressure-diagram for a wall temperature  $t_w = 125$  and  $320^{\circ}\text{C}$ , is demonstrated by Fig. 3 a, b. On the basis of these figures the following facts can be stated:

1. In case of strong (tangential) spraying on the wall, the temperature of the wall will decisively influence the evaporation, and so, the mass-velocity of the combustion.

2. In case of spraying into the center of the chamber, the wall temperature does not influence the mass velocity of combustion perceptibly, however, the ignition lag increases in a small degree.

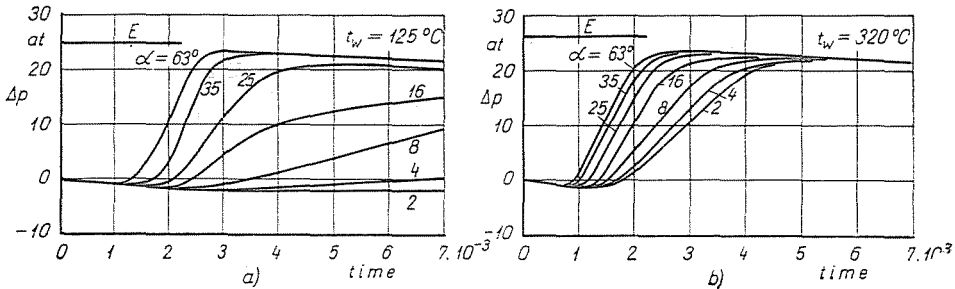


Fig. 3. a) b) Pressure curves at various angles of spraying

3. At an identical wall-temperature the increasing of the jetting augments the combustion lag to a certain degree.

4. At identical wall temperatures the increase of the spraying brings about a reduction of the mass-velocity of combustion, by which the velocity

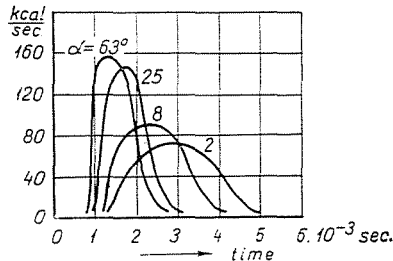


Fig. 4. Velocity of heat development, when spraying at various angles

of pressure rise is reduced, too, and the combustion process becomes more and more easy to adjust.

Fig. 4 shows the heat development in case of spraying under various angles. The curves clearly show the influence of the wall on the mass-velocity of combustion, which fully explains the smooth running of the engines.

The photographs taken by PISCHINGER further show that the combustion always starts directly at the wall, wherefrom it spreads as a turbulent flame; then according to the above-mentioned "thermic mixing", it travels on a spiral course towards the centre. This — as a purely experimental fact—contradicts the statement of MEURER, according to which the main part of the

fuel becomes ignited by the earlier-ignited particles. Even if those particles would indeed be ignited (which is not to be seen on any of PISCHINGER's photographs) they would be placed, in any case, in the centre of the chamber.

Let us note that in case of other mixture formation systems — so also in case of swirl chambers — a significant part of the fuel gets to the walls of the chambers [6, 7]. The relatively smooth running of the vortex-chamber-motors is explained by this circumstance.

## 2. Meurer's interpretation of self-ignition and combustion in Diesel engines

In explaining the phenomena of the M-procedure, the considerations on reaction kinetics play an important part. The author justly observes that during the development of Diesel engines the main interest — up till the present — was shown towards the mixture formation, while to factors of reaction kinetics have been entirely neglected. "For many years engineers had only had a single purpose, that of mixing the injected fuel immediately with the compressed air" [1—250 p.].

At the same time — as proved by many experiments and among others by the observations of the author himself, — approaching conditions of rapid and complete mixing did not improve combustion but led to strong knocking and, contrary to all expectations, and despite good fuel distributions, to bad utilization of the air and *intensive* smoke-formation\* [1—252 pp].

If the laws of injection were determined by experiment, so as to secure combustion without knock, this would infallibly result in increasing the formation of smoke. The author justly remarks at this point that the Diesel-cycle displays "an inner contradiction". However, the explanation of the contradiction and of the reaction kinetics of the process can not be accepted without reserve.

Let us now proceed to the discussion of the two phenomena: "Knock and Smoke", being most often the cause of irregular development of the cycle.

### a) Ignition and knock in Diesel engines

Innumerable experiments have proved (among others [1] Fig. 23 on page 267) that the occurrence of knock is related to the shock (detonation) wave of finite amplitude. There is still no answer to the question how such a shock wave occurs in the engine.

\* It has to be noted here that at the above-mentioned experiments, where the fuel was injected into a spherical chamber, the intensive pulverization and evaporation made the realization of a good macrostructure more difficult, which *explains* the smoke formation.

The author is right in stating that the ignition of Diesel engine and the knock which occurs in carburettor engines is identical, taken from the kinetic point of view. The knock in the carburettor engine is characterized by "disaggregation of molecules in the presence of oxygen, through the development of peroxides". The same process in Diesel engines "appears at the first stage of combustion when — during the ignition lag — the necessary conditions for oxygen concentration and fuel evaporation occur" [1, p. 253]. According to MEURER, this process is broken by the inadequate oxygen supply in the reaction-zone and it is therefore that the temperature rise — caused by the pre-reaction — results in disaggregation of CC and CH bonds.

But from this scheme it is not clear how ignition ends and how local flames of "2100° C temperature come about, the temperature of which is independent of the relation between air and fuel concentration" [1 — p. 253].

#### b) *The mechanism of smoke formation*

According to MEURER, it is by the increase of reaction speed and temperature that less and less oxygen than necessary gets into the reaction zone, until the moment when the peroxide oxidation process ceases because of lack of oxygen. This leads to the cracking of the fuel and by this to the separation of free carbon, which could burn — according to the author's opinion — only in the following reaction:



The process of the reaction needs a sufficient amount of combustion products ( $\text{H}_2\text{O}$ ).

Regarding the above scheme:

a) the rise of temperature, favourable in the first stage of the reaction, is unfavourable in the further stages of the reaction [1 — p. 254].

b) the thermal disintegration of fuel is to be prevented at all costs and can be attained by slowing down the pre-oxidation process (p. 253).

It is a basic idea of the M-process to reduce the speed of oxidation in order to prevent smoke formation: this is an underlying design principle. According to the ideas of the author, the wall of the combustion chamber plays the role of an intermittent carburettor. This wall ensures the slow and even pre-oxidation of fuel [p. 1—255].

According to MEURER, the smoke in the exhaust gas is a result of the pre-oxidation procedures, when "in the reaction zone there occurs a disproportion between the velocity of cracking and the velocity of oxygen feeding". To prove the above-mentioned scheme, the author states the fact that there appeared, directly after ignition, CC lines in the spectrum which testify the disaggregation of CC and CH bonds (p. 253).

However, these reflections are evidently based on an error because the CC, CH and OH lines are characteristics of hydrocarbon flame spectrum and testify that in those ordinary thermal flames there were CC, CH and OH radicals of determined concentration in excitation. But the conclusion can not be drawn from that, as if the CC radical was disaggregating as the author supposes. Besides, the supposed reaction mechanism which would lead to the separation of free carbon, contains an inner contradiction. Namely, one can regard only the oxidation of fuel as the only possible exothermic process and therefore a significant increase of temperature in the reaction-zone is only possible in case of oxygen feeding. When oxygen feeding ceases, the temperature increase ceases too, so that there is no reason to await an increasing "disproportion" between the two processes which was essentially the basis of the above-mentioned smoke-forming mechanism.

### c) *Fuel combustion in the M-engine*

Starting out from the erroneous notion that the avalanche beginning with ignition continues its course until the formation of free carbon, the author arrives at the conclusion (and quite rightly, as will be seen) that ignition would have to be restricted to as small a part of the fuel as possible to decrease smoke forming. It is about 5% of the entire fuel which mixes directly with air near the pulverizer, igniting by itself and producing for the fuel which evaporates from the wall "the external cause of ignition". The fuel ignites in quick order by the incandescent fuel particles (p. 257).

According to this scheme, it is just by the outside ignition that combustion without smoke and knock was ensured, preventing the self-ignition of the fuel. Neither can we unreservedly accept the other reasonings of the author regarding the protection of the main part of the fuel from auto-ignition.

He declares *e. g.* on the basis of the obsolete conclusions of WOLLERS and EHMCKE [8] that: "The auto-ignition temperature of hydrocarbons is higher than that of liquid fuel derived from the former, and so the temperature at the end of the compression stroke is too low to cause auto-ignition in the evaporated fuel" (p. 254). Whereas it is a long-established fact that in both cases — with pure gas-phase or with pure liquid-phase as well — we are faced with the self-ignition of air—vapour mixture. The auto-ignition of air—moisture-mixture and the auto-ignition observed at a lower temperature in the presence of a liquid-phase — when the pan-method is employed — is connected with the development of concentration fields which are favourable for multi-stage auto-ignition.

The author also mentions at a later point that the "evaporating particles of the fuel consist of pre-oxidation products (aldehydes, ketones, olefins) which arise with moderate heating and considerable lack of air and which

ignite at a much higher temperature than the vapour generated in hot air" (p. 257). At the same time the aldehydes, among the enumerated products, ignite at a considerably lower temperature than the initial hydrocarbon [9].

On the other hand, as innumerable experiments have proved, the ignition by an incandescent object needs a temperature of at least 1100—1200° C which can scarcely arise after the combustion of 5% of the fuel.

The above-mentioned circumstances testify that the considerations on reaction kinetics of the M-procedure are on the whole not acceptable and do not furnish a satisfactory explanation of the auto-ignition and combustion in Diesel engines.

### 3. § The reaction kinetics of combustion in Diesel engines

#### 1. General characteristics of auto-ignition and combustion

It is well-known that there is a definite connection between the Cetane- and Octane-numbers of fuel which may be generally expressed as follows:

$$C_n = A - B \cdot O_n$$

namely, that the increasing tendency to auto-ignition also increases the tend-

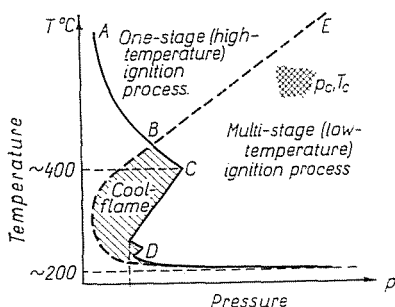


Fig. 5. Characteristic diagram of self ignition of fuels

ency to detonation. Therefore, the above-cited relation also refers to the identically kinetic nature of auto-ignition in Diesel engines and the detonation combustion in Otto-motors. A further fact also refers to the identical kinetic nature of the two phenomena, namely that both occur at an identical pressure and temperature.

The kinetical characteristics of the auto-ignition process are determined by the relation between the state-characteristics of the gas ( $p$ ,  $T$ ) and the dividing line between high and low temperature auto-ignition fields (Fig. 5). As proved by SOKOLIK in 1941, in case of paraffin hydrocarbons the dividing

line BE passes within the auto-ignition limit and the points  $p_c$ ,  $T_c$ , of compression ignition are always in the zone of low temperature multi-stage ignition. Researches made in the last decade confirm the fact that the auto-ignition of hydrocarbons by compression is a multi-stage process — cool flame, blue flame and hot flame in succession. The examination of detonation combustion in Otto-engines shows that this, too, is a multi-stage auto-ignition process, where the great velocity of combustion (about the same as sound velocity) results in detonation waves. The measurements on the latest type of Diesel engines also testify that the auto-ignition process is multistage [2].

Schlieren photographs also show that auto-ignition generates several seats of fire from which combustion spreads in the form of a turbulent flame front — with a reaction zone of considerable width.

Based on these facts, two phases of the combustion process are distinguished:

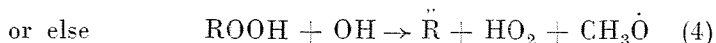
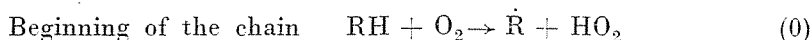
1. Multi-stage auto-ignition of the evaporated fuel and at the same time generation of a seat of fire of definite volume.
2. The spreading of a turbulent combustion field in a heterogeneous medium.

These two time phases can not always be separated. There are cases when the flame front is already spreading from the first centre, while at the same time new ones are coming into being and new flame fronts expand over the remaining space.

## 2. Auto-ignition and knock

The generation of a detonation shock-wave characterizing the knock phenomenon, is a peculiarity of the multi-stage space auto-ignition. These auto-ignition processes are characterized by the following general features:

1. The oxidation of hydrocarbons begins with a cool-flame process which occurs — by degenerating chain branchings — through subsequent accumulations and aggregations of relatively stable intermediate products (hydroperoxides), accordingly the following reaction mechanism:



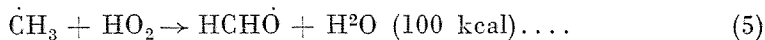
Free radicals and fissured hydrocarbon molecules of great chemical activity (0. reaction) arise accidentally and as rare reactions. These result in a peroxide



radical if they react with oxygen (reaction 1.), and after further oxidation build hydroperoxide molecules (ROOH) (reaction 2.). This is the relatively stable, but chemically active intermediate product which disaggregates from time to time. When this occurs several free radicals come into being, possibly forming the beginning of a new independent chain of reactions (reaction 3.).

As the free radicals which came into being when peroxide disaggregated cause the disaggregation of new peroxide molecules (reaction 4.), the process becomes an "avalanche". The reaction itself is exothermic, so the heating of the mixture — after the decomposition of the thermal equilibrium — accelerates the aggregation of peroxide and the process acquires the character of detonation. The reaction zone then spreads in the form of a cool-flame front. The liberated heat is about 10—15% of the combustion heat of the fuel. The main reaction products of the cool-flame are the following:

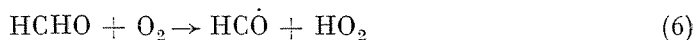
- a) free radicals favouring the further rapid oxidation of hydrocarbon;
- b) large quantities of formaldehyde which occurs not only according to reaction No. 3, but also as re-combination of free radicals, so *e. g.*:



where the liberated energy fully suffices for exciting formaldehyde molecules. The characteristic luminescence of the cool-flame is a consequence of the deactivation of the excited formaldehyde molecules.

The intensity of cool flame is proportional to the concentration of the atoms and free radicals they contain and it characterizes the effect of the cool flame upon the further development of the process. The intensity of the cool flame is determined by the critical concentration of the peroxides at which these disintegrate and increase with the increase of pressure with the falling of temperature and with the mixture becoming poorer until the equimolecular composition,  $a \leq 0,1$ .

2. After the cool flame has covered the available space, a considerable quantity of formaldehyde comes into being which is an intermediate product of the degenerating branches. So *e. g.*:



The chain reaction of formaldehyde can also take the character of detonation, marked by the appearance of the so-called blue-flame front, when initial hydrocarbon oxidates into carbon monoxide (CO). The spectrum of blue flame shows — like that of the cool flame — formaldehyde (HCHO), further HCO and CH radical lines. CC lines are, however, absent in this spectrum and only to be found in that of hot flame.

According to reactions No. 6 and 7, blue flame originates more easily when a certain surplus of oxygen is present ( $\alpha > 1$ ), in which case a considerable quantity of heat is liberated.

3. The CO mixture which comes into being after blue flame, and the residual oxygen, — in the presence of a rather high temperature and a great concentration of active centres — result, with a very short ignition lag in hot flame, with which the oxidation of hydrocarbon is completed.

On the basis of the above-mentioned facts the multi-stage ignition process can be interpreted as a series of subsequent flames, in each of which the charging hydrocarbon is transformed to a certain degree. In cool flame mainly up to formaldehyde, in blue flame up to CO and in hot flame up to the final products. The subsequent flames spread out with the increasing concentration of the active centres, with increasing velocity, which under favourable conditions reach the velocity of sound. When the velocity of flame propagation has reached or surpassed the velocity of sound, the pressure — in a given space — can not continuously equalize, and a shock wave arises. This shock wave causes the “knock” in the engine. The rise of the shock wave is determined by the chemical activity of the flame, mainly by the intensity of the cool flame, while its force is determined by the increase of temperature in the blue flame and in the hot flame. To reach the maximal kinetical and thermal effect in each of the flames, several conditions have to be realized; so *e. g.* regarding the composition of the mixture — a very poor mixture in cool flame, a somewhat poorer mixture than a stoichiometrical one in blue flame and a nearly stoichiometrical one in hot flame.

a) *Auto-ignition of homogeneous and heterogeneous gas-mixtures*

On the basis of the facts given above, we can reach important conclusions regarding auto-ignition of homogeneous and heterogeneous mixtures. As optimal mixture composition of the various flames differ, one can not obtain optimal conditions for all flames with a homogeneous mixture. In case of heterogeneous phases, zones of different compositions will arise. There will be very poor zones, favouring cool flame process, and the oxygen-penetrating into them will favour blue flame and hot flame development, that is: a heterogeneous phase is favourable from the point of view of a rapid combustion process.

These theoretical considerations are supported by the experiments of SVIRIDOV [10] who examined combustion at different temperature zones where the relation between chemical reaction and velocity of mixture formation has shown various developments. When the velocity of mixture formation was essentially surpassed by the velocity of reaction, there arose a so-called diffusion combustion.

This combustion process is characterized by a short ignition lag, a drawn-out combustion and an intensive smoke formation. The curve of combustion mass velocity has the form of a sickle (Fig. 6, curve I).

The other extreme case is when the velocity of mixture formation is considerably higher than the reaction velocity. In these cases there is a homogeneous mixture in the entire space at the beginning of auto-ignition where the flame is spreading. The mass velocity of combustion changes according to an S-shaped curve in the same way as in carburettor engines (Fig. 6, curve III).

If the duration of mixture formation accords with the duration of chemical reactions, then the phases of mixture formation and of the pre-oxidation process become interwoven and fields of different concentrations will develop. Measurements testify that in these cases the combustion is very rapid and occurs in a detonation-like manner and almost entirely without smoke (Fig. 6, curve II).

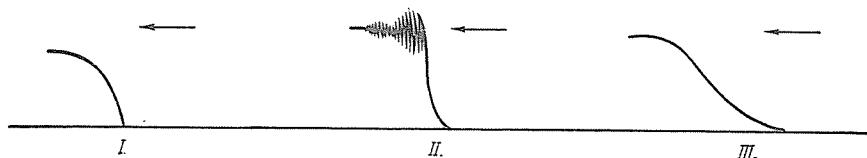


Fig. 6. Pressure curves at different temperature ranges

Special examinations carried out at our Department show that a homogeneous mixture does not favour the pre-oxidation process. Mixtures of different homogeneity were produced in a MIB-D Diesel engine with piston chambers during ignition lag by changing the injection pressure. At an injection pressure of 300 kg/cm<sup>2</sup> the fuel spray completely spanned the whole piston chamber and the distribution of fuel along the spray was nearly uniform. Because of the low penetration force of the spray, the air entering the chamber mixed the finely-pulverized fuel evenly, right at the beginning of the process.

At lesser injection pressures (100—150 kg/cm<sup>2</sup>) the cone angle of the spray became smaller while the penetration was bigger. In this way the solid part of the spray produced a richer mixture in some parts of the chamber. Namely:

It was a case of heterogeneous mixture.

The changes of the over-all ignition lag (determined essentially by the ignition lag of the cool flame) are shown as functions of the injection pressure in Fig. 7. It can be observed that ignition lag increases with the injection pressure and — through it — by the increase of homogeneity of the mixture — although the evaporation of the fine, homogeneous mixture is more rapid.

Fig. 8 shows the characteristic pressure curves. When injection pressure is great and the ignition lag is long, and so a considerable part of the fuel is

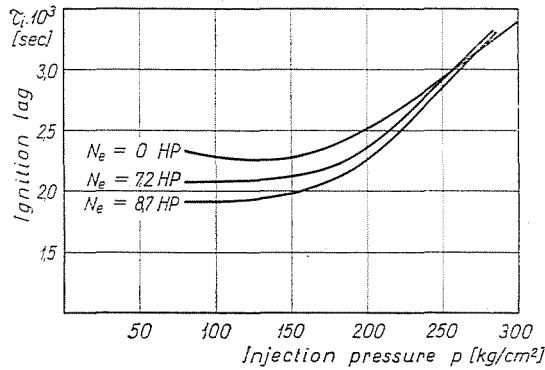


Fig. 7. Ignition lag at various injection pressures

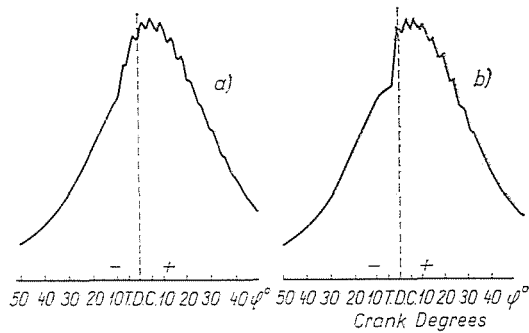


Fig. 8. Indication diagrams at low and high injection pressures

already in the cylinder at the moment of auto-ignition, resulting in great pressure-rise velocity.

The above-mentioned experimental results are easily understood on the basis of the former theoretical considerations.

It is also explained by these facts that MEURER quite rightly states that the too rapid evaporation of the fuel and its too rapid mixing with air do not produce the optimal conditions for auto-ignition and combustion.

#### b) The minimum quantity of fuel needed for auto-ignition

It is well-known that by establishing the condition of turbulent combustion, the size of the flame should be of the same order of magnitude as the size of the prevailing turbulent pulsation. The Schlieren photographs showed that this critical flame size has the diameter of 2—3 cm. To get a flame front of this size — regarding a four-fold combustion expansion — a mixture of

about 3—4 cm<sup>3</sup> volume has to be ignited. Taking a combustion space of 100 cm<sup>3</sup>,  $a = 1,3$  excess air ratio, 4—5% of the entire fuel is needed.

This approximate calculation shows that the 5% of fuel, needed for the M-procedure to get directly into the air, is sufficient for the development of the turbulent combustion zone. However, the development of such a turbulent combustion zone needs an adequate fuel concentration, which is difficult to realize when feeding so small a quantity.

How the presence of larger fuel quantities than the critical 5% influences the auto-ignition, — has not yet been looked into and we can only answer this question on the basis of general data. As already stated, for the optimal development of blue flame and hot flame after cool flame, the rich mixture must gradually get poorer. Superfluous fuel can hinder, by its evaporation, the development of optimal concentration fields. This effect was eliminated by the M-process, in spraying the larger part of fuel on the wall of the chamber, in this way separating the auto-ignition process from the basic phase of combustion.

### c) *Auto-ignition in heterogeneous phases and the "knock"*

The combustion in Diesel engines and the detonational combustion in Otto-engines is an identical phenomenon, taken from the kinetical viewpoint, both being multi-stage auto-ignition processes. However, the conditions producing knock considerably differ.

The detonational combustion in the Otto-engines develops in the space before the flame front, in case the ignition lag of the multi-phase process is less than the time needed for the propagation of the flame:

$$\tau_i = \tau_{cf} + \tau_{bf} + \tau_{hf} < \Theta.$$

Among the part ignition lags the ignition lag of cool flame is the longest, so that the above condition can best be expressed in the following form:

$$\tau_{cf} < \Theta. \quad (8)$$

With a given fuel the realisation of condition (8) can be advanced by reducing the velocity of combustion (reducing turbulence) or else by augmenting the temperature in the space before the flame front, — which would reduce the value of  $\tau_{cf}$ . (The raise of pressure does not alter the value of  $\tau_{cf}$  essentially.) The development of detonation waves needs, however, a greater intensity of cool flame which can only be realised by increasing pressure. Therefore, the detonational combustion in Otto-engines is only realised in the area of maximal pressures (Fig. 9).

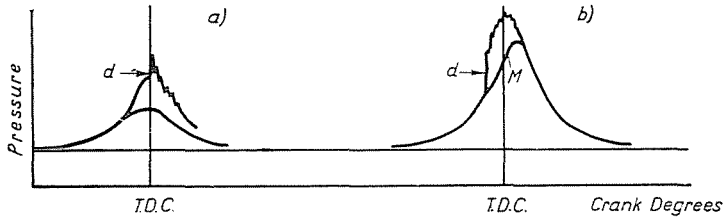


Fig. 9. Indication diagrams of knock *a)* in Otto-engines; *b)* in Diesel engines; *d)* beginning of knock

M — Pressure diagram of M-engine operating without knock

In Diesel engines auto-ignition is realised before combustion, therefore the condition expressed in equation (8) can be omitted. Contrary to the Otto-engines, the sufficient intensity of the cool flame process is caused by the augmentation of the induction period which at the same time results in increasing the quantity of evaporated fuel. By a certain decrease of temperature, the process is displaced towards the top dead centre (maximal pressure).

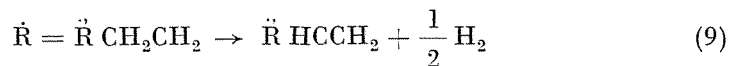
The induction period of cool flame increases with the reduction of the Cetane number, that is: with the increasing resistance against detonation.

In case of a given fuel, the induction period of the cool flame is increased by the superfluous fuel near the reaction zone. Therefore, the reduction of fuel charged into the auto-ignition process — as seen in the M-process — hinders the arising of “knock” (Fig. 9).

#### *d) Smoke formation in Diesel engines*

In Otto-engines, in case of strong detonations, there is smoke in the exhaust gases. The auto-ignition in Diesel engines is process analogue to the one mentioned above, therefore, it is advisable to examine the possibility of smoke formation.

In a multi-stage auto-ignition process the only probable way for cracking [5] seems to be the decomposition of hydrocarbon radicals before their reaction with oxygen begin (1. reaction):



namely that the saturated radical is transformed into non-saturated hydrocarbon. In the presence of oxygen, however, full cracking to free carbon is not to be expected and indeed there are no lower products of hydrocarbon decomposition to be found either in cool flame, or in blue flame. We must therefore regard exclusively the mechanical effect of the detonation wave as

the source of smoke formation during knock, as a result of which the oil film on the cylinder wall becomes torn and cracks at the temperature of combustion products.

In case of Diesel engines, at the stage of auto-ignition, the rise of temperature is a function of the oxygen charge needed for the blue and the hot flame. Therefore, a deep cracking of the fuel can not be expected here either. Further, as in Diesel engines smoke is generally formed during knock-less operation, the mechanical effect of the detonation wave is omitted — especially in case of divided combustion space.

Considering the above-mentioned facts, we have to search for the source of smoke formation in the basic phase of combustion. After auto-ignition of a definite volume, a turbulent flame front spreads in the heterogeneous mixture, also in case of average excess air ratio of  $a = 1,3-1,5$ , oxygen-poor zones can occur. In these zones free carbon can be separated when the flame passes through — as in case of diffusion flames. The result of which is that the only way to prevent smoke formation is to completely mix the fuel with air.

The above considerations essentially differ from those of MEURER who holds that smoke occurs not so much through the absence of oxygen but is caused by the reaction kinetics of combustion.

The minimal smoke at the M-process is due, first of all, to the good mixture formation. The mixing with air of the fuel evaporating from the wall is ensured by air turbulence. The "thermal mixing" still increases the good exploitation of air.

### Summary

In this paper the kinetical interpretation of the new MAN M-process and of the combustion process in Diesel engines is given. Further the defects of Meurer's theory was pointed out and are explanation of the fundamental theories of "knock" and of smoke formation given.

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