An Experiment on the Reduction of Vehicles Emission

— The Improvement of the Idling Combusion —

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Abstract

Under idling conditions, to reduce emissions of hydrocarbons and carbon monoxide, leaner mixture and stable combustion are necessary. On the other hand, for the same apparent mixture ratio (measured on the intake side), increased new charge and the lower CO concentration, and higher exhaust temperature cause reduced combustion variation.

Then, to realize a stable idle running with leaner mixture, a device available for wider throttle opening was invented. For the purpose, the following methods are available.

(1) Retarded ignition
(2) Heating of the intake air
(3) Heating of the mixture

In this paper, the profits and losses of those methods are discussed, and the comparisons between those methods and the procedures which cause the reduction of the absolute quantities of the fuel by screwing the idle adjuster (leaner mixture is also observed), are studied.

1. Introduction

In the present paper, we presented a report on a trial for reducing emissions in idle runing by varying operation conditions such as the ignition timing, the setting of idle adjuster screw, and idling speed. And also, another two procedures were investigated i. e., intake air heating and heating of mixture.

These methods to improve idling combustion were compared and discussed.

2. Equipment and Procedure

A single cylinder, vertical type, air cooled 4 cycle engine was used for the experiment, and which has the L-type valve arrangement. It has a 174 cc swept volume with a compression ratio of 5.9 and its rated output is 3.0 PSe/3400 rpm.

For the cylinder pressure measurement, a strain gauge type pressure indicator was attached to the cylinder head immediately above the piston center. A DC-amplifier, a synchroscope and a long recording camera were also used for measurements of the indicator curve.

On the other hand, a surge tank (20+40 liters capacity) was inserted into the suction system of the engine to measure the inlet air quantities.

An 8.4 mm nozzle and Betz type manometer were also provided for this measurement. To analyze exhaust gas components, a gas chromatograph was made

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for trial and an analysis was made mainly on CO_2 and CO.

The arrangement of heating equipment for incoming air and the mixture are shown in Fig. 1. Two 100 V–100 W Ni–Cr wires were arranged in parallel with each other and to heating the incoming air, the wires were wound on a quartz

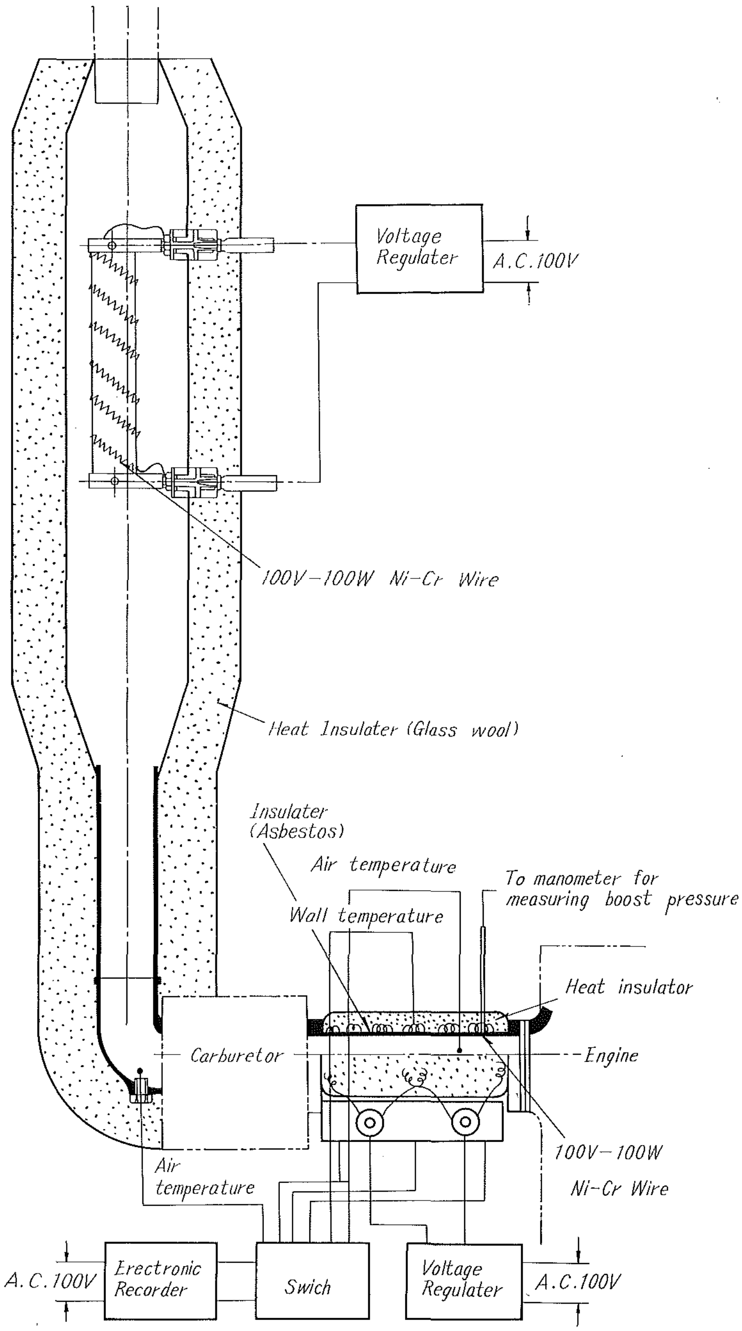

Fig. 1. The heating apparatus of intake air and mixture

pipe and inserted into the air passage. The outer surface of air passage was insulated by glass wool. And, to heat up the mixture, the outer surface of the air passage was heated by a Ni–Cr heater.

The temperature was adjusted by current regulator. The temperature at each point were measured and recorded by a C–C thermocouple and electronic recorder.

3. Experimental results and discussions

If an engine is operated under constant idling speed, and the friction loss is kept in constant, the indicated mean effective pressure Pi may be obtained from :

$$P_i = \frac{G_f \cdot H_u \cdot \eta_i}{A \cdot V_s} \quad (1)$$

On the other hand, λ and G_a are expressed in the next formula. $\lambda = G_a / G_f \cdot L_0$; $G_a = \eta_c \cdot P_0 \cdot V_s \cdot RT_0$

And by the insertion of these relations to equation (1)

$$P_i = \frac{H_u P_0}{A L_0 R T_0} \left(\frac{\eta_u \eta_* \eta_c}{\lambda} \right) = K \frac{\eta_u \eta_* \eta_c}{\lambda} \quad (2)$$

where ;

G_f ; fuel quantities per cycle
G_a ; air quantities per cycle
H_u ; lower calorific value of fuel
A ; heat equivalent of mechanical work
V_s ; stroke volume
η_i ; indicated thermal efficiency
L_0 ; theoretical air consumption
λ ; excess air factor
η_u ; combustion efficiency
η_* ; η_i / η_u
P_0, T_0 ; pressure and temperature under the normal condition
R ; gas constant of air
η_c ; charging efficiency

We know here that in order to obtain a stable running with a leaner mixture in attempt to improve idling combustion, λ must increase under a constant $\eta_u \cdot \eta_* \cdot \eta_c / \lambda$.

This may be accomplished by the reduction of the absolute quantities of the fuel by screwing the idle adjuster, or by the idling with a wider opening throttle. In regard to the latter procedure, it is a general characteristic of a carbureter that the mixture becomes leaner in accordance with the increased throttle opening under a condition where the throttle is almost closed for the idling. Thus a stable idle running with a widely opened throttle may be invented. And, this may be accomplished by the direct prevention of the charging efficiency under a widely opened throttle, or a means by which to cut down on the thermal efficiency.

For this purpose, the following means are available.

(1) Screwing the idle adjuster
(2) Retarded ignition

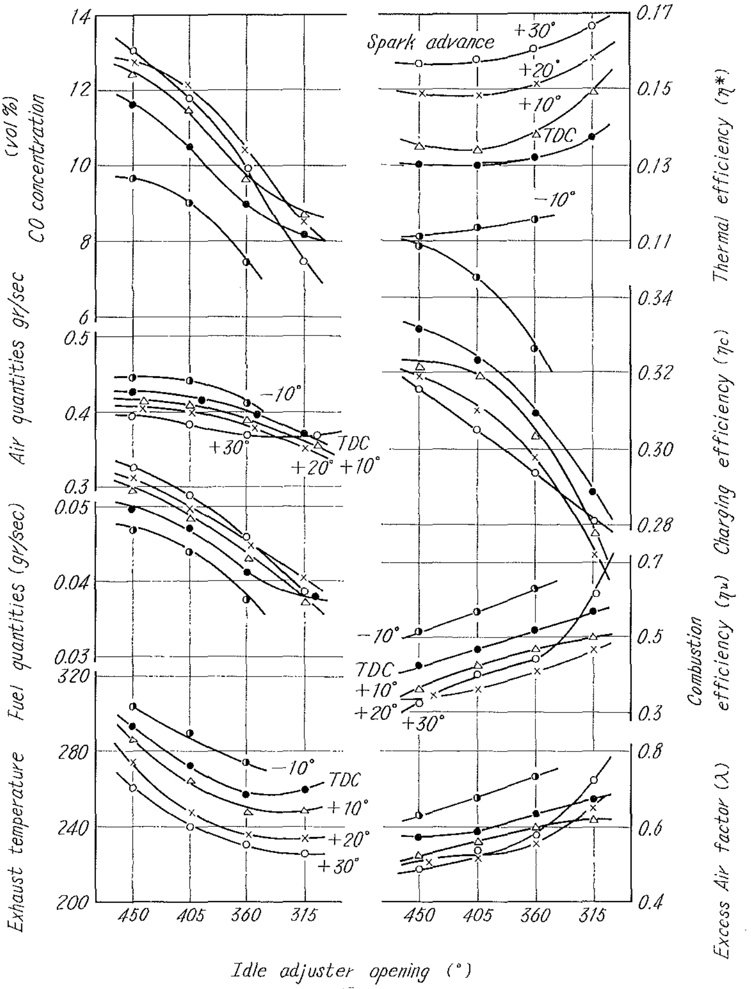

Fig. 2. Engine performance under the varied opening of idle adjuster

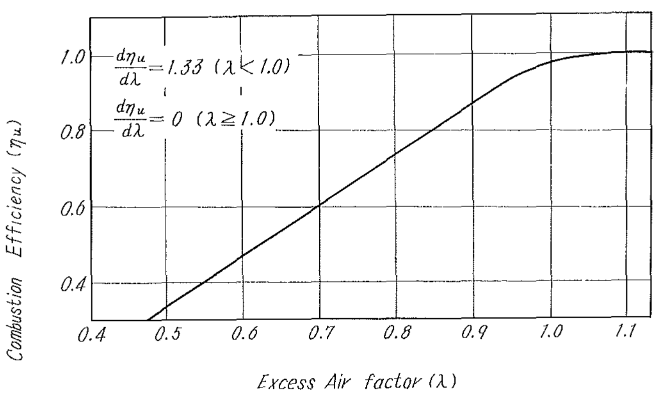

Fig. 3. The relation bet' combustion efficiency and excess air factor (K=3.4)

(3) Heating of the intake air
(4) Heating of the mixture

Here, the means by which to obtain stable idle running with a lean mixture, the profits and losses of such methods are discussed.

(1) Screwing idle adjuster

Engine performance under varied idle adjuster setting is shown in Fig. 2. In general, by screwing the idle adjuster, the mixture becomes leaner and combustion improvement may be obtained, then indicated mean effective pressure P_i increases as a result of the improved combustion efficiency η_u. And thus increased idling speed results. In this case both η_u and λ increase (cf. equation 2), but as shown in Fig. 3, in a range of $\lambda > 1$, the increasing rate of η_u becomes larger than the rate of increase of λ. Thus, the P_i increase is obtained. Namely, if the idle adjuster is screwed, and the engine operation is carried out under a smaller throttle opening than in the initial state. Then, the negative pressure near the idle hole increased in accordance with the closing of the throttle valve, but as shown in Fig.4, the mixture ratio increases under reduced air and fuel quantities.

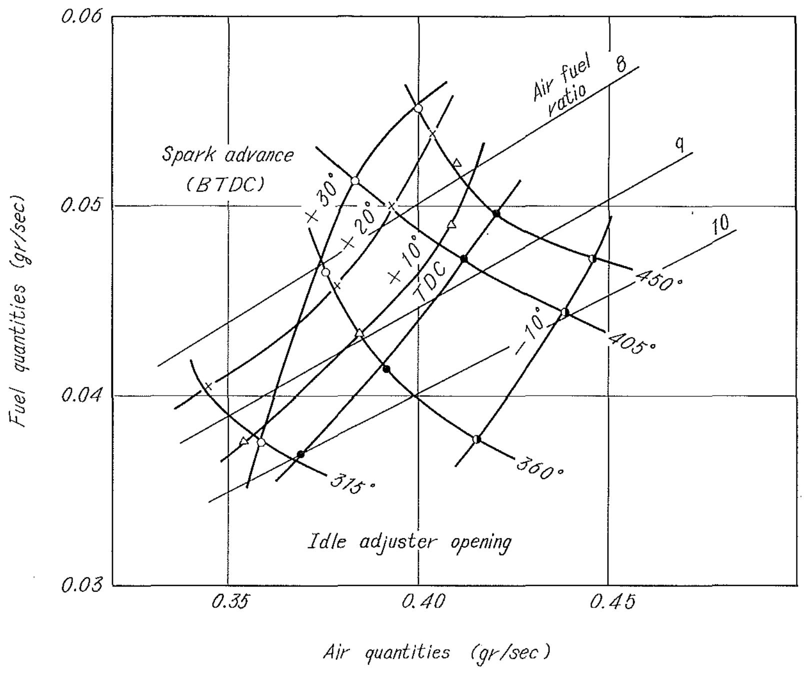

Fig. 4. Combustion improvement with the setting of idle adjuster and spark advance

Because, the fuel quantities are restricted by the screwing of the idle adjuster, hence a leaner mixture is assured with a reduction in air and fuel quantities.

(2) Retarded ignition

Fig. 5 shows engine performance under varied ignition timing. As shown in this figure, the CO concentration shows its highest values in the range of the spark timing BTDC 20∼10°, regardless of the degree of the idle adjuster opening.

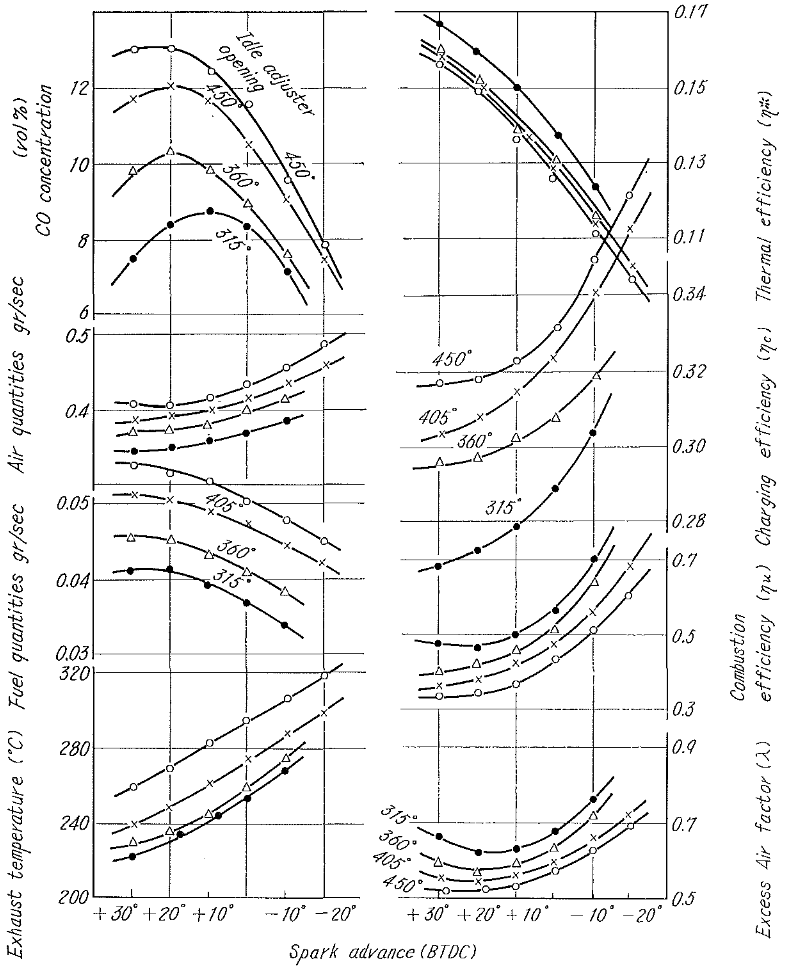

Fig. 5. Engine performance under the varied spark advance

Moreover the CO concentration decreases by advancing the spark timing. On the other hand, for the same spark timing, the CO emission decreases with the screwing of the idle adjuter, and in this case, if the fuel is cut down in excess, even a small variation of operation conditions may cause the revolution of the engine to become unstable. This may be because the actual mixture ratio approaches to the upper limit of combuston.

Fig. 6 shows an example of the indicator diagrams in such a case. As may be seen in this figure, with the spark timing in the range of BTDC 20~10°, a good combustion with a comparatively higher thermal efficiency is achieved. However, as a result the mean effective pressure increases and the higher idling speed is obtained. So, in order to maintain a constant idling speed, the throttle valve must needs be closed. As a result, the mixture ratio becomes smaller and an increase in CO emission is resulted.

In contrast, when the spark timing is retarded as shown in Fig. 6 (d), (e), (f), combustion starts on the expansion stroke. Thus, combustion efficiency decreases and a reduced mean effective pressure results lastly, the throttle valve must be

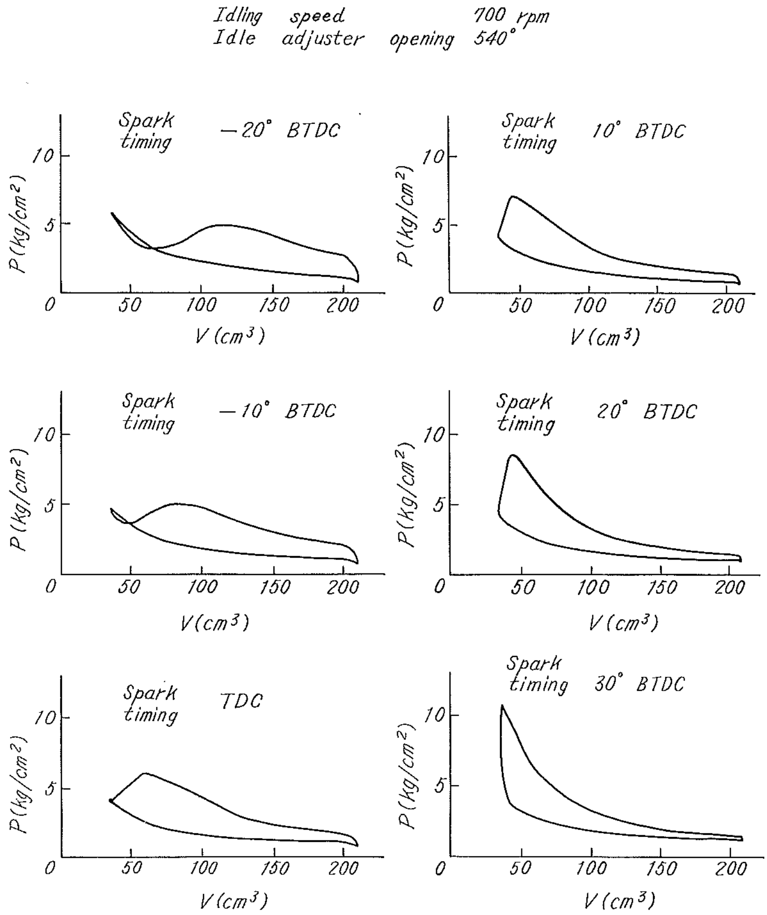

Fig. 6. Indicator diagram under the varied spark timing (Idling speed 700 rpm, Idle adjuster opening 540°)

opened to maintain a constant idling speed. This brings about an increased air quantities, however because of the widely opened throttle, the negative pressure across the idle hole decreased and finally an idling operation with a leaner mixture is achieved (Fig. 4). But, if the spark timing was additonally delayed exceed ATDC 20°, the engine running losses its stability and stable operation becomes impossible. Also, in such a case, CO increase will obtained.

In addition as shown in Fig. 4, when the ignition is advanced to BTDC 30°, a somewhat peculiar tendency appears. Namely, if ignition occurs too early, by screwing the idle adjuster, the negative work due to the start of combustion during the compression stroke increases rapidly, thus it becomes necessary to open the throttle valve to compensate for the increased negative work. As a result, the fuel quantities shows a large decrease, however stable running cannot be obtained under these extreme spark timing.

Further in Fig. 2, it may be seen that the peak of the CO concentration curves show the tendency to shift towards the TDC by screwing the idle adjuster. This fact may be attributed to the difference in ignition timing and flame velocity.

In other words, within the range of over rich mixture such as used in the present experiment, the increased mixture ratio brings the increased flame velocity. Thus, even if the ignition timing was the same, the combustion peak pressure will attained more rapidly. Here, when the idle adjuster is screwed, the mixture ratio becomes larger aud even if the sparke timing is slightly retarded, since a fine combustion is obtained, it is surmised that the peak of the CO concentration curves show a shift to the side of the TDC.

(3) Preheating of incoming air

Fig. 7 shows the engine performance under varied intake air temperatures. When intake air preheating is applied, a lowering of air dencity near the idle hole resulted, and this gives rise to boost pressure decrease and reduced fuel quantities.

Also, air quantities are restricted by preheating air, thus the indicated mean effective pressure becomes decreased under lowered charging efficiency and slightly

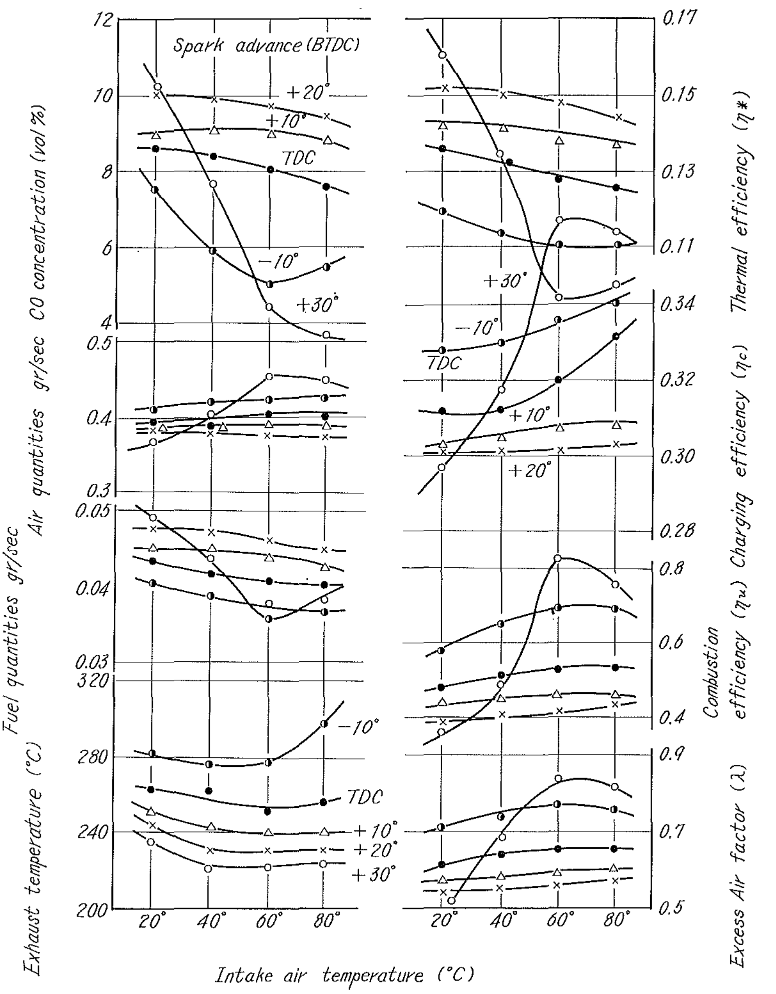

Fig. 7. Engine performance under the varied intake air temperature

reduced excess air factor (cf. eq. 3), and finally, this results in a slower idling speed. Hence it is necessary to compensate by the aid of an opened throttle valve.

As a result leaner mixture is achieved under the reduced fuel quantities and slightly increased air quantities (Fig. 8).

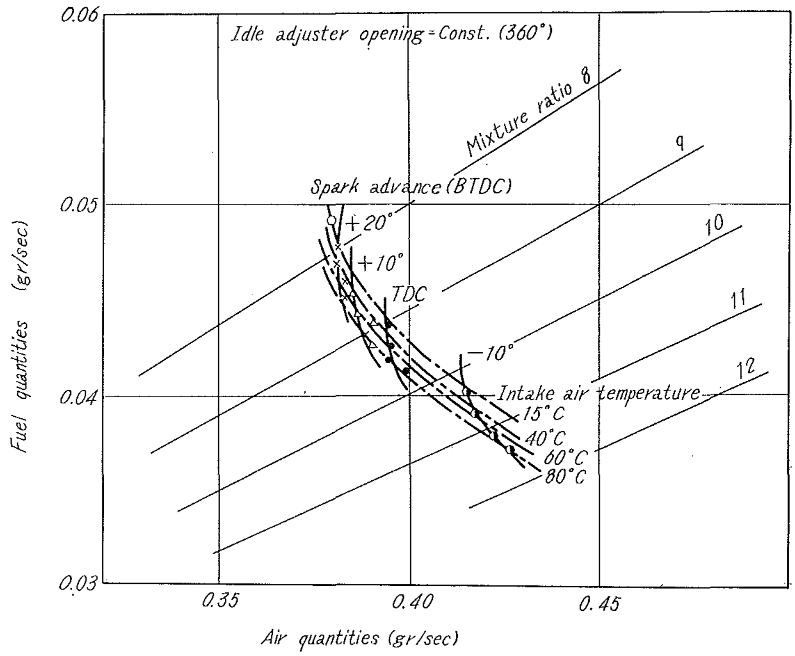

Fig. 8. Combustion improvement with the heating of intake air

(4) Mixture heating

Heating of the mixture by heating the intake pipe wall was attempted. The engine performance in this case is shown in Fig. 9. In the case heating is applied just before the engine intake port, and a reduced charging efficiency and engine speed decreases resulted, and this must be compensated by a widely opened throttle.

As a result, air quantities are reduced from the initial state and engine running is achieved under a somewhat lower charging efficiency η_c (Fig. 9). In this case, reduced fuel quantities are obtained by opening the throttle valve. This gives rise to an increased excess air factor λ and markedly improved combustion efficiency η_u, thus, the effect of decreased charging efficiency is compensated and a stable idle running with a leaner mixture results under a constant mean effective pressure P_i. Fig. 10 shows this procedure. In this figure, it is obvious that, when the rate of opening of the idle adjuster is larger (450°), the effect of mixture heating is restricted compared with the case of a smaller openig of the idle adjuster (360°). Because, in the former, the throttle valve is opened widely, and engine running is maintained with larger air quantities, the fuel is sucked partly from the main system, then the total fuel quantities supplied to the engine are not reduced markedly by the opening of the throttle valve.

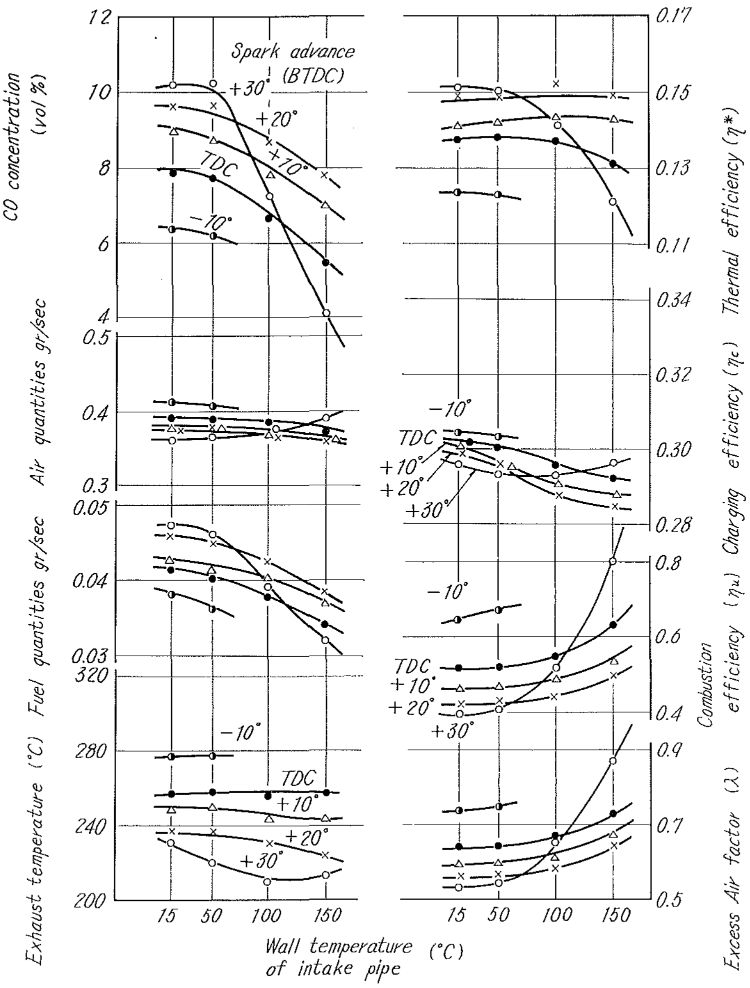

Fig. 9. Engine performance under the varied mixture temperature

(5) The difference between air preheating and mixture heating

In general, the air/fuel ratio regulated by the fuel quantities from the system may be approximated by the next formula.

$$MR = \frac{G_a}{G_f} = \frac{1}{C_f A_f \sqrt{\left(\frac{\gamma_f}{\gamma_a}\left(\frac{1}{A_2^2} - \frac{1}{A_1^2}\right)\right)}} \tag{3}$$

where ;

- MR ; air fuel ratio regulated by the idle fuel quantities
- A_1 ; sectional area of suction pipe
- A_2 ; clearance formed between throttle valve periphery and suction pipe inner wall
- A_f ; sectional area of idle hole
- C_f ; coefficient of flow of idle hole

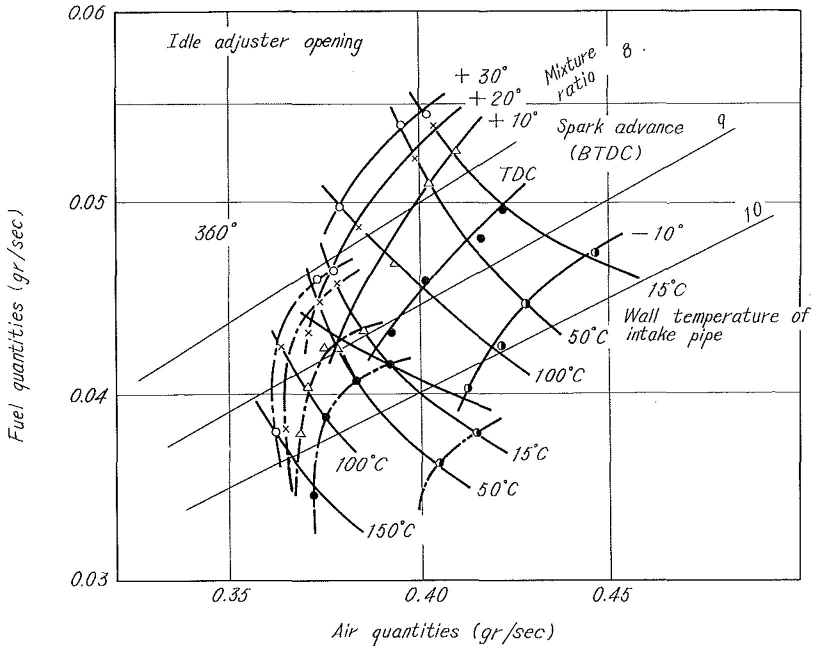

Fig. 10. Combustion improvement with the heating of mixture

γ_a ; specific weight of air
γ_f ; specific weight of fuel

As shown in equation (3), if the specific weight of the air across the idle hole is lowered, the air/fuel ratio becomes smaller. Thus, when the incoming air is heated, the specific weight of the air across the idle hole becomes markedly smaller and the air/fuel ratio decreases. On the contrary, if the mixture is heated, the variation of the air/fuel ratio which depends on the heating may be very small. That is, when the mixture is heated, a reduction of engine speed occurs mainly by the decreased charging efficiency η_c. But, if the incoming air is heated, the charging efficiency and the excess air factor is reduced together and as a result, the engine speed decreases under lowered combustion efficiency η_*. Thus, if the idling speed is kept constant, the openig of the throttle valve becomes larger in the case of intake air heating compared with the mixture heating. And thus, when the intake air is heated, a leaner mixture is assured under slightly increased air quantities (cf. Fig. 8 and 19).

(6) The relation between the mixture ratio and CO concentration under the idling conditions

Fig. 11 shows the relation between the mixture ratio and CO concentration. The solid line in this figure indicates the values based on the apparent mixture ratio measured on the intake side. And the dotted line indicates the values based on the mixture ratio obtained from an analysis of the exhaust gas (H_2 and unburned HC in the exhaust gas were negrected in the calculations). As shown in this figure, there exists a considerable difference between two values. It was surmised that this may be due to the air leaking in from the valve guide, and leaking out to the crankcase and also due to the unburned hydrocarbon emissions.

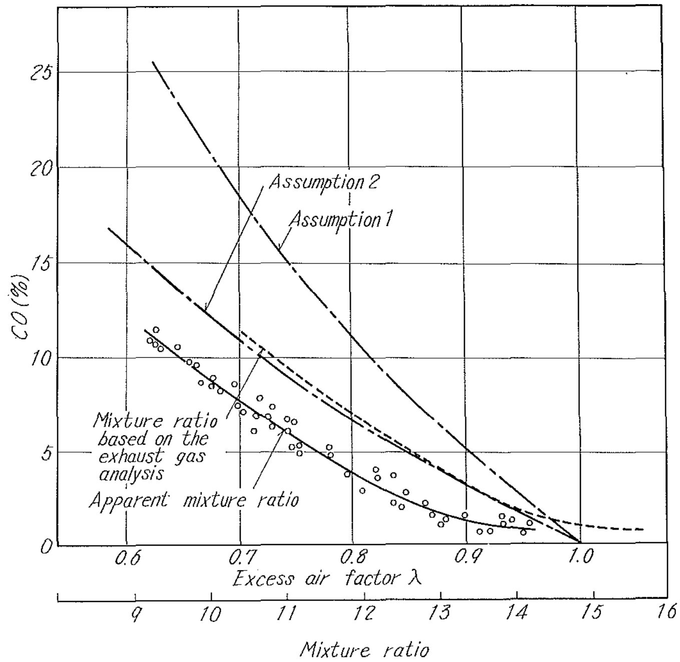

Fig. 11. The relation between mixture ratio and CO concentration

Further in the figure, two dot-dash curves were plotted. These two curves indicate the values of the CO concentration calculated under the following two assumptions, that is ;

(1) Any carbon molecules are not emitted in the form of free carbon, and all H_2 react on H_2O.

$$C_nH_{2n+2}+\lambda\left(\frac{3n+1}{2}\right)O_2 \rightarrow n'CO_2+n''CO+(n+1)H_2O$$

$$n''=(3n+1)(1-\lambda)$$

$$[CO]=\frac{(3n+1)(1-\lambda)}{n+\lambda\left(\frac{3n+1}{2}\right)\times\frac{79}{21}}\times 100\%$$

(2) Any carbon molecules are not emitted in the form of free carbon, and H_2 corresponding to λ react on H_2O.

$$C_nH_{2n+2}+\lambda\left(\frac{3n+1}{2}\right)O_2 \rightarrow n'CO_2+n''CO+(n+1)H_2O+(1-\lambda)(n+1)H_2$$

$$n''=2n(1-\lambda)$$

$$[CO]=\frac{2n(1-\lambda)}{n+\lambda\left(\frac{3n+1}{2}\right)\times\frac{79}{21}+(1-\lambda)(n+1)}\times 100\%$$

As shown in the figure, the CO curve plotted based on the exhaust side measurement shows a good coincidence with the calculated curve baced on assumption (2).

(7) The relation between the combustion variation and CO concentration under the idling conditions

As well known, the CO emission is strongly influenced by the air fuel ratio. And it is apparent that by the use of leaner mixture, the CO concentration may be lowered to a considerable extent.

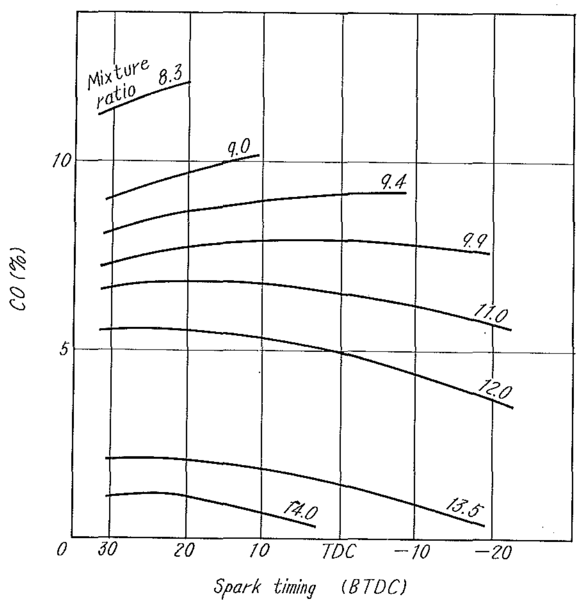

Fig. 12. The relation between CO concentration and spark timing (Mixture ratio = Const.)

However, the CO concentration is not determined by the air fuel ratio alone. For example, as shown in Fig. 12, even when the mixture ratio is constant, the CO concentration does not necessarily show the constant values under the varied spark timing. In other words, if the richer mixture was suipplied, CO concentration shows the increasing tendency according to the retarded spark timing. In contrast to the above, when the leaner mixture was used, the CO concentration shows a decreasing tendency by the retarded spark timing. As described within a range of richer mixture, the reason why the CO concentration increases with the increase in delay of the spark timing even when the same mixture ratio, is because the throttle valve is closed with the increase in retard of the spark timing till BTDC 20°. On the other hand, the reason why the CO concentration becomes lower with the increase in the retardation of the spark timing under the leaner mixture, is because the throttle valve is opened and incoming mixture increases according to the lowering of thermal efficiency due to the retarded spark timing. That is, even when the apparent mixture ratio is almost the same, the CO concentration seems to decrease because the new charge to be burned in the cylinder increases and the degree of dilution of the new charge by residual gas decreases, resulting in an improvement of combustion.

On the above described view point, the variation of combustion during idling operation was investigated by following the variation of combustion peak pressure.

Fig. 13 shows the frequency distribution of the combustion peak pressure during idling operation. In this experiment, the engine speed was maintained at 700 rpm and measurements were made by varying the spark timing and the degree of idle adjuster opening. As may be seen in the figure, the combustion peak pressure shows a scattering like a normal distribution. And, the deviation rate was 2～13% or thereabouts, and it seems considerably large compared with that of 3～5% under the partial load and 1～1.5% of full throttle operation. Besides, under

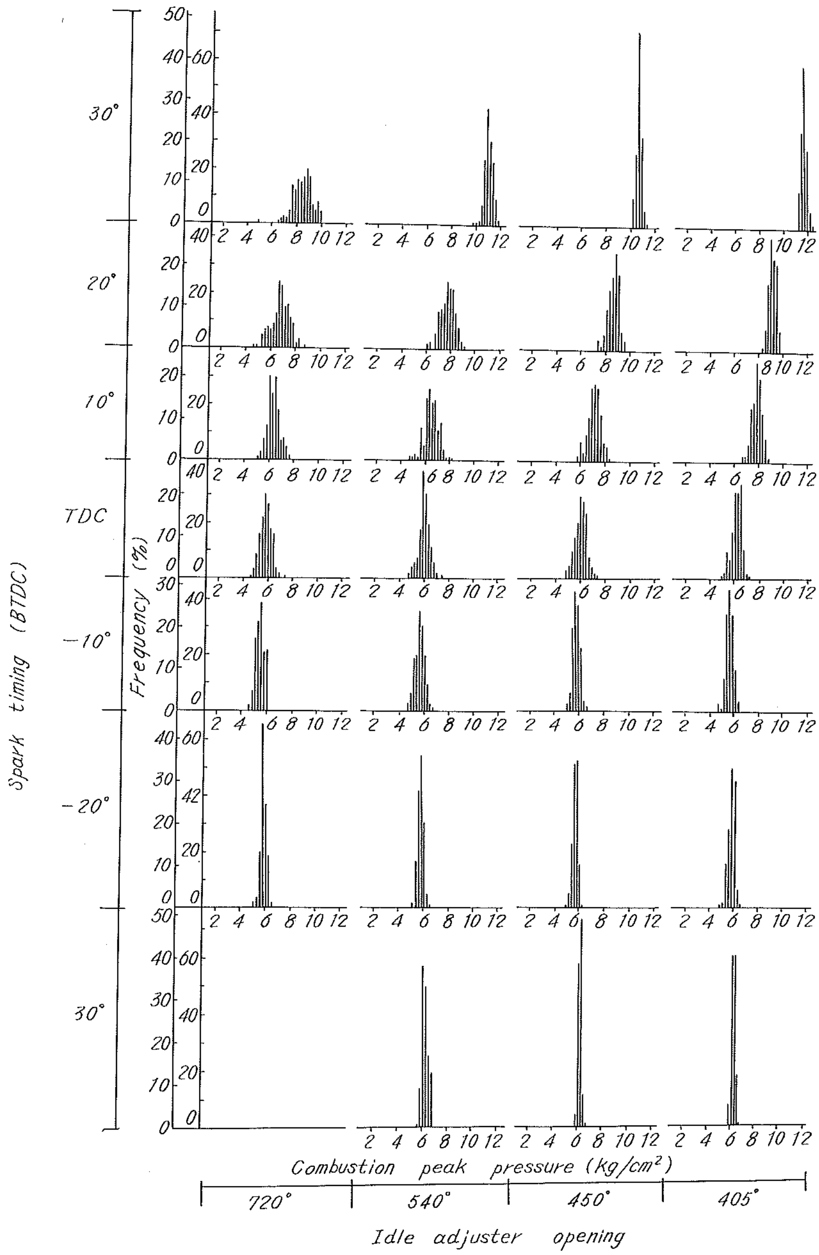

Fig. 13. The frequency distribution of combustion peak pressure

the same opening of the idle adjuster, the combustion pressure rose with the advance of the spark timing. Fig. 14 shows the standard deviation and mean values of the combustion peak pressure under the varied opening of idle adjuster and spark timing with the constant idling speed of 700 rpm. As may be seen in the figure, the variation of combustion shows maximum values at a certain spark timing and it becomes increasingly smaller with the decrease in fuel flow brought about by the adjustment of the idle adjuster setting. This tendency is very much likely as the tendency seen in the CO concentration against spark timing curve as previously indicated in Fig. 5. And it is clear that the increased combustion variation produces the in creased CO emission.

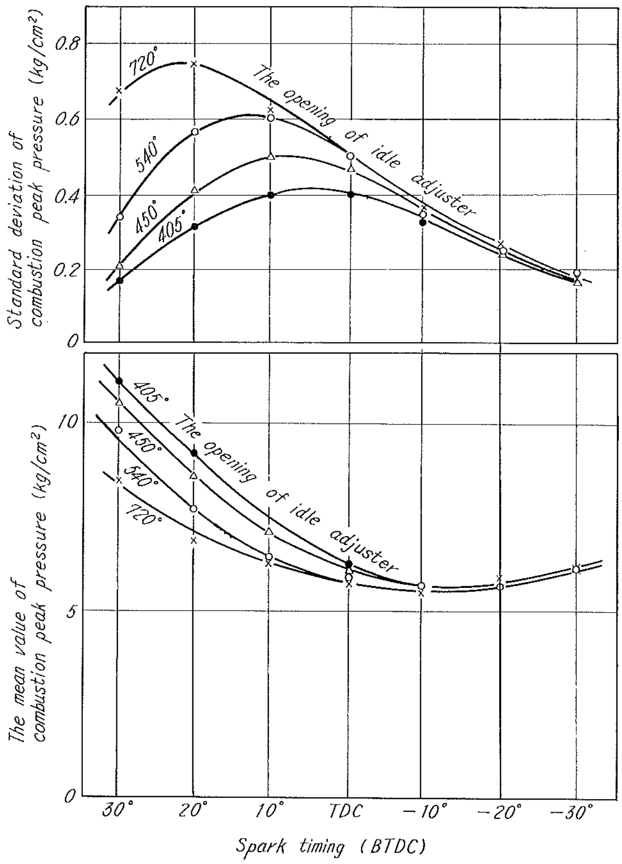

Fig. 14. The standard deviation and mean value of combustion peak pressure against spark timing

Fig. 15 shows the relation between CO concentration and the standard deviation of combustion peak pressure, and as may be seen when the variation are numerous, the CO concentration likewise becomes larger one.

In this manner, the CO concentration increases with the increase of combustion variation and also becomes larger as the air fuel ratio decreases as described previously.

However, there is no significant correlation between the combustion variation

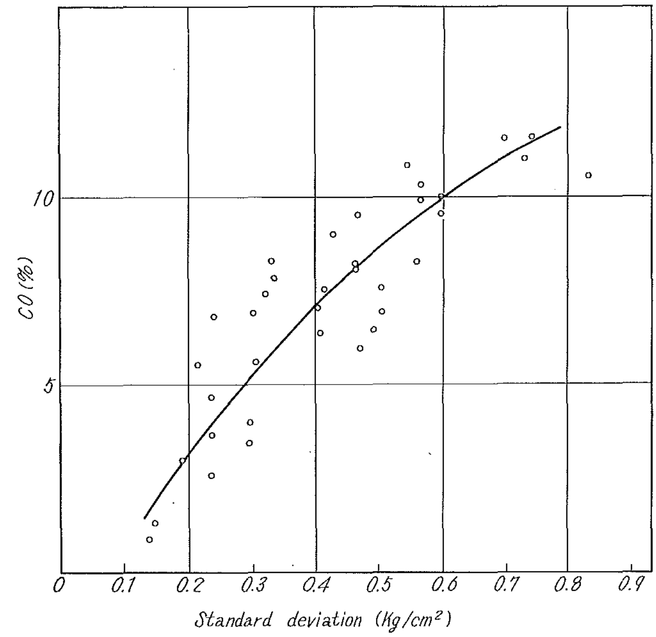

Fig. 15. CO concentration vs standard deviation of combustion peak pressure

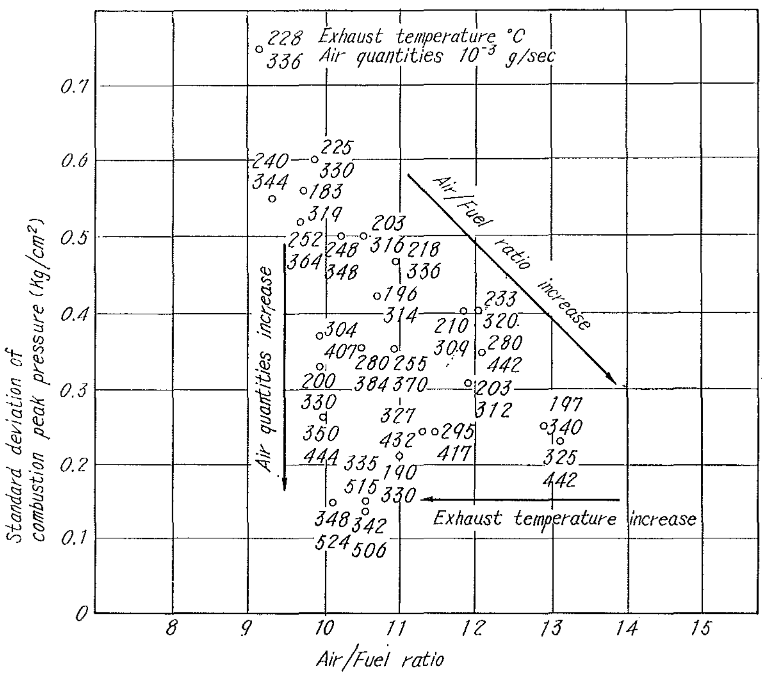

Fig. 16. The variation of combuftion vs mixture ratio

and the air fuel ratio. Namely, as shown in Fig. 16, when the spark timing is not too retarded and under the lower exhaust temperature, it is a fact that when the mixture becomes leaner, a decreased combustion variation is obtained. In short, a line of constant exhaust temperature is in parallel with the line designated as the air fuel ratio increases in this figure. Here, together with the increase in air fuel ratio, the variation of combustion has decreased. Moreover, this line shifts towards the original point, with the increase of the exhaust temperature, so the higher exhaust temperature brings the decreased combustion variation under the same air fuel ratio. (Under the too retarded ignition, the exhaust temperature kept in higher value. And in such a case, the degree of combustion variation kept in constant and relatively smaller under the widely changed mixture ratio produced by the change of the idle adjuter setting.)

On the ohter hand, the gradual decrease of the combustion peak pressure may be seen in the lower tier of Fig. 9 according to the retarded spark timing. But, when the retardation is brought to an extreme, to the contrary, the combustion peak pressure shows an increasing tendency. Further, when the idle adjuster is screwed in still further and the fuel is cutted down, the combustion peak pressure shows a tendency to increase. Thus, under the advanced spark timing, the reason of the higher combustion peak pressure seems because the nearer starting point of combustion to the TDC. And, with the increase in retardation of the spark timing, the combustion will start during expansion stroke and the combustion peak pressure is lowered. However, when the spark timing is retarded to the extreme, to the contrary, the combustion peak pressure increases slighly. The reason for this may be considered as follows. At first, it brings the lowering of thermal efficiency, and to compensate for the lowering of the output arising from the above, it becomes necessary to open the throttle valve. As a result, the incoming mixture increases and it brings the increased compression pressure and flame velocity accompanying to the mixture ratio increase. The increase in the combustion peak pressure likewise arising from the throttling of the idling fuel

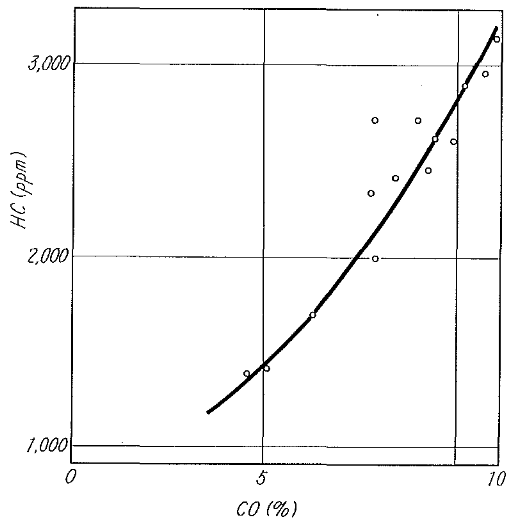

Fig. 17. The corelation between HC and CO concentration

quantities may also be explained by the flame velocity. As described above, we have attempted to explain the mechanism of CO emission under the idling condition. Apart from the above investigations, another trial using a hydrogen ion detector was carried out and HC measurements were made. And it was clarified that the lowering in CO concentration during idling operation was clearly connected with the lowering in HC concentration. Fig. 17 illustrates this relationship.

(8) **The relation between the idling speed and CO concentration**

Finally, the influence of the idling speed on the CO concentration was investigated. Fig. 18 shows the relationship between the CO concentration and the air fuel ratio against the engine speed with the following conditions. The opening of the idle adjuster was hold at 540° with the spark timing of BTDC 30°~ATDC 30°. In this case, also an exact correlation was seen between the CO concentration and the mixture ratio. In other words, when the spark timing is advanced, CO concentration decreases with the increase of idling speed. However, when the spark timing is extremely retarded, the increase of idling speed produces the increased CO concentration. But, if a decrease in CO concentration was attempted

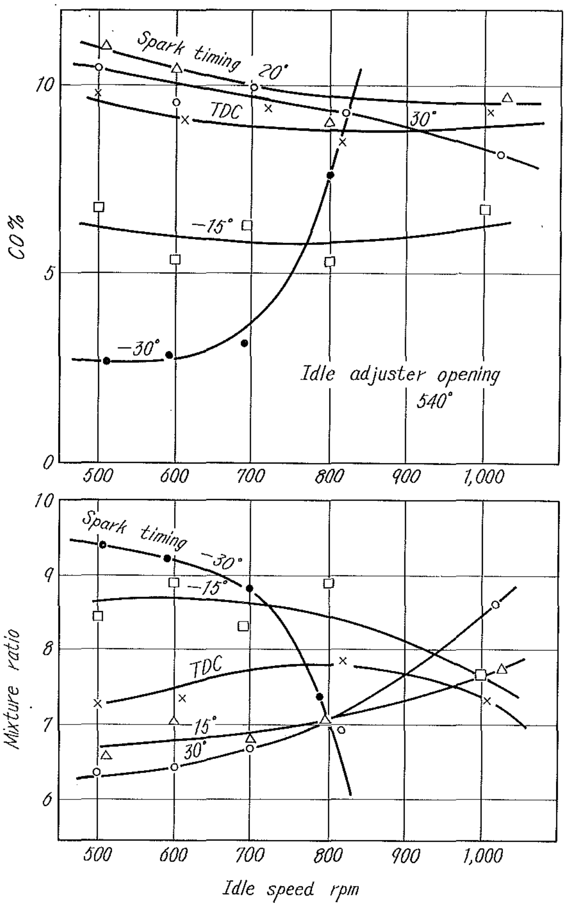

Fig. 18. The relation between CO concentration and mixture ratio against idling speed

by the increases of idling speed, the extent of it is very small, and since the quantities of emitted CO gas increases with the rise of engine revolution. So it can be said that the increase of idling speed is not an effective method for the decrease of CO emission.

4. Conclusions

In this paper we attempted to use 4 methods to improve the combustion of idle running, and discussed the mechanism for obtaining a cleaner exhaust. These are summarized in Fig. 19, as follows;

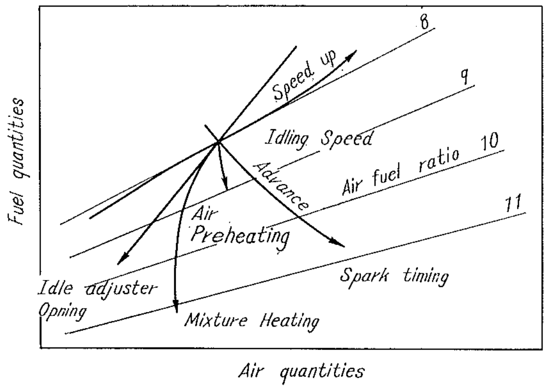

Fig. 19. The summary of the procedures of combustion improvement

(1) If the idle adjuster is screwed, a leaner mixture is obtained with the reduced air and fuel quantities.

(2) When the timing of ignition is retarded, a leaner mixture results under increased air quantities and decreased fuel quantities.

(3) A leaner mixture is obtained by preheating air as a result of slightly increased air quantities and reduced fuel quantities.

(4) If the mixture is heated, an operation with a leaner mixture is achieved under almost constant air quantities and decreased fuel quantities. And this effect becomes remarkable when the idle adjuter is screwed. Also, by heating, the quality of mixture is affected, but here this problem could not be separated and studied.

(5) If one attempts to obtain a leaner mixture by opening the throttle valve, when the opening is in excess, the fuel begins to be sucked from the main system and the effect for a leaner mixture is restricted. Thus, if it is necessary to obtain a leaner mixture effectively, a lower idling speed and smaller fuel quantities of a slow system may be available for attempts using intake air preheating, mixture heating or retarded ignition. In addition, as shown in Fig. 19, an increased idling speed under a widely opened throttle valve is not effective for achieving a leaner mixture.

(6) The CO concentration emitted during idle running is mainly decided by the air fuel ratio, but under the same mixture strength, CO concentration increases with the increased variation of combustion. And to reduce this variation, it is

desirable to obtain a larger incoming charge, hence retarded ignition may be more effective as compared with the screwed idle adjuster.

On the other hand, a procedure to obtain a leaner mixture by a reduced incoming charge shows a tendency of unstable running, because the true mixture strength approaches the lower limit of combustion. The variation of combustion is reduced by an improved ignition system. For instance, by the adaption of a transistor igniter, the variation of combustion decreases as compared with the battery ignition system and stable running under a more leaner mixture becomes possible. Further study is required along these lines.

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