



室蘭工業大学

学術資源アーカイブ

Muroran Institute of Technology Academic Resources Archive



Behavior of Fuel Liquid-Film Flow in Intake Manifold of two Stroke Cycle Engine

メタデータ	言語: eng 出版者: 室蘭工業大学 公開日: 2014-07-24 キーワード (Ja): キーワード (En): 作成者: 林, 重信, 澤, 則弘 メールアドレス: 所属:
URL	http://hdl.handle.net/10258/3651

BEHAVIOR OF FUEL LIQUID-FILM FLOW IN INTAKE MANIFOLD OF TWO STROKE CYCLE ENGINE.

Shigenobu Hayashi and Norihiro Sawa*

Abstract

In a carburettor engine, the most of fuel feed from a carburettor flows along inside wall of intake manifold in the form of liquid, which shows an aspect of very complex. Therefore, it seems that the behavior of liquid-film flow has a remarkable influence on, in particular, the cycle variation of effective mixture strength in the cylinder, the fuel distribution in a multi-cylinder engine and also the mixture formation during a transitional running.

Accordingly, to examine in detail the behavior of fuel liquid-film, the authors have tried to measure directly the amount of liquid-film by means of a separator inserted in intake manifold and at the same time to record the instantaneous behavior and the distribution of its thickness by the change in electric conductivity.

This paper presents the results obtained from the experiments as mentioned above.

1. Introduction

In a gasoline engine, the most of fuel supplied from a carburettor does not vaporize and flows along inside-wall of intake pipe to an engine cylinder as liquid. Not only the flow quantity of this liquid-fuel is remarkably influenced by the dimension of intake pipe system and the running condition but also the flow state shows an aspect of very complex.⁽¹⁾ Therefore, it seems that the behavior of fuel liquid-film flow has a remarkable influence on, in particular, the cycle variation of effective mixture strength in the cylinder, the fuel distribution in the multi-cylinder engine under a stationary operation and also the mixture formation during a transitional running⁽²⁾⁻⁽⁶⁾. Accordingly, to examine in detail the behavior of liquid-film flow, the fuel distribution and the fuel supplied state under a transitional running as well as a stationary operation, the authors have tried to measure directly the amount of fuel liquid-film flow by means of the separator inserted in the intake manifold of the small-sized two stroke cycle engine and to record the instantaneous behavior and distribution of fuel liquid-film thickness from the change in electric conductivity. Such experimental results will be described in the following.

2. Experimental Apparatus and Method

2.1 Experiment on Behavior of Fuel Liquid-Film Flow

A general layout of experimental apparatus for the behavior is shown in Fig. 1. In this figure, an intake pipe system used is transparent, so that it is possible to observe the behavior of fuel liquid-film flow and to take the photograph of these. The authors used a test engine E-125 i.e. a crankcase compressed two stroke cycle engine for motor bicycle, whose dimensions are described in Table 1. Moreover, all the tests are carried out in the motoring state

* Prof. at the Ibaragi Univ.

Table 1 Dimension of test engine

Test engine	Stroke volume	Diameter of intake pipe	Type of inlet valve	valve timing		Cylinder number
				I.O.	I.C.	
E-125	123cc	21mm	Piston	70°	70°	1
E-360	359cc	36mm	valve	53°	68°	2

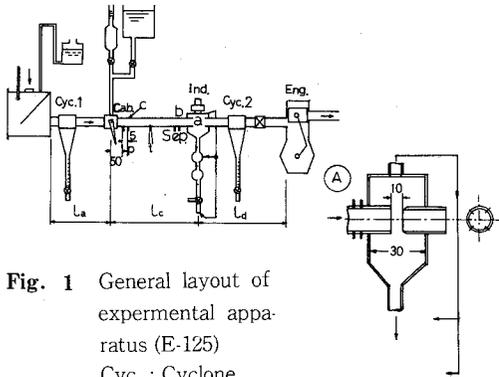


Fig. 1 General layout of experimental apparatus (E-125)
 Cyc. : Cyclone
 Cab. : Carburettor
 p : Electrode
 t : Thermocouple
 Sep. : Separator (Fig. A)
 Ind. : Pressure indicator

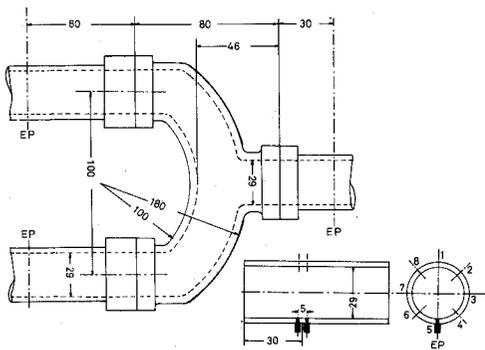


Fig. 3 Dimension of intake manifold
 EP : Position of electrode

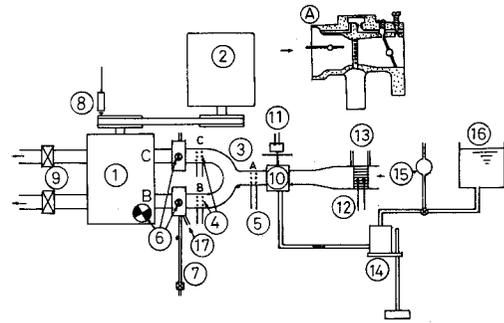


Fig. 2 Genral layout of experimental apparatus (E-360)
 ① Test engine ② Variable speed motor ③ Inlet pipe ④ Electrode for measuring liquid-film thickness ⑤ Pressure indicator ⑦ Burette ⑧ TDC marker ⑨ Exhaust throttle valve ⑩ Carburettor ⑪ Index of carburettor opening ⑫ Instantaneous laminar flow meter ⑬ Manometer for laminar flow meter ⑭ Float chamber ⑮ Fuel flow meter ⑯ Fuel tank ⑰ Manometer for measuring inlet pressure

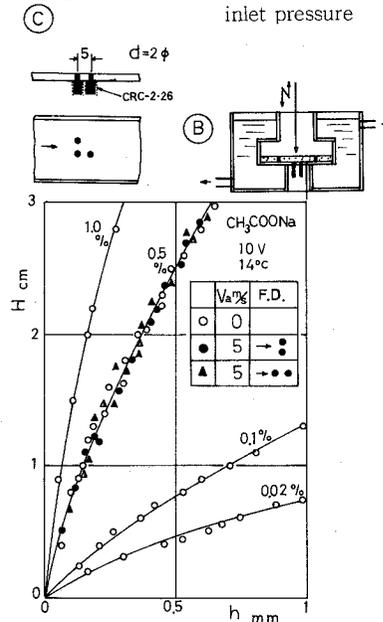


Fig. 4 Calibration curve (Concentration of solution)
 H : Amplitude on oscillogrm
 h : Thickness (or depth) of liquid-film

Table 2 Charactor of used rlethanol

Methanol CH ₃ OH	Specific weight	viscosity 20°C cst	Suface tension 20°C dyn/cm	Evaporating heat kcal/kg	Boiling point °C	Evaporating velocity g/cm ² ·h	Specific heat kcal/kg °C
	0.791	0.595	22.6	267.5	64.56	0.02~0.025	0.59

Table 3 Calculated value of $[G_a/G_f]/(G_a/G_f)$

Mixture ratio (G_a/G_f)	Carburettor opning (θ)	
	30°	90°
5	1.277	0.890
20	1.196	1.004

and then a separator and two cyclones were exserted, if necessary for the purpose of experiment. For the measurement of instantaneous thickness of fuel liquid-film, methanol (see Table 2) instead of gasoline is used as fuel, in which extremely small quantity of CH₃COONa is dissolved to increase the electric conductivity and the fuel liquid-film thickness is indirectly determined from the change in its electric conductivity owing to the thickness of solution. Therefore, the many electrodes were setted on the pipe wall in the respective positions (see Fig. 1) to measure the circumferential and longitudinal distribution of liquid-film thickness. The flow rate (G_{fi}) and thickness (h) of fuel liquid-film are simultaneously measured over a wide range of the intake pipe length (L_s), the flow rate of supplied fuel (G_f), the opening of carburettor (C) and the engine speed (N) etc..

2.2 Experiment on Distribution of Fuel Liquid-Film Flow

A general layout of experimental apparatus for the distribution is shown in Fig. 2. A test engine is a crankcase-compressed two stroke cycle engine with two cylinder E-360, whose main dimensions are discribed in Table 1 and all the tests carried out in the motoring state. An intake pipe system ③ wth the exception of branch part is transparent so that it is possible to observe the state of fuel liquid-film traveling from a carburettor to the individual cylinder via an intake manifold and to take the photograph of these. Beside, to measure the instantaneous thickness of fuel liquid-film flow, the many electrodes were setted on the inside-wall in front and in rear ④ ⑤ of branch part of intake manifold and that two separators ⑦ were inserted in the cylinder side to measure directly its flow quantity. The principle dimension and shape of intake manifold are shown in Fig. 3. Further, though regular gasoline was mainly used to examine the effects of various factors on the quantitative distribution of fuel liquid-film flow, on the other hand, for experiment pertaining to the behavior of fuel liquid-film thickness, methanol instead of gasoline was employed as fuel, in which contains CH₃COONa of 0.1~1 volume percentage. In the wide range of various operating conditions, that is, the carburettor opening (Θ) is from 30° to 90 (full open), the inclined angle (β) of intake manifold is 4°~ -4°, the additional pipe length (L_s) is 0~100cm and the mixture ratio (G_a/G_f) is 5~20 etc., we measured breathing air capacity (G_a), the amount of supplied fuel (G_f), the quantity of fuel liquid-film flowing to individual cylinder (G_{ib} , G_{ic}) and its temperature (t) after the engine condition reached to a stationary state in

motoring operation. Moreover, to examine the principle cause of maldistribution, the circumferential distribution of fuel liquid-film thickness in each position ④, ⑤ and the pressure variation in both crankcase ⑥ and intake pipe ⑥ are simultaneously recorded on a electromagnetic oscillogram.

2.3 Measurement of Fuel Liquid-Film Thickness

Before adopting the method, as was stated previously, we have repeated many preliminary experiments on the selection of electrode's material and of substance to be dissolved and then the condition of fuel liquid-film formation, which is mainly affected by its viscosity and surface tension etc.. In general, since the electric conductivity of fuel (i.e. solution) can be changed by its concentration, the temperature decrease of the solution due to evaporation and the source voltage for measuring circuit etc. as understood from Fig. 4 and Fig. 5, it is necessary to determine the experimental conditions. Therefor, we adopted the following conditions from the experimental results.

- Electrode's material : platinum or stainless steel
- Electrode's diameter : 2mm ϕ (see Fig. 4 C)

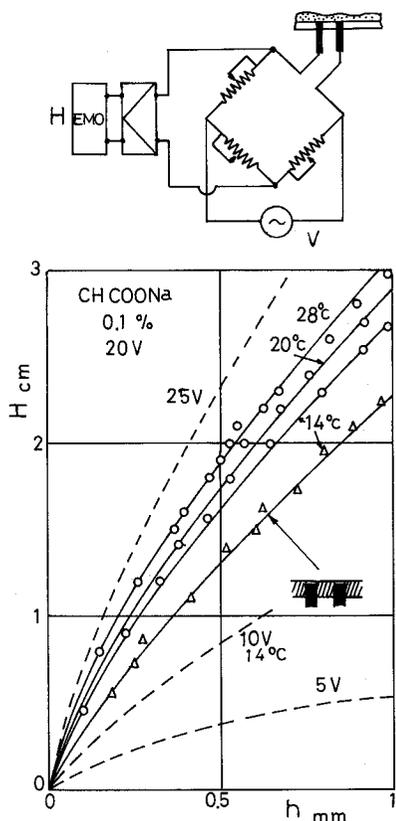


Fig. 5 Calibration curve (Effects of source voltage and fuel temperature)

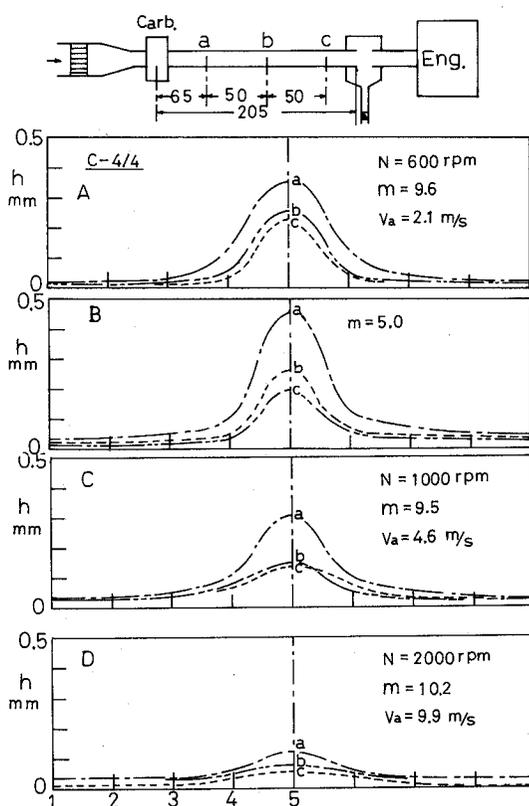


Fig. 6 Circumferential distribution of fuel liquid-film thickness for engine speed (E-125)

Distance between electrodes	: 5mm (see Fig. 4 ©)
Source voltage	: 5 V (50 Hz)
Fuel	: wood alcohol
Dissolved substance	: CH_3COONa (volume ratio 0.1~1%)

3. Experimental Results and Considerations

3.1. Flow Rate and Thickness of Fuel Liquid-Film under Stationary Operation

3.1.1 Intake Pipe Length (L_s)

The distribution of fuel liquid-film thickness (h) in the longitudinal direction of intake pipe depends on the spray's condition of fuel flowing out from a carburettor, the adhesion of floating fuel droplet to the pipe wall, the evaporation from fuel liquid-film flow, the gravitational force etc., so that the phenomenon is extremely complicated and can be changed by not only the atmospheric state but also the driving condition of engine, that is, the mixture ratio (m), the opening of carburettor (C) and the engine speed (N) etc..

For this reason, the authors have not been able to draw any systematic conclusion, but the outline of results obtained from Fig. 6 and Fig. 7 are as follows.

① Some part of fuel flowed out from a carburettor attaches to the pipe wall in front of the electrode a (i.e. $l = 65$ mm) and that flows along the inside wall in the form of liquid. In the case of low engine speed (e.g. $N=600$ rpm, $V=2.1$ m/s in Fig.6), at first, the fuel liquid flow is drop-like but the drops gather with their advance towards the engine, consequently so-called fuel liquid-film flow is formed. Of course, there is the descending flow under the influence of the gravitational force while the evaporation from liquid-film flow proceeds.

Since this amount of evaporation exceeds a sum of the descending fuel liquidfilm flow rate and the floating fuel-droplet quantity adhered to the pipe wall, the fuel liquid-film at the bottom wall (i.e. position 5) gradually becomes thinner. Such a tendency becomes more remarkable with richer mixture ratio (m) as shown in Fig. 6. Both come under an equilibrium, however, if the distance from the fuel jet of carburettor becomes 115mm (i.e. position b) and the thickness of fuel liquid-film does not almost change.

② Since the velocity of breathing air ($V_a=Q_a/f_i$) increases with the engine speed (N), the evaporation of fuel liquid-film is promoted and its quantity approaches to a saturation.

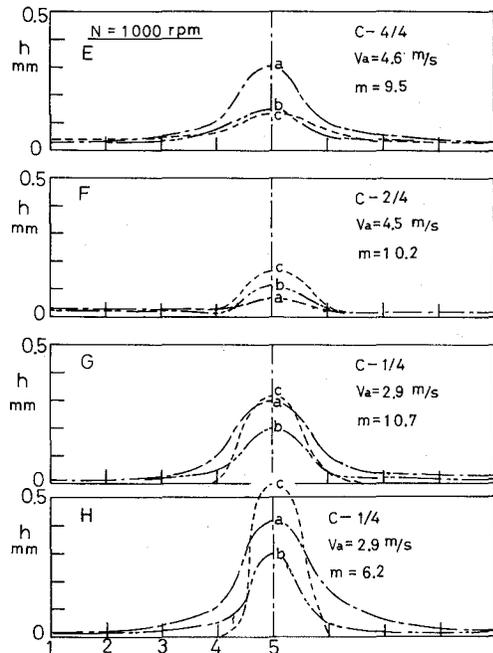


Fig. 7 Circumferential distribution of fuel liquid-film thickness for carburettor opening (E-125)

On the other hand, the place attached with the floating fuel droplet moves towards the engine side. Thereupon, the fuel liquid-film thickness on the upper wall (i.e. position 1) does not always become thinner at a place nearer to the engine side and also the thickness at the bottom wall (i.e. position 5) does not become so much thinner.

③ If the opening of the carburettor is small (for example $C=1/4$), vortexes appears in the downstream of the throttle valve and fuel spray adheres on the pipe wall in front of the electrode a (i.e. $l = 65$ mm). While the evaporation of fuel is promoted and the fuel liquid-film at the electrode b ($l = 115$ mm) tends to become thinner because of high negative pressure in the intake pipe, the fuel liquid-film is affected by the gravitational force due to low velocity of breathing air and becomes rather thicker at the electrode c ($l = 165$ mm).

④ The evaporation of fuel depends very much on the atmospheric condition, that is, the temperature and the humidity of breathing air so that, on the contrary, the fuel liquid-film becomes gradually thicker at a place nearer to the engine side in the case of high humidity and low temperature.

3.1.2 Engine Speed (N)

While the circumferential distribution of fuel liquid-film thickness in the high engine speed (e.g. $N=3000$ rpm, $V_a=11.5$ m/s) is approximately uniform, when the low engine speed (i.e. both of G_a and G_f decrease), the fuel liquid-film becomes gradually thicker and its variation is also increased. When less than 1000 rpm ($V_a=5.2$ m/s), however, the influence of the gravitational force predominates, on the contrary, the fuel liquid-film, in $N=600$ rpm

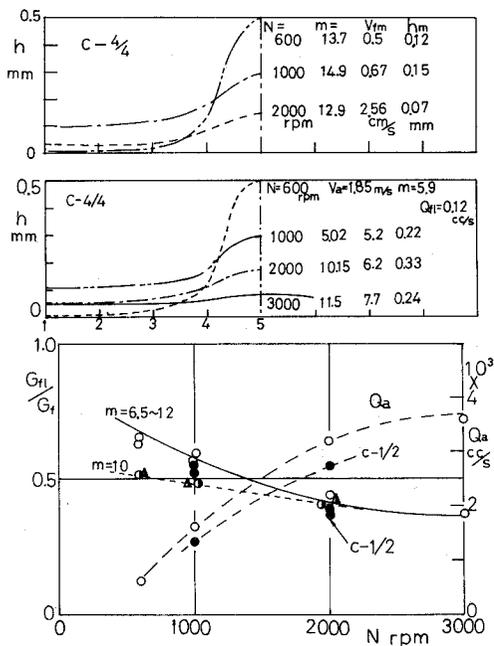


Fig. 8 Effect of engine speed on circumferential distribution of fuel liquid-film thickness (h) and fuel liquid-film flow rate ratio (G_{fl}/G_f)

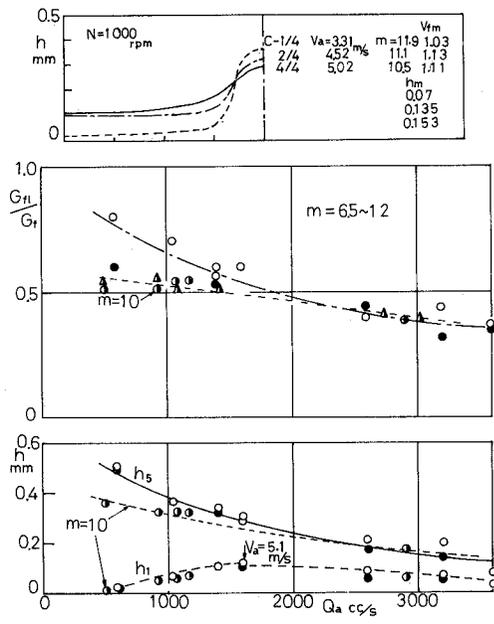


Fig. 9 Fuel liquid-film thickness (h) and flow rate ratio (G_{fl}/G_f) for breathing air amount

air, Q_a is volume flow rate of breathing air.

3.1.4 Flow Rate of Supplied Fuel (G_f)

If the flow rate of supplied fuel (G_f) is low, the liquid fuel on the pipe wall flows as drop-like form and its velocity is not high, but with the rich mixture strength, it forms fuel liquid-film flow, its velocity is also increased and its distribution in the circumferential direction results in heterogeneous as seen in Fig. 10. At this time, since the evaporation of fuel within the intake pipe is not so much altered (presumed on the basis of temperature decrease of mixture), the ratio of fuel liquid-film flow rate to supplied fuel (G_{fl}/G_f) is gradually increased. The mutual relation between this ratio (G_{fl}/G_f) and the fuel liquid-film thickness (h) (in particular, at the bottom wall) at the electrode (c) of engine side can be also observed in same figure. Such a fuel liquid-film is more easily affected by pulsating wave if the mixture is richer, the intake pipe is longer, the rotation is of lower speed, the carburettor opening is full, consequently, the liquid surface variates violently as shown in Fig. 11. Sometimes, the stagnant fuel ($h=1\sim 3\text{mm}$) appears near a nodal plane ($s=3$) of the vibration of air column in the intake pipe and the spray is produced.

This spray moves slowly within the intake pipe or disappears suddenly, then another

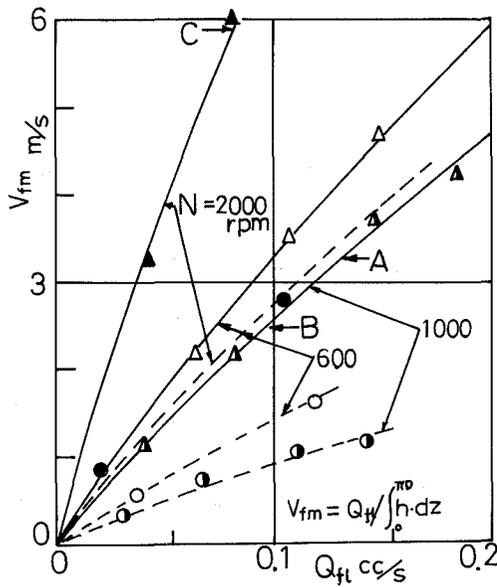


Fig. 12 Mean flow velocity (V_{fm}) of fuel liquid-film

new one is originated and so forth, the circumference being very irregular and unstable. It appears, for this reason, that the air-fuel ratio of mixture actually sucked into the engine cylinder fluctuates remarkably.

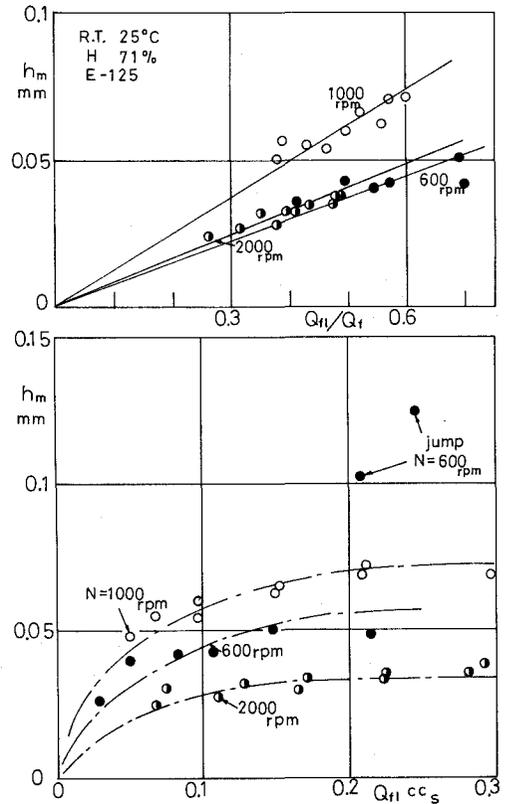


Fig. 13 Mean thickness of fuel liquid-film flow (h_m) for Q_{fl}/Q_f and Q_{fl}

3.1.5 Flow Rate and Thickness of Liquid-Film

The liquid-film flow rate (Q_{fl} cc/s) is given by

$$Q_{fl} = \int_0^{\pi D} \int_0^h V_f dh \cdot dz$$

Where it is difficult to measure directly the flow velocity of liquid-film (V_f cm/s), of which thickness is extremely thin (for example $h=0.05 \sim 0.5$ mm).

Now, Fig. 12 shows the mean flow velocity of fuel liquid-film ($V_{fm} = Q_{fl} / \pi Dh_m$) calculated on the basis of the mean thickness ($h_m = 1 / \pi D \int_0^{\pi D} h \cdot dz$) in the circumferential direction of fuel liquid-film and of the flow rate (Q_{fl}) obtained by a separator. As can be seen in the figure, although the mean velocity of liquid-film (V_{fm}) is proportional to the flow rate (Q_{fl}), it is not always proportional to the engine speed (N), i.e. the mean velocity of breathing air (V_a).

If it is assumed that the flow velocity distribution follows a law of $1/7$ power, Q_{fl} is given as follows

$$Q_{fl} = \beta V_a \int_0^{\pi D} h^{8/7} \cdot dz$$

It seems that this is caused by the increased mean flow velocity, because, under the

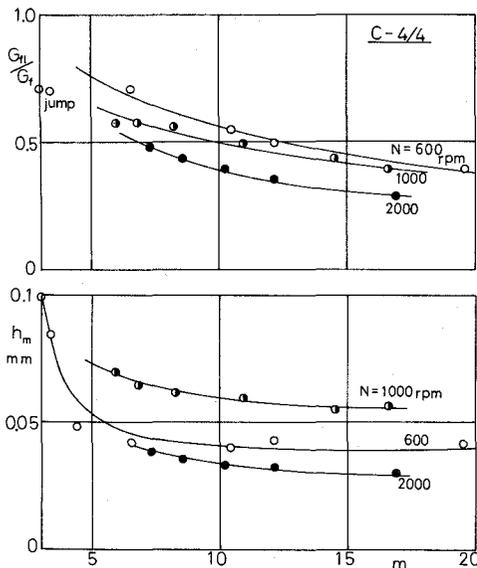


Fig. 14 Fuel liquid-film flow rate ratio (G_{fl}/G_f) and mean thickness (h_m) for mixture strength (m)

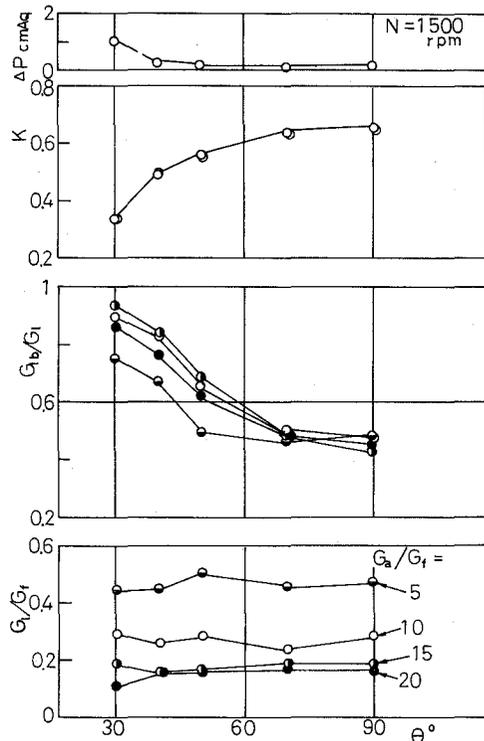


Fig. 15 Distribution of fuel liquid-film flow and carburettor opening (θ)

influence of the gravitational force, the liquid-film on the bottom wall becomes remarkably thicker and it results the increase of its flow velocity in spite of lower air velocity (V_a) as 600rpm. In the same figure, the mean flow velocity (V_{fm}) determined from the time lag in the beginning of fuel liquid-film flow, which is observed with electrodes at three points (a, b, c.) when the engine has started (A in Fig.) and the value (B) obtained by a method to supply fuel rapidly by means of rapid ascent of the float chamber are also indicated. Since the mean flow velocity (V_{fm}) under pulsating flow is slow as observed in this figure, it thus appears that even with a practical length of intake pipe, there exist several seconds of so-called manifold lag. In addition, the mean thickness (h_m) is proportional to the ratio of fuel liquid-film flow rate to supplied fuel (Q_{fl}/Q_f) as shown in Figs. 13 and 14, so that it is possible to estimate, by contraries, Q_{fl}/Q_f from the measured value of h_m .

3.2. Distribution of Fuel Liquid-Film Flow under Stationary Operation.

3.2.1 Opening Angle of Carburettor (Θ)

If the engine speed (N) and the mixture ratio (G_a/G_f) are kept a constant, the delivery ratio (K) shows a tendency to increase in proportional to the opening angle of throttle valve (Θ), on the other hand, the declination of boost pressure (Δp) between both cylinders (B, C) decreases with that as shown in Fig. 15. On this occasion, the ratio of the fuel liquid-film flow quantity ($G_l = G_{lb} + G_{lc}$) to the supplied fuel (G_f), the so-called fuel liquid-film flow quantity ratio (G_l/G_f) is little changed. However, at 1500 rpm, a throttle settling of 90 degrees (that is full opening), the amount of liquid-fuel flowing into the cylinder B, in other words, G_{lb}/G_l is less than 0.5. On the other hand, when the opening angle of carburettor (Θ)

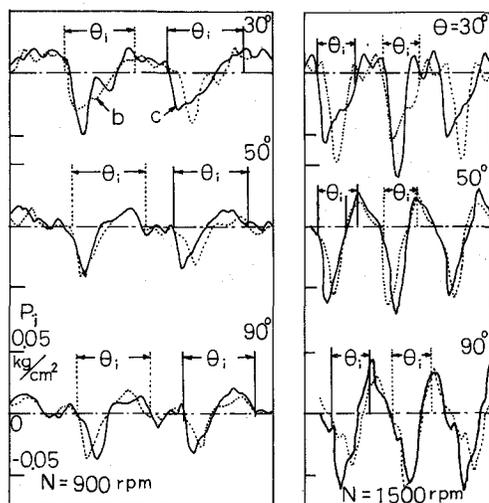


Fig. 16 Pressure variation in intake pipe (P_i)

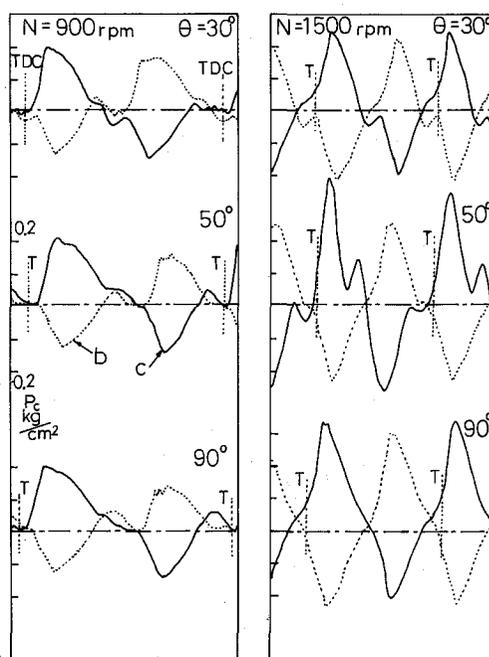


Fig. 17 Pressure variation in crankcase (P_c)

is smaller than 50 degrees, the more fuel liquid-film flows rather into the cylinder B side, namely, G_{lb}/G_l is greater than 0.5; Besides, the distribution of fuel liquid-film travelling to individual cylinder becomes rapidly poor and then the so-called distribution ratio (G_{lb}/G_l) reaches in 0.8 to 1.0 at the condition that the carburettor opening angle (Θ) equals to 30 degrees (idle setting). In this way, the experimental result that the most part of fuel liquid-film is flowed into one-side cylinder means to make the true mixture ratio in individual cylinder very ununiform, however, the pressure variations during intake process in the inlet port and crankcase of both cylinders are observed little dissimilarity as shown in Figs. 16 and 17.

If keeping a constant mixture strength (G_a/G_f), the delivery ratio (K) becomes less, and the amount of fuel liquid-film flow (G_l) diminishes because of the supplied fuel quantity (G_f) decreases with the delivery ratio (K).

But, since the ratio of the fuel liquid-film travelling on the only bottom surface to that on the whole circumference wall of intake pipe is increased by the effect of gravitational force and then the rotative flow occurs, it is resulted that the circumference distribution of fuel liquid-film becomes very ununiform as shown in Fig. 18. Consequently, it thus appears that the maldistribution of fuel liquid-film thickness has a large influence on the distribution of its flow quantity and also the smaller the absolute value of that (G_l) becomes, the larger the distribution ratio (G_{lb}/G_l) results in.

3.2.2 Mixture Ratio (G_a/G_f)

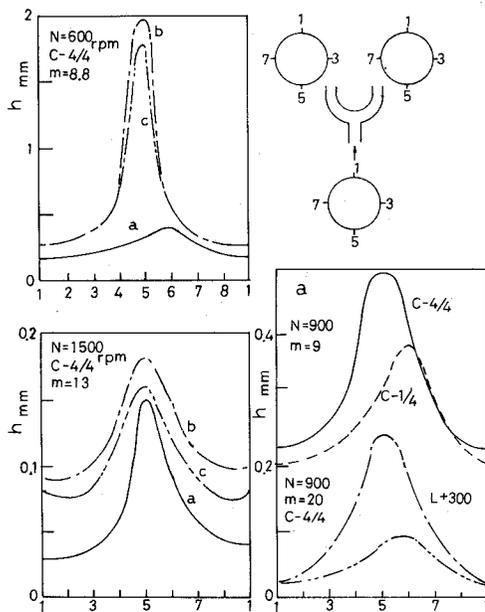


Fig. 18 Distribution of fuel liquid-film flow in each position (a, b, c)

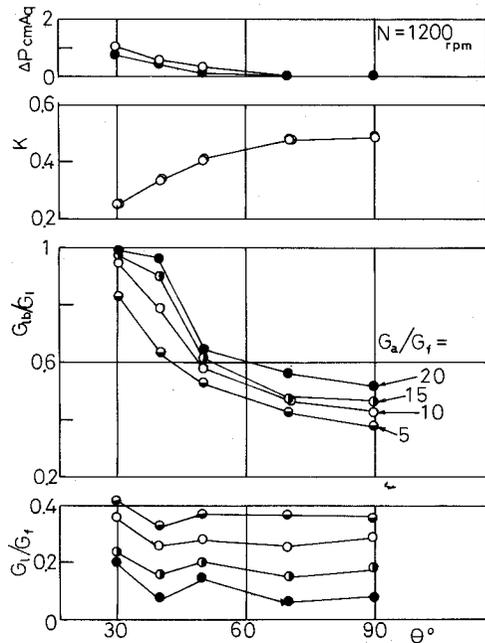


Fig. 19 Distribution of fuel liquid-film flow and mixture ratio (G_a/G_f)

When the supplied fuel quantity is gradually decreased while the other condition being kept a constant, the delivery ratio (K) is little variation as shown in Fig. 19. Consequently, the evaporation of liquid-fuel in the intake manifold is promoted so that the fuel liquid-film flow ratio (G_l/G_f) becomes less, the distribution ratio (G_{lb}/G_f) is increased. It is seemed by the reason that the leaner the mixture ratio (G_a/G_f) becomes, that is, the smaller the supplied fuel quantity (G_f) becomes, the larger the influences of microscopic shape deviation in branch part and of uniform thickness of fuel liquid-film on its distribution becomes. Now, if it is assumed that the floating fuel in intake manifold is equally divided into each cylinder, the relation between the essential mixture strength [G_a/G_f] in individual cylinder and the mixture ratio (G_a/G_f) supplied from a carburettor is given by

$$\{G_a/G_f\}/(G_a/G_f) = \{1 + \frac{G_l}{G_f} (1 - 2 \frac{G_{lb}}{G_l})\}^{-1}$$

The rough calculated result with the experimental data (G_{lb}/G_l , G_l/G_f) obtained from Fig. 19 are shown in table 3, which presents that the smaller not only the carburettor opening (Θ) and also the mixture ratio (G_a/G_f) becomes, the poorer the mixture distribution between both cylinders (B, C) becomes.

3.2.3 Engine Speed (N)

Although the delivery ratio (K) increases with the engine speed (N) as understood from Fig. 20, the fuel liquid-film flow ratio (G_l/G_f) is not almost changed within the range of this experiment (i.e. N=1200~2000 rpm). But it appears ordinarily that the increase of delivery ratio (K) acts as uniform for the circumferential distribution of fuel liquid-film thickness (h) so that, in particular, the distribution in the case of small throttle setting is improved and the change of distribution ratio (G_{lb}/G_l) owing to the carburettor opening (Θ), for example, the difference of distribution ratio between $\Theta = 30$ deg. and 90 deg. becomes small.

3.2.4 Inclined Angle (β) of Intake Manifold

As a rule, the delivery ratio (K) decreases with the carburettor opening (Θ) and also with the engine speed (N) so that the ratio of fuel liquid-film flow quantity flowing on the bottom surface to that on the whole inside wall of a horizontal intake pipe is increased by the influence of gravitational force.

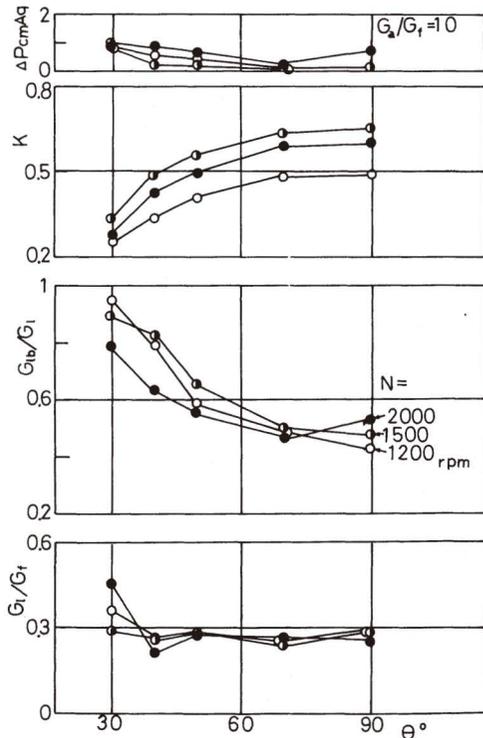


Fig. 20 Distribution of fuel liquid-film flow and engine speed (N)

On such an occasion, if the inclined angle (β) of intake manifold is changed, the distribution ratio (G_{lb}/G_l) is remarkably varied as shown in Fig. 21, for example, with a throttle setting of 30 deg., G_{lb}/G_l is changed from 0.2 at $\beta = -10$ deg. to 0.9 at $\beta = 0$ deg.. Accordingly, if a automobile engine is operated at the partial load, in addition to that, the intake manifold is slightly inclined or the mechanical vibration is occurred, it is conjectured from the result mentioned above that the distribution of fuel liquid-film flow becomes very poor and yet unsteady.

3.2.5 Inlet Pipe Length (L_s)

When the pipe length (L_s) between the carburettor and the branch part of intake manifold is very long, the delivery ratio (K) is not change at the range of $\Theta < 50^\circ$ or rather decreases at $\Theta > 50^\circ$ as shown in Fig. 22. On the other hand, since the fuel liquid-film is evaporated while flowing toward the separator, the thickness becomes gradually thin and it is resulted that the fuel liquid-film flow ratio (G_l/G_r) for the long pipe is smaller than that of the short length.

Moreover, the liquid-fuel just adhered on the pipe wall after injected out a carburettor is unsteady state and also very turbulent, but it approaches the steady state and then the turbulence is declined in proportion as the liquid-film proceeds toward the engine cylinder via intake manifold. On account of these effects, the longer the additional intake pipe length (L_s) from the carburettor to the branch part becomes, the better the distribution of liquid-film becomes.

Especially, it appears that the smaller the throttle setting of carburettor (Θ) and then the supplied fuel (G_r) are kept, the larger its effort becomes.

3.2.6 Kind of Fuel

Although the regular gasoline was mainly used, it was unavoidable from a reason men-

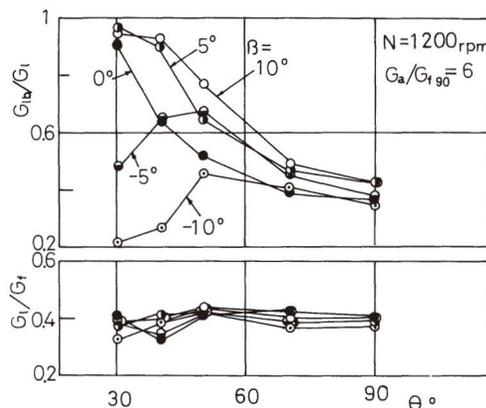


Fig. 21 Distribution of fuel liquid-film flow and inclined angle (β) of intake manifold

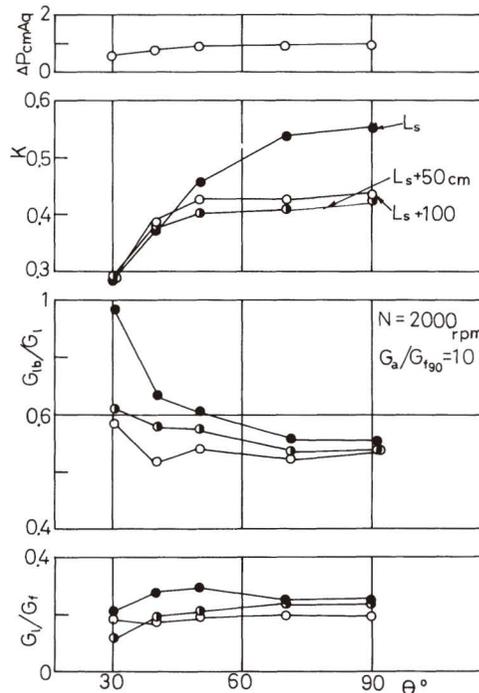


Fig. 22 Distribution of fuel liquid-film flow and intake pipe length (L_s)

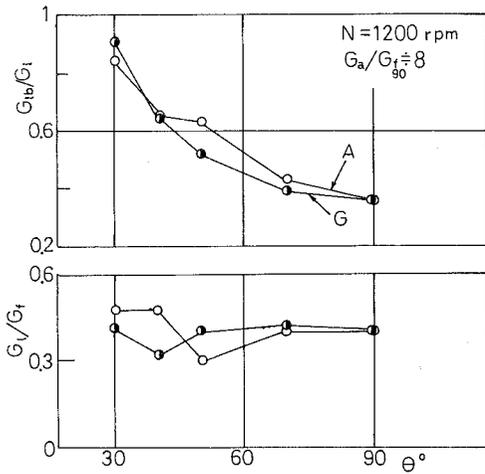


Fig. 23 Distribution of fuel liquid-film flow and kind of fuel
 A : Methanol
 G : Gasoline

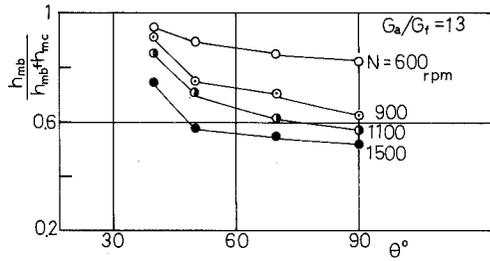


Fig. 24 Deviation of mean fuel liquid-film thickness

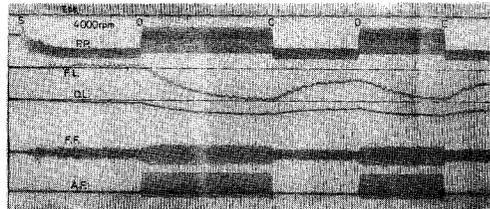


Fig. 25 Response of fuel flow (E-125)
 A. F. : Air flow rate (laminartyped flow meter)
 F. F. : Fuel rate (capacitytyped flow meter)
 P. P. : Pressure in inlet port (strain gauge typed indicator)

tioned at the experimental method so that methanol instead of gasoline was used to measure the thickness of fuel liquid-film flow (h). But, in spite of some difference of physical character between both fuel for example, latent heat, surface tension and aensity etc., it can be known from Fig. 23 that the distribution ratio (G_{lb}/G_t) is not mostly difference. In the next place, the mean thickness of fuel liquid-film ($h_m = \frac{1}{\pi D} \int_0^{\pi D} h \cdot dz$) in each point (B, C) calculated with the experimental value of its circumferential thickness and the so-called distribution ratio of fuel liquid-film thickness ($h_{mb}/(h_{mb}+h_{mc})$) are arranged against the carburettor opening (θ) in Fig. 24. As compared these with the experimental results shown in Fig. 15, the mutual relationship between the distribution of fuel liquid-film flow quantity and of its thickness is sufficiently estimated.

3.3 Behavior of Fuel Liquid-Film Flow under Transitional Operation

3.3.1 General Behavior

Generally, although such a small-sized carburettor is comparatively superior in the indicial response of fuel injected from a fuel-jet (see Fig. 25), the most of its fuel are sucked into the engine cylinder as liquid, it thus appears that the behavior of fuel liquid-film flow has a remarkable influence on, in particular, the mixture formation during a transitional runing and the mixture distribution in multi-cylinder engine. According to the experimental result in Fig. 26, it is observed that the behavior of fuel liquid-film thickness in the intake pipe (T_2 , T_3) is closely related to not only that in the scavenging passage (S_2 , S_3) and also the aspect of fuel vapour concentration (E_3) obtained from the electrical conductivity in the exhaust mixture from the cylinder.

Similarily, we operated a single cylinder engine by using methanol instead of gasoline as

fuel and recorded the behavior of the fuel liquid-film thickness as well as the maximum combustion pressure (P) while opening rapidly the throttle valve of a carburettor. The correlation between the both are observed from the experimental result shown in Fig. 27 and also it is understood that the behavior of fuel liquid-film flow in the intake manifold have a large influence on the mixture formation, that is, the combustion state during a transitional running.

Although the behavior of fuel supply condition under the transitional operation is complicated as mentioned above, it is possible to obtain easily the instantaneous flow rate of fuel practically sucked into the engine cylinder ($G_{fi}(t)$) if the fuel liquid-film thickness in the circumferential and longitudinal direction of the intake pipe are approximately uniform. Accordingly, that is roughly given by

$$G_{fi}(t) = G_f(t) - dG_f(t)/dt$$

Where $G_f(t)$ is the instantaneous fuel flow rate supplied from a carburettor, $G_{fi}(t)$ is the instantaneous fuel liquid-film flow rate. Let us now assume that the flow velocity of fuel liquid-film (V_f) is proportional to the breathing air velocity (V_a) and the former's distribution follows a law of $1/7$ power, then

$$G_{fi}(t) = G_f(t) - \beta \cdot V_a h^{1/7}(t) \frac{dh(t)}{dt}$$

If the instantaneous thickness of liquid-film $h(t)$ is actually measured, consequently, it is possible to know the behavior of difference- [$G_{fi}(t) - G_f(t)$] between practically sucked

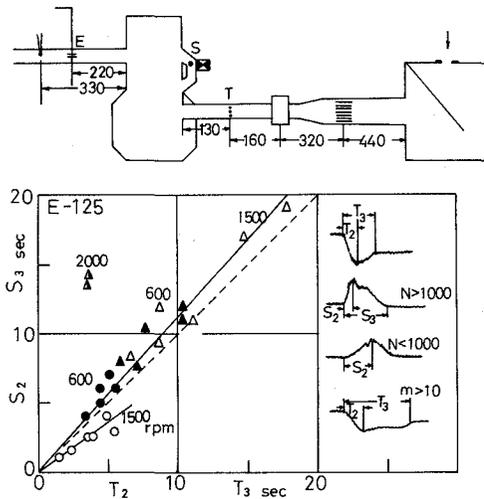


Fig. 26 Mutual relation between behavior of fuel liquid-film thickness in intake pipe, in scavenging passage

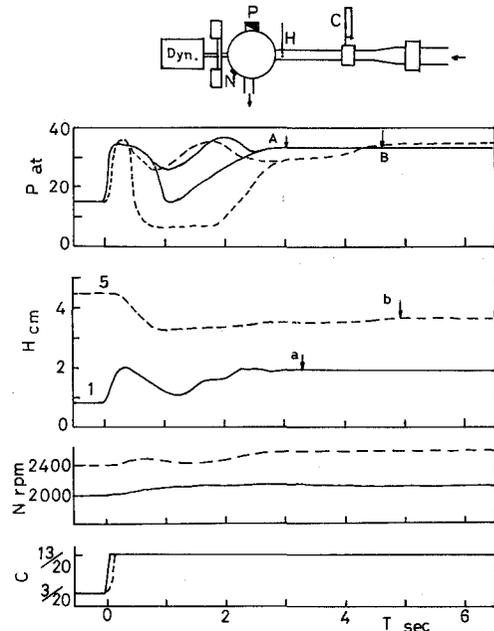


Fig. 27 Combustion maximum pressure (p) and fuel liquid-film thickness (H)

and supplied fuels. That is, when $dh(t)/dt > 0$, $G_{fs}(t) < G_s(t)$ and vice versa. With such an inference, the authors have measured the variation of fuel liquid-film thickness when the carburettor has been rapidly opened and closed. The outline of results obtained are as follows.

3.3.2 Opening and Closing Speed of Carburettor

If the throttle valve of carburettor is slowly opened, both breathing air and fuel are supplied without any time lag (see Fig. 25), but the response of fuel liquid-film flow is inferior so that the fuel liquid-film thickness attains a value at the stationary condition only after it becomes once thicker $\frac{dh(t)}{dt} > 0$ as shown in Fig. 28. Perhaps this means that the difference between sucked and supplied fuel becomes negative, at first, that is, the mixture ratio is weaker than the set-up value and then it becomes positive, consequently, richer mixture and so forth to attain finally the condition of a stationary running (this phenomenon is often realized in the case of a low engine speed and a long intake pipe). If the carburettor is rapidly opened, however, the fuel liquid-film follows the inverse course. That is, the fuel liquid-film begins to become rapidly thinner slightly after the opening of the carburettor and returns slowly to the stationary thickness after a while as shown in Fig. 29 (in the case of a high engine speed with a short intake pipe).

3.3.3 Engine Speed (N)

Since, in general, the fuel liquid-film changes as shown in Fig. 29, the influences of prescribed engine speed (N) on beginning of thickness reduction (t_1), the time (t_2) when the liquid-film becomes thinnest etc. are investigated.

Those results are included in same figure. According to the figure, the more the engine speed is high, the more the change of air flow velocity (V_a) caused by the opened carburettor

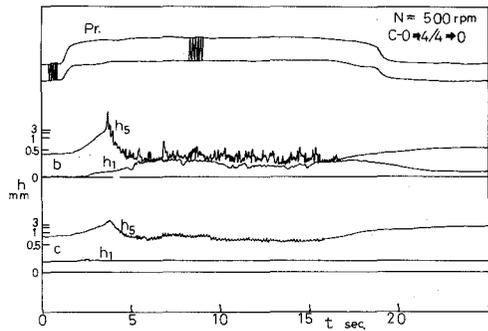


Fig. 28 Variation of fuel liquid-film thickness

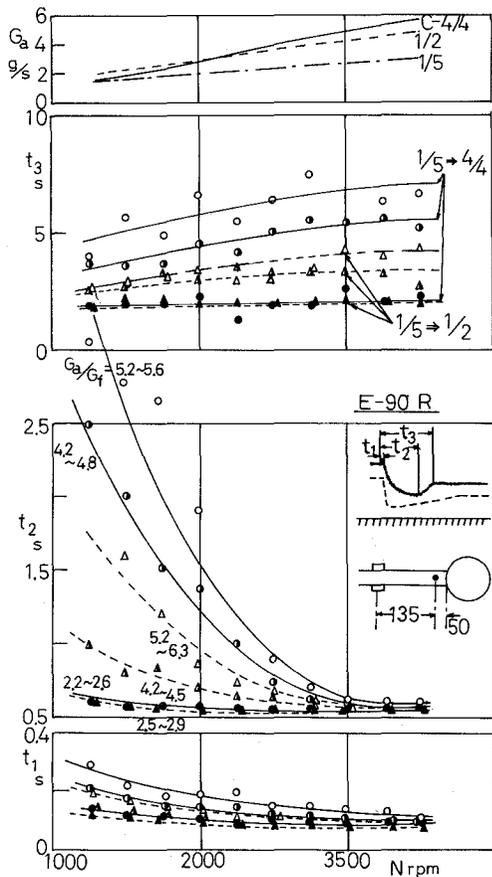


Fig. 29 Response time lag (t_1, t_2, t_3) of fuel liquid-film thickness

is larger. Consequently, the response time lag (t_1 , t_2) of fuel liquid-film thickness become shorter but on the other hand the time (t_3) which is necessary to return to a stationary state becomes longer with slow change, so that it is difficult to decide the correct value. In the next place, larger displacement (e.g. $C-1/5 \rightarrow 4/4$) of throttle valve causes larger change of fuel liquid-film thickness and larger response lag (t_2).

3.3.4 Mixture Ratio (m)

The fuel liquid-film on the bottom wall becomes thicker if the mixture is excessively rich. Under such a condition, the responsiveness of fuel liquid-film flow is comparatively better, that is $t_1 = 0.2$ sec., $t_2 = 1.5$ sec. when the mixture strength equal to 5.5. Moreover, t_1 , t_2 and t_3 increase with the mixture ratio as shown in Fig. 29. This means that the more rich condition of actual sucked mixture than set-up value continues for about two seconds and further several seconds are necessary until a stationary condition is realized. In this way, one can understand that the existence of fuel liquid-film flow in the intake pipe has a large influence on the fuel supply condition during a transitional running.

3.3.5 Carburettor Opening (C) and Pipe Length (L_s)

The response lag of the fuel liquid-film thickness (t_1 , t_2 and t_3) increase with the change of throttle valve of carburettor (ΔC) and the length of intake pipe (L_s) as shown in Fig. 29 and 30.

3.4 Distribution of Fuel Liquid-Film Flow under Transitional Operation

We recorded the history of fuel liquid-film thickness while changing rapidly the opening of carburettor (Θ) or the engine speed (N) for the purpose of knowing the qualitative behavior on the distribution of fuel liquid-film flow quantity. The typical results are presented in Fig. 31, in which show the behavior of fuel liquid-film thickness while the throttle valve of carburettor is rapidly opened or closed. Moreover, the result during an accelerating

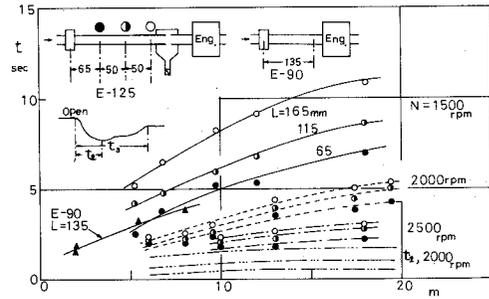


Fig. 30 Response time lag (t_2, t_3) of fuel liquid-film thickness

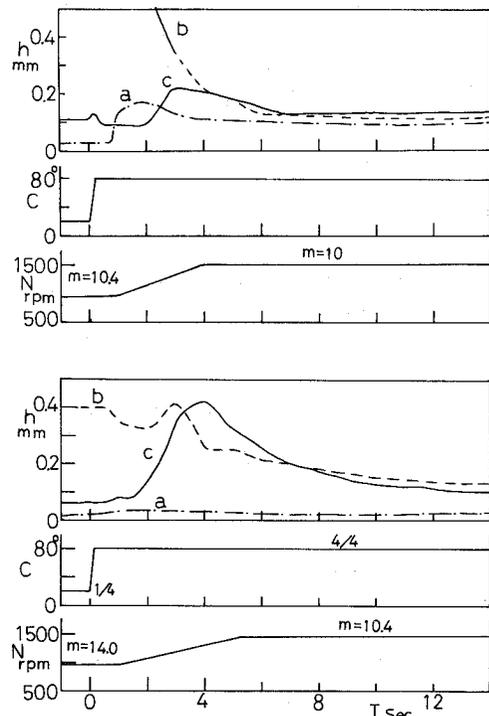


Fig. 31 Behavior of fuel liquid-film thickness during transitional operation

operation with full throttle shown in Fig. 31 shows the history of its thickness under a rapidly open throttle acceleration started from 1000 rpm. From these figures, it is seen that the thickness of fuel liquid-film flowing to individual cylinder show the differential behavior at all the engine operating condition, in particular, the thickness before the carburettor opening is changed affects largely on these behavior. Such a tendency is shown in even the case of decelerating operation as presented in Fig. 32, which shows the results during only a decelerating running with full throttle and under a rapidly close throttle deceleration started from 2000 rpm. However, since the supplied states of fuel liquid-film flow during a transitional running are complex as mentioned above, it is necessary to perform the quantitative explanation on the distribution of fuel liquid-film flow quantity and on the influence of various factors in order to eliminate a transitional state from a stationary running.

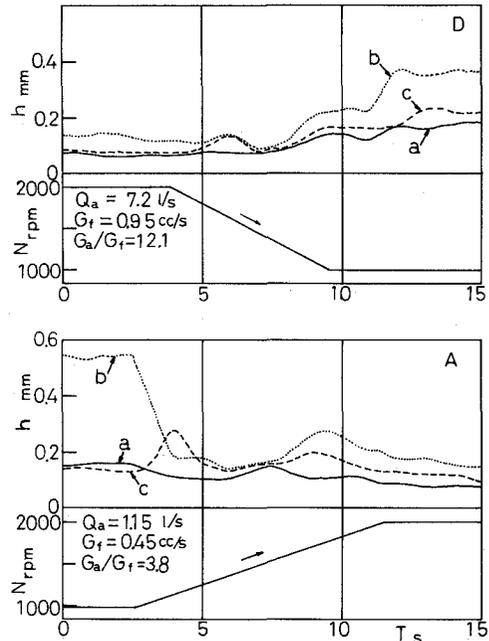


Fig. 32 Behavior of fuel liquid-film thickness during transitional.

4. Postscript

The authors have measured the fuel liquid-film thickness from its electric conductivity and the flow rate with a separator to investigate the behavior of fuel liquid-film flow a stationary operation, the influence of running condition on the fuel liquid-film flow rate. We have further inferred its fuel supply condition on the basis of the behavior of fuel liquid-film thickness under a transitional operation, pointed out that the fuel liquid-film flow has a large influence on effective mixture formation and has described, at the same time, the influence of running factors.

In general, with low engine speed and small opening of carburettor, the distribution of fuel liquid-film to individual cylinder in multi-cylinder engine is very poor. And yet, the distribution state are governed by the dimension of intake manifold and the engine operating conditions. Moreover, it is surmised from the behavior liquid-film thickness that the flow distribution during a transitional running is remarkably ununiform. Therefore, it is necessary to certify in detail the effects of various factors versus the distribution.

(Received May. 22, 1976)

References

- (1) N. Sawa, S. Hori : On the Behavior of Fuel Liquid-Film Thickness in the Intake Pipe. JARI Tech. Memo, No. 2 (Sep. 1971)
- (2) D. E. Cooper, et al. : Radioactive Tracers Cast New Light on Fuel Distribution SAE Trans., Vol. 67, 1957.
- (3) M. H. Collins et al. : A Technique to Characterize Quantitatively the Air/Fuel Mixture in the Inlet Manifold of a Gasoline Engine SAE Paper, 690515 (May, 1969)
- (4) J. S. Clarke : Initiation and Some Controlling Parameters of Combustion in the Piston Engine Proc. IME, No. 5, 1969—61.
- (5) D. R. Liimatta : Effects of Mixture Distribution on Exhaust Emissions as Indicated by Engine Data and the Hydraulic Analogy SAE Paper, 710618 (June 1971)
- (6) M. Tanaka : A Study of the Flow of Fuel Film along the Wall of the Induction Pipe (1 st Report) JARI, Technical Memorandum, No. 1 (Sep. 1970)