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AN EXPERIMENTAL STUDY ON THE IMPROVEMENT OF MIXTURE DISTRIBUTION FOR THE AUTOMOTIVE S.I. ENGINES —DEVELOPMENT OF DEVICE TO IMPROVE ATOMIZATION IN THE INTAKE MANIFOLD—

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In a fuel supply system of gasoline engines, a part of the fuel ejected from the carburetor floats in flow with high speed as dro plets in an intake manifold and the rest of it flows as the liquid film along the wall of the intake manifold and is gradually vaporized in the flow. Finally, most part of the fuel terminates the vaporization after introducing mixture into cylinders. Accordingly, it is desirable to maintain the optimum mixture ratio in conventional carburetor systems for all operating conditions of engines. The intake system including the carburetor of automotive gasoline engines which are mostly operating in partload conditions have many unsolved problms, such as the increase of specific fuel consumption and reduction of exhaust emissions due to the rich mixture in starting, acceleration and over load operations. Therefore the main purpose of the study is to develop a special device(so called Eco-Ring) for the enhancement of atomization that has ability to separate the liquid film spray flowing along the pipe wall of the intake manifold and to atomize it to fine droplets, then the device can overcome some defects which arise in the conventional carburetor systems as mentioned above.

Key Words: Spark Ignition Engine, Intake Manifold Mixture Distribution

1. INTRODUCTION

The main functions of the intake system in the automotive gasoline engine are as follows; the first is to quantitatively measure and making air/fuel mixture, and the second is to distribute mixture to each engine cylinder. For the best performance of an engine, the perfect atomization of fuel injection, the homogeneous mixing of injectied fuel with air stream, and the uniform intake of the mixture into combustion chambers are essential. If the mixture is not mixed ideally, it can increase the amount of exhaust pollutants and the fuel consumption as well.

Recently, the strict requirements of emission control and fuel economy necessarily give a strong motive for the improvement of the intake system performance. Extensive efforts have been concentrated on the studies relevant to the air fuel mixing phenomena and the effects of uniform distribution of the mixture in an engine cylinder.

When the fuel spray ejects from a fuel injection nozzle or from the carburetor in the fuel spray system of the gasoline engine, some portion of fuel spray floats as droplets along with the high speed air stream in the manifold, and the other portion flows as liquid film along the wall of intake manifold. Especially for this movement, the moving liquid film evaporates itself continuously and most part of it terminates the vaporization when the mixture is introduced into the cylinders(Park, 1982).

Therefore, the performance of the gasoline engine of an automobile largely depends on the sturcture and the function of the intake system. In other words, it is not too much to say that the power performance of the engine, drive-ability and warming-up, the problem on the fuel economy, and the air pollutant emission controls are strongly dependent on the characteristic performance of the fuel supply system.

Robert and Lalas(1977) developed a model of vaporization phenomena and heat transfer between flow air, fuel droplets and wall of the manifold. Their model was based on one dimensional steady state flow conditions. According to the model, they could solve an equation of energy or mas conservation and organization numerically, using the Bulirsh Stoer Intergration Scheme, and they found that the most efficient method was to make the size of early droplets as small as possible and to increase atomization in the stream of recirculation of exhaust gas. Besides, it is also known that the homogeneity of the air/fuel mixture influences the fuel consumption and exhaust emission, and in return the atomization degree influences the degree of uniform mixing.

Matthes and McGill(1976) reported that the degree of atomization could have considerable effect on exhaust emissions, but little effect on fuel consumption. It was suggested that the reason for the effects is that good atomization probably resulted in an essentially homogeneous air/fuel mixture, while bad and wall-wetted atomizations resulted in some form of stratification or inhomogeneity with in the charge.

Yu(1969) studied on two factors of fuel distribution in multi cylinder engines, such as the change of cycle time of mixture ratio(air/fuel) in a cylinder and the geometric change(cylinder to cylinder) of the mixture ratio in another cylinder.

In order to analyze fluid flow in a carburetor of the single cylinder engine, Baiema and Gateliff(1978) developed mathematical models for the single state and multi-state flow for the periodic and temporary conditions in the normal state.

Boan and Finlay(1979) used a model for the fuel vaporization process in the engine intake system having a carburetor

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in order to study various variation effects on the vaporization of fuel.

Lilmatta(1971) presented a new method for the study on the mixing condition originated from an intake system. Ishigami(1980) postulated that the fuel ejected from carburetors of gasoline engines was not vaporized perfectly, but the fuel was introduced into the cylinder with the air as a form of fluid particle or droplet, and the rate of vaporization influenced on the volume efficiency and the degree of uniform mixing significantly. He studied the vaporization rate of actual carburetors using a method separating liquid similar to a cyclone.

Sawa and Masayosi(1966) reported that the rate of fuel atomization of small gasoline engines depended on the length of intake pipes, port timing and throttle opening degree.

As reviewed above, a new carburetor is strongly desirable which is able to supply the mixture with the optimum mixture ratio for all operating conditions of the engine, because the increase of atomization rate in the intake system is very important. The intake system including the carburetor of automotive gasoline engines operating in part-load conditions have many problems to solve, such as the increase of specific fuel consumption and the reducton of exhaust emissions due to the rich mixture in starting, accelerating and over load conditions.

Therefore, the main aim of this study is the development of a special device for the enhancement of atomization(named Eco-Ring) that has ability to separate the liquid film spray flowing along the pipe wall of the intake manifold and to atomize it to fine droplets. The device could then overcome the defects which arise in the conventional carburetor systems as mentioned above.

2. THE BEHAVIOR OF EJECTED FUEL IN THE INTAKE MANIFOLD

Generally, the intake system of a gasoline engine consists of a carburetor, intake manifold, intake valves and so on. The carburetor is required to mix and supply fuel to the system with optimum condition for all the operational conditions. In other to supply the optimum mixture, the fuel flux ejected from the carburetor as well as the state of spray should be controlled, and at the same time, the state of flow should be understood definitely.

A part of fuel ejected from the carburetor floats as droplets in the intake manifold and is generally vaporized. However, the state of fuel spray in the engine(particle diameter, distribution and so on), the vaporization properties of fuel, and the state of liquid film flow are influenced by velocity of the suction air, pressure, temperature, humidity, flow state, length of the intake pipe and so on. Therefore, these phenomena are extremely complex. The results of this study on the fuel flow in the intake manifold are as follows(Park, 1983)

2.1 Experimental Apparatus

Figure 1 shows a basic model for an intake tube designed to investigate the behavior of ejected fuel from the craburetor. The tube is a horizontal straight one which looks like the intake system in a practical engine.

Accoriding to experimental studies, in the condition of steady flow, there are some relations among the air flow rate, the behavior of liquid film, and the atomization rate. The liquid film flow rate was measured on 400mm length of the intake tube by a separator of liquid film flow(Cyl).

The liquid film thickness was measured by the electrode probe method. The probes were set at a distance of 100mm form the ejected nozzle of the carburetor with 50mm interval between the probes.

The liquid film flow should not be affected by the probe, thus the probe was not extruded on the wall face. In this experiment the probe was symmetrically equipped in a tube. By rotating the tube 90 degree in a test section, the probe could also measure the change of liquid film thickness on 8 equally partitioned places. Then measurement was performed equally on the entire sections on a tube circle.

2.2 The Variation of Liquid Film Thickness

(1) The Variation of Liquid Film Thickness

Figure 2 presents the variation of liquid film thickness according to each position on the inside of the intake pipe, when methanol is used as fuel. As shown in the figure, a part

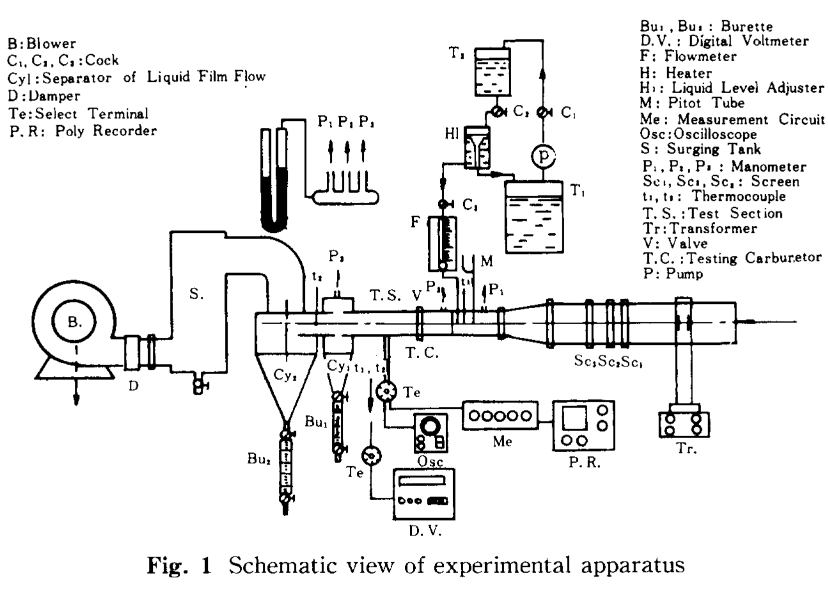

Fig. 1 Schematic view of experimental apparatus

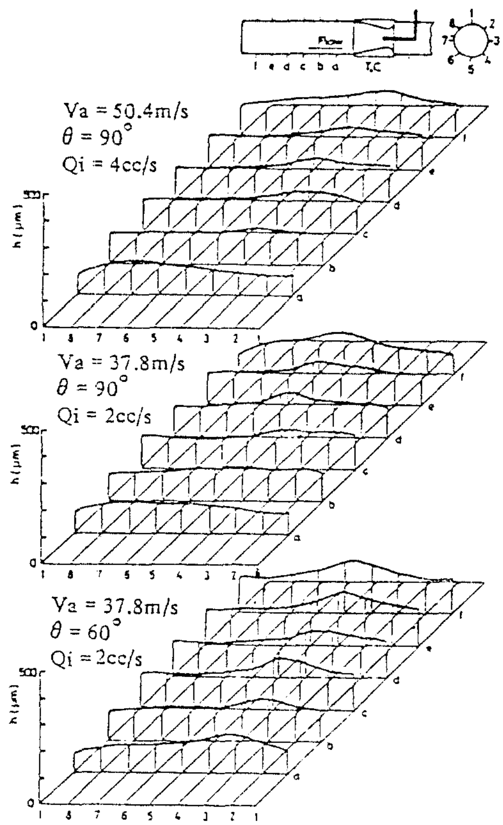

Fig. 2 Variation of liquid film thickness in test section(methanol)

For a case of the high air velocity as an effect of the throttle opening degree, the liquid film thickness is decreased on the side of higher air velocity applied and becomes thicker on the side which is affected by the throttle opening degree, i.e., the right sides(mark of circumference direction 1, 2, 3, 4) which are observed in a testing carburetor. In this case, it presents that the whole liquid film becomes thinner because of high vacuum pressure.

Therefore, as an effect of the throttle opening degree, it is revealed that its influence is getting severe with the decrease of throttle opening degree. However, the degree of throttle opening is not changed significantly in the region of 300mm downstream from the carburetor so that the distribution of liquid film thickness at circumferential position is almost constant.

(2) The Variation of Mean Liquid Film Thickness

Figure 3 shows variations of the mean liquid film thickness for each amount of flow at various air velocities. In this figure, when the amount of ejected fuel is fixed at constant flow, the mean liquid film thickness is decreased with the increase of the air velocity. And also, it is found that this trend becomes more remarkable with the decrease of the amount of ejection fuel.

2.3 The Variation of Liquid Film Flux

(1) The Influence of Air Velocity in the Intake Pipe

The experimental results show that the rate of liquid film of the fuel ejected from the carburreor was attached to the inside wall nearby(in front of) position "a" located at a distance of 100mm from the ejection nozzle, an the liquid film is formed there. As the liquid film is attached to the inside wall, the liquid film thickness is increased gradually by the influence of gravity, and the remarkaby trend was shown in case of low speed. Besides, when the throttle valve is not fully open, the effect on the degree of throttle valve opening, and the liquid film thickness along the position of intake pipe are nearly not dependent on the opening degree of the throttle valve in low air velocity, but are affected by high air velocity.

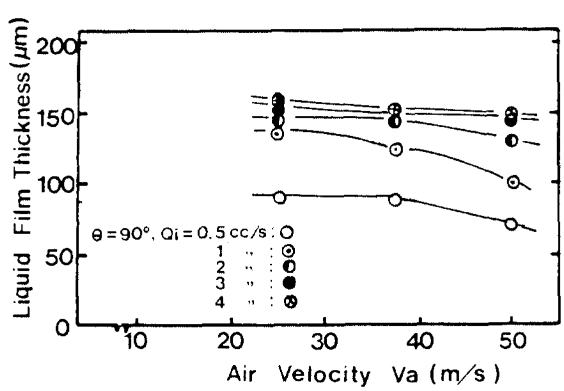

Fig. 3 Effect of air velocity on mean liquid film thickness for $\theta=90°$

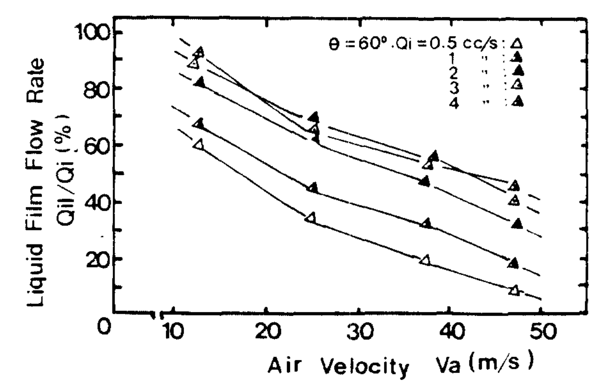

Fig. 4 Effect of air velocity on mean liquid film flow rate for $\theta=60°$

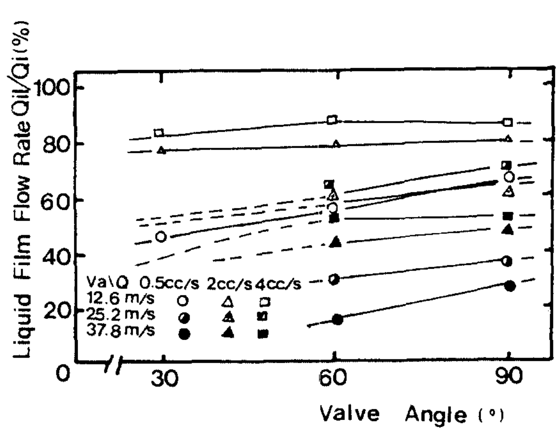

Fig. 5 Relationship between liquid film flow rate and throttle opening

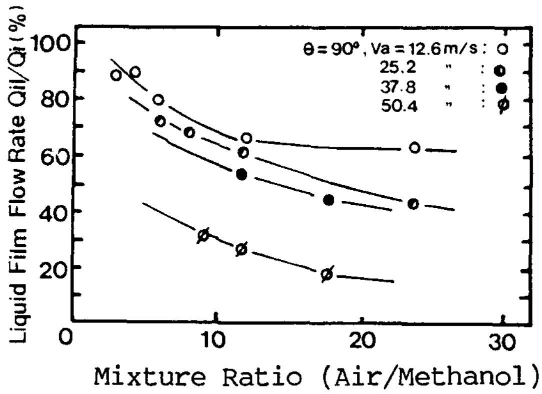

Fig. 6 Effect of mixutre ratio on liquid film flow rate at constant throttle opening

flow is the ratio of the amount of ejected fuel to the amount of liquid film fuel. Figure 4 show the relationship between the mean air velocity in the intake pipe and the liquid film flow is decreased with the increase of the air velocity. And when the air velocity is constant, the rate of liquid film flow is increased with the increase of the amount of ejected fuel.

(2) The Influence of Throttle Opening Degree

Figure 5 presents the relationship between the rate of liquid film flow and the amount of ejected fuel accroding to the throttle opening degree. In the figure, the rate of liquid film flow is increased gradually with the change of throttle opening degree, and finally, the effect becomes almost negligible when the amount of ejected fuel flow is quite little.

(3) The Influence of Mixture Ratio

Figure 6 illustrates a comparison of liquid film flow rate with the mixture ration at various air velocities. In the figure, at both high air velocity and low air velocity, the rate of liquid film flow is decreased depending upon the increase of the mixture ratio, and it could be shown that the trend is remarkable in case of a rich mixture.

3. THE TRIAL MANUFACTURE OF THE DEVICE FOR THE ATOMIZATION PROMOTION OF INDUCED FUEL

3.1 The Trial Manufacture of Eco-Ring

In this study, the Eco-Ring was devised in order to increase the atomization rate of liquid film flows as one of improved methods of controversial points, mainly on the liquid film flow, which are all defects that the intake system included. Regarding the shape of liquid'droplets, there are several kinds of model which produce the liquid droplets by breaking up liquid. However, in this study, in the case that the liquid film is broken up, the author postulates the breakup mechanism of liquid film(Sato, 1971; Adelberg, 1968; Mayer, 1961) called the subject of improved method. Figure 7(a), (b) and (c) represent the cross section of three typical kinds of the Eco-Rings which are specially devised by the author. Henceforth, (a), (b) and (c) is named as Eco-Rings of T0 type, T1-type, and T1-80-n type respectively.

T0 type was tried to re-break up the liquid film flow flowing along the wall of the intake manifold in the venturi throat of the Eco-Ring. This is the type installed two venturies in series in the intake mainfold of the multi-venturi type carburetor.

T1 type differs from T0 type in having 1mm clearance between the intake pipe wall and the Eco-Ring and in setting small holes(dia., ; 2mm) in the circumference of the venturi throat of the Eco-Ring. Therefore, T2 type was tried to promote the atomization of the mixture by re-ejecting and breaking up the collected liquid film flow along the pipe wall through the clearance of 1mm.

T1-80-n type has n(n=4, 8, 12, 24, 30, 36) small holes(dia. ; 1.5mm) around the venturi throat. It is tried to enhance the atomization rate by re-ejection and re-break up the collected liquid film flow.

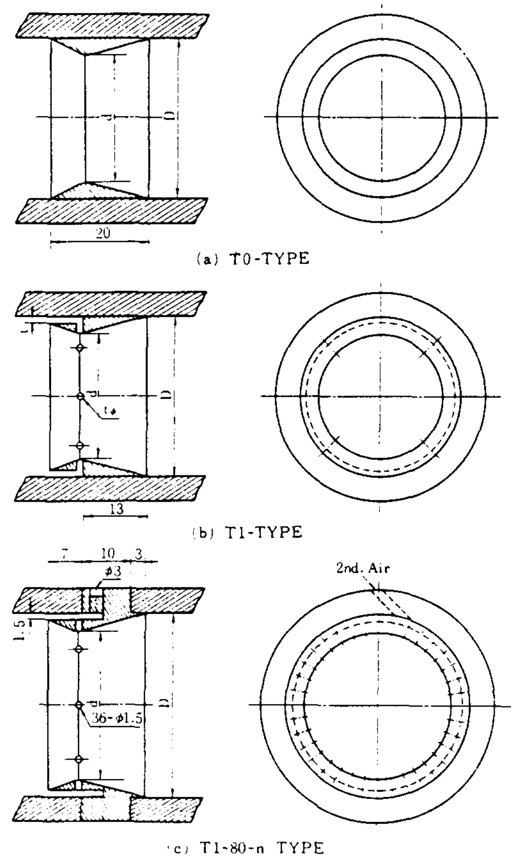

Fig. 7 Type of test rings

3.2 The Experiment of Element Function

(1) Experimental Apparatus and Procedure

Figure 8 shows a schematic diagram of the experimental apparatus for testing elementary function of the Eco-Ring. The body of this apparatus is a sort of visible straight tube type model an the hypothetical intake manifold similar to the engine practically being used.

By using the apparatus, it was observed the behavior of ejected liquid toward air flow in the pipe. Thus, the atomization rate of ejected liquid was obtained.

The Eco-Ring was set at a distance of 250mm from the ejected nozzle and the liquid film flow rate was measured by a mass cylinder (M2) at the point of 50mm from the Eco-Ring.

In this paper, the atomization rate is defined as the ratio of

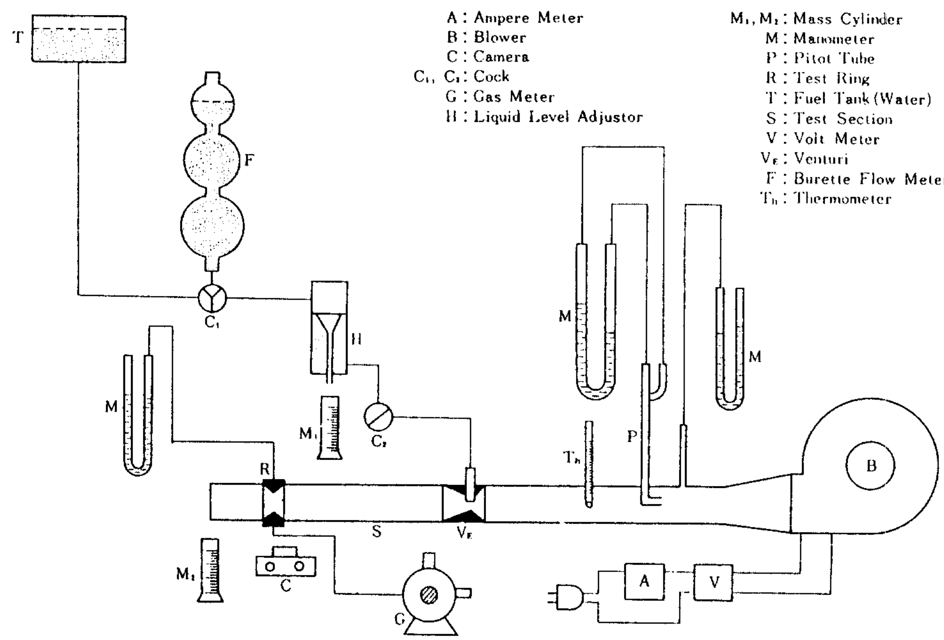

Fig. 8 Schematic view of experimental apparatus

total ejected liquid flow rate minus total liquid film rate divided by total ejected liquid flow rate. Here, atomized liquid means vaporzed liquid plus droplets of liquid.

Atomization rate

$$(\phi)=\frac{Q_i - Q_i 1}{Q_i}\times 100(\%)$$

where,

Q_i = Total ejected liquid(fuel) flow rate,

$Q_i 1$ = Total liquid(fuel) film flow rate

(2) The Rate of Atomization

(i) The influence of diameter ratio(d/D×100%) of the Eco-Ring

Figure 9 and Fig. 10 represent the results of experiment on the influence of the change of the Eco-Ring diameter ratio on the relationship between the atomization rate and the mixture ratio for T0 type Eco-Ring. The diameter ratio of the Eco-Ring affects the rate of atomization significantly, and it is found that the rate of atomization is increased with the decrease of the diameter ratio. Its full range of increase depends upon the shape of the rings with the exception that it is almost constant without regard to the mixture ratio. When the shape of the Eco-Ring is different, the author can conclude that the change of diameter ratio can increase the atomization rate tremendously.

(ii) The influence of mixture ratio and Eco-Ring shape

Figure 11 is an example to show the relationship between the mixture ratio and the atomization rate with constant Eco-Ring diameter. In the figure, when the diameter ratio is constnat, the atomization rates of T0 type and T1 type have been improved a little in the range of increased mixture ratio. However, in general, we could conclude that the mixture ratio does not affect the atomization rate significantly. Fig. 12 is an example of the variation of the atomization rate along with the diameter ratio of T0 type. When the mixture

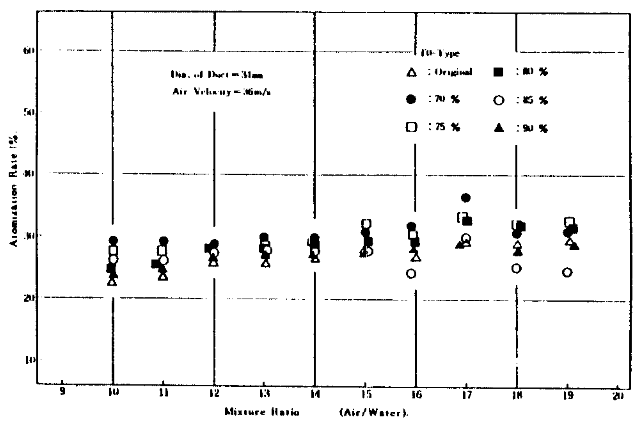

Fig. 9 Effect of ring diameter ratio on atomization rate for T0-type

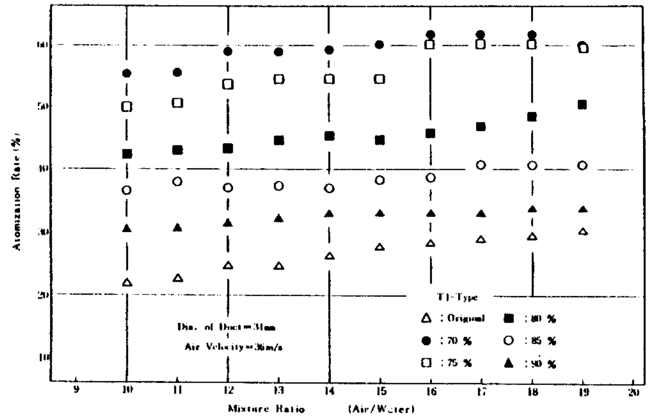

Fig. 10 Effect of ring diameter ratio on atomization rate for T1-type

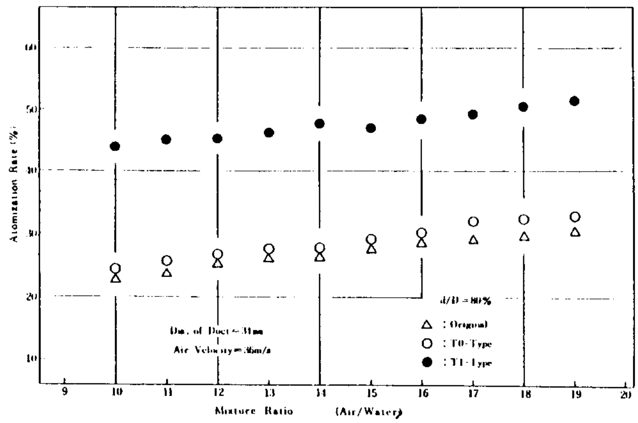

Fig. 11 Comparison of atomization rate for test ring types of constant(d/D)

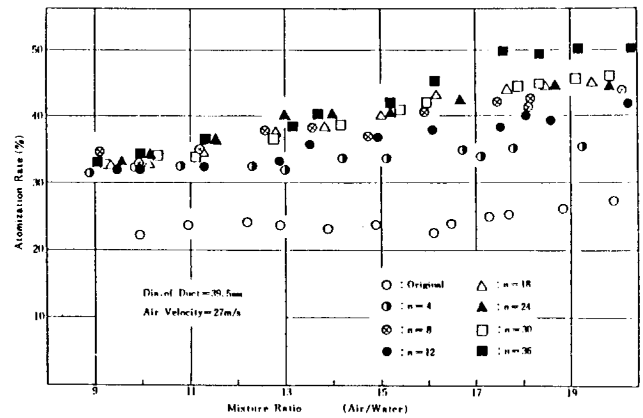

Fig. 13 Effect of hole number(n) on atomization rate for T1-89-n type ring

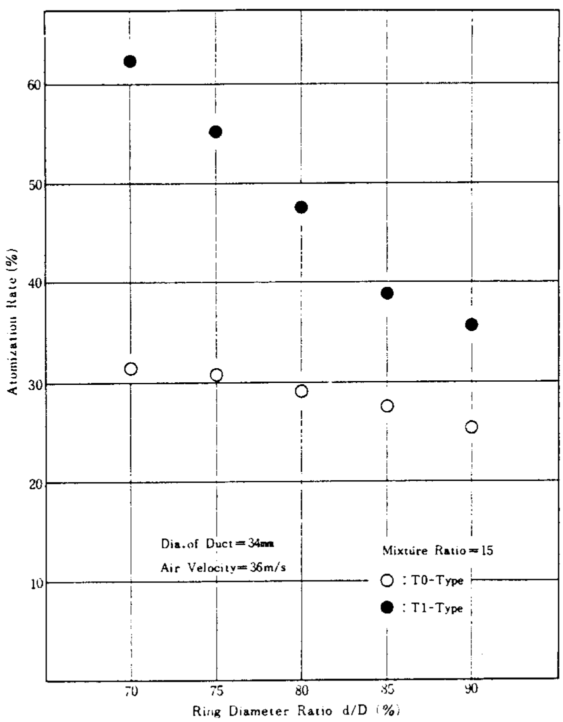

Fig. 12 Comparison of atomization rate for test ring types at constant mixture ratio

ratio is fixed, the ring shape of T0 type and T1 type affect the atomization rate in the whole sections of the established diameter ratio and the difference of the atomization rate becomes larger where the diameter ratio is small.

(iii) The influence of the number of small holes(n)

Figure 3 shows the result of the experiment on the relationship between the atomization rate and the mixture ratio, in case of changing the number of small holes. In the figure, the number of small holes affect the atomization rate ; it presents that the atomization rate increases with the increase of the number of small holes, and its full range of increase is almost the same. However, the full span growth is dependent on the increase of the mixture ratio.

(3) The Investigation of the Flow Phenomenon

In the visible straight tube model of the intake manifold, the experimental results observed are as follows ;

(i) In case of the orginal manifold without the Eco-Ring, the liquid film flow formed inside the pipe flows like a wave on the wall of the manifold at a high flow speed, and its thickness becomes thin gradually. Finally, the flow becomes a long-narrow stream with the mass of droplets, and moves into downstream.

(ii) For the Eco-Ring of T0 type, the phenomenon of liquid film flow and droplet flow in the intake manifold is similar to the original intake manifold on the whole. But the thickness of liquid film flow formed at downstream of the Eco-Ring rear by the Eco-Ring becomes thin when compared with that of the original intake manifold, and the size of droplet formed on the wall of the manifold and the size of the droplet floats in the intake manifold appear somewhat minute. When the Eco-Ring is mounted, the shape of liquid film formed at the upstream changes as follows ; the ligament type of narrow and long flow pattern is formed, and the length of liquid film flow is shortened. This phenomenon becomes significant as the diameter ratio of the Eco-Ring becomes shortened.

(iii) Especially in case of T1 type Eco-Ring, the author observed to be collected in the groove made at the space of T1 type Eco-Ring and the intake manifold wall, and the collected fuel was re-ejected and re-broken. It shows that extremely fine long flow and minute droplets are flowing along the wall of manifold. Besides, the phenomenon of flow patterns depending on the diameter ratio of the Eco-Ring is similar to the case of T0 type.

4. THE EFFECT OF ATOMIZATION PROMOTION DEVICE(Eco-Ring)

4.1 Experimental Apparatus and Procedure

Figure 14 is a schematic diagram of the experimental apparatus for experimenting the function of the Eco-Ring. In the figure, air is induced in a steady flow by a blower(CI) and fuel is ejected in the carburetor(K) through a flowmeter(Q) from a fuel tank(L). The mixture formed in the carburetor is discharged through the Eco-Ring installed at the test section and the intake manifold.

Two differernt setting positions for the Eco-Ring were selected in the intake manifold. For one case, the Eco-Ring was set just after the down stream of a throttle valve ; for the other case, just before the intake valves. These two cases being compared, the former had more efficient atomization

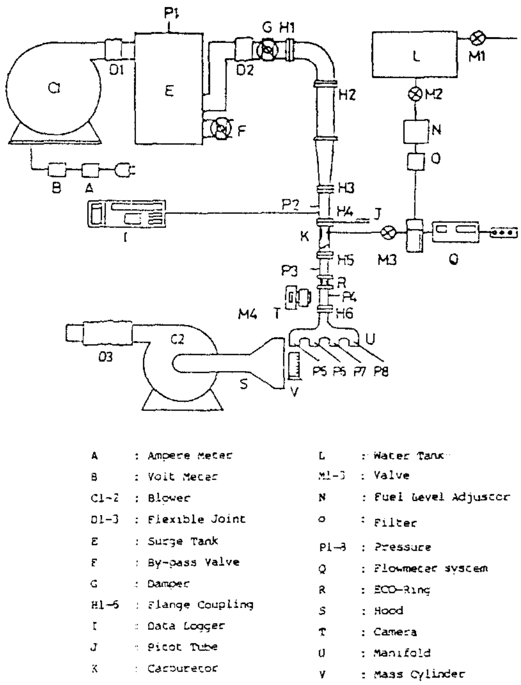

Fig. 14 Schematic view of experimental apparatus

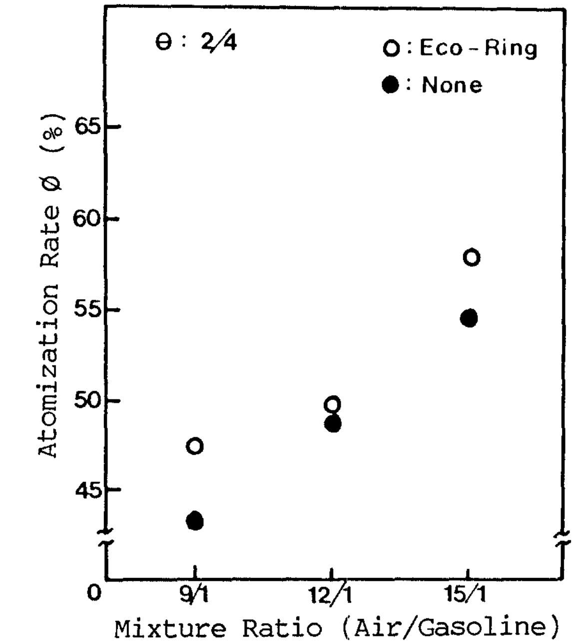

Fig. 16 Atomization rate with and without the Eco-Ring

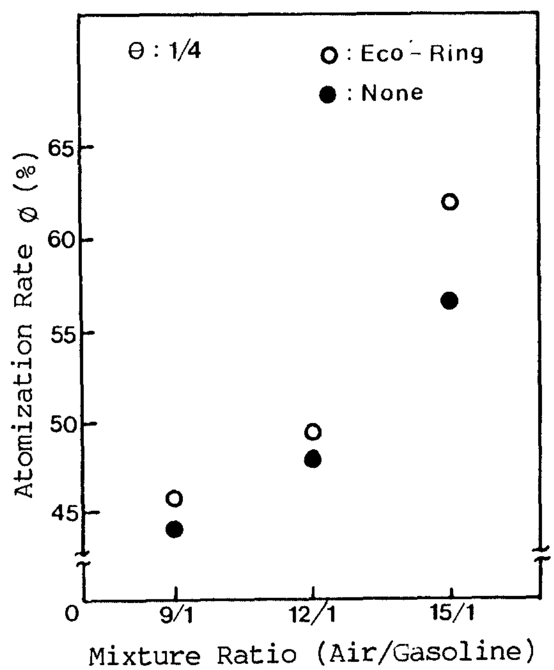

Fig. 15 Atomization rate with and without the Eco-Ring

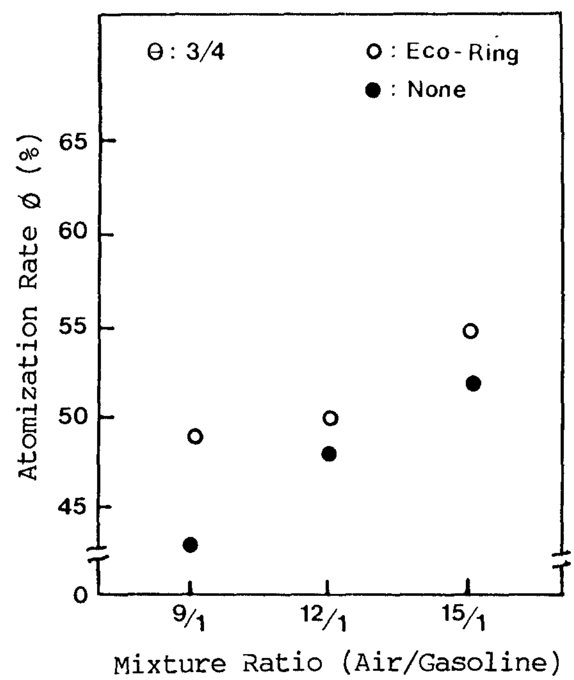

Fig. 17 Atomization rate with and without the Eco-Ring

rate and better uniform distribution for the mixture in each cylinder.

The cylinder number(i) is labelled by arranging order from the left outlet of the intake manifold for a 4 cylinder engine.

4.2 The Effect of Atomization

Figures 15~18 show the effect of atomization in case using the Eco-Ring, when gasoline is ejected in the air flow by the main nozzle in the carburetor. In those figures, the effect of atomization by the Eco-Ring becomes high in the whole range of the mixture ratio. When the throttle opening degree(θ) is large, the effect of atomization is high in the ratio of the rich mixture, and when the throttle opening is small, the effect of atomization is high in the lean mixture.

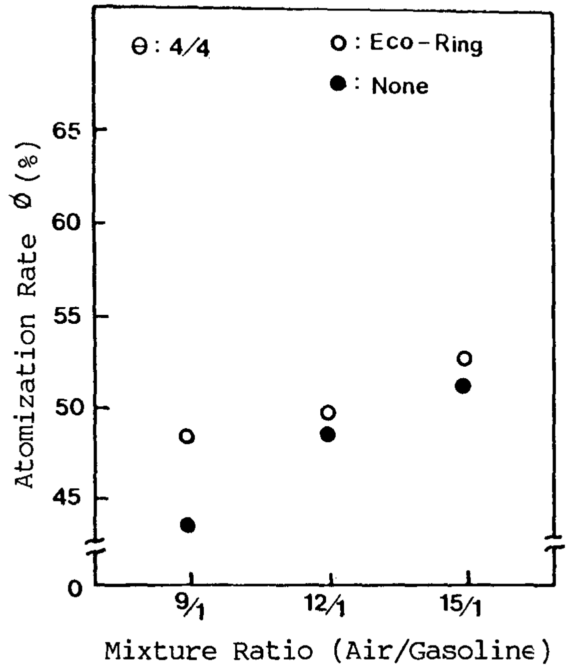

Fig. 18 Atomization rate with and without the Eco-Ring

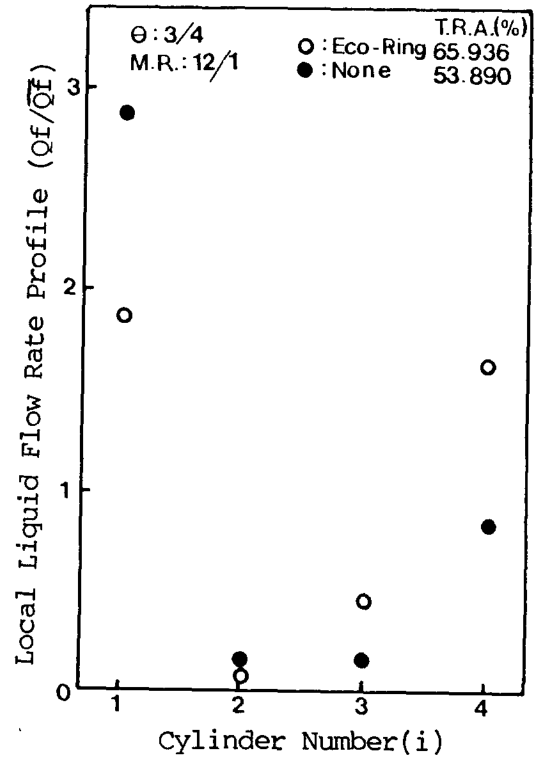

Fig. 20 Distribution characteristics with and without the Eco-Ring

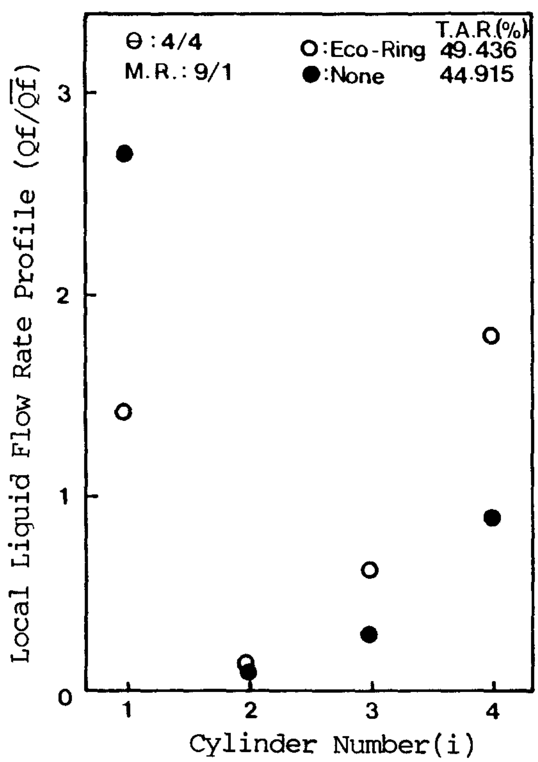

Fig. 19 Distribution charateristics with and without the Eco-Ring

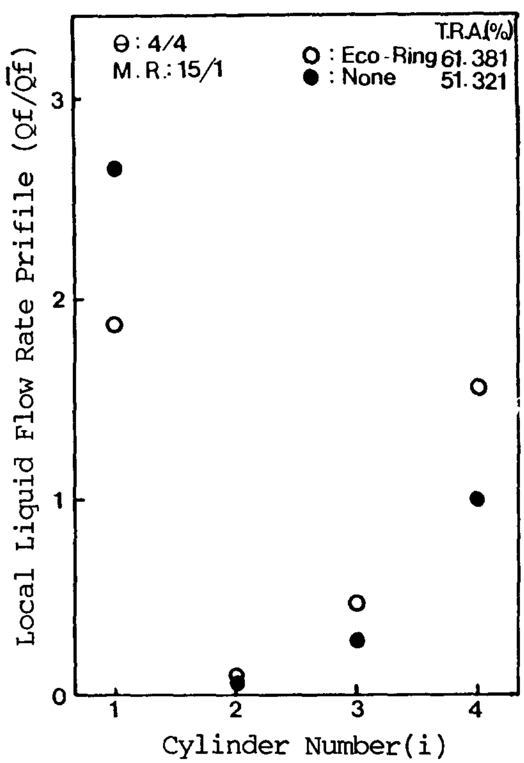

Fig. 22 Distribution characteristics with and without the Eco-Ring

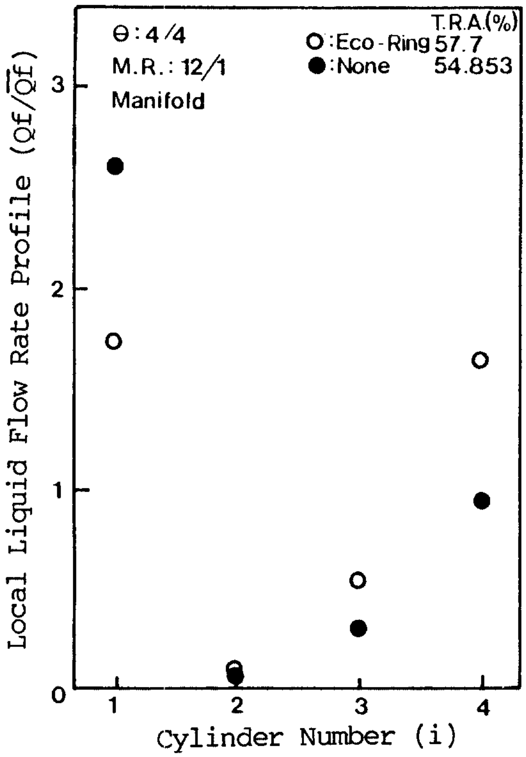

Fig. 21 Distribution characteristics with and without the Eco-Ring

4.3 The Effect of Uniformity Distribution

Figures 19~22 show the effect of distribution of mixture the mainfold with and without the Eco-Ring.

The local liquid film flow rate is defined as the actual liquid film flow rate to each cylinder divided by the mean liquid film flow rate to each cylinder. Here, the mean liquid film flow rate to each cylinder means the total liquid film flow rate divided by the number of cylinders(in this case, 4). As shown in those figures, in the case of the former, the liquid film flow ejected into each cylinder for every experimental condition is found to be uniform depending highly upon the geometrical shape. Moreover, the total rate of atomization(T. R.A) was improved for the whole conditions (Cha and Park, 1987).

5. CONCLUSIONS

(1) By constructing the visible straight tube model of the intake manifold which is imagined after the fuel supply system of the conventional engine, the author could investigate the visible phenomena on the liquid film flow of methanol fuel. When the author observed the behavior of ejected fuel from the carburetor, the thickness of liquid film was found to be formed uniformly on the wall of the pipe as the air flow rate increases, and thereafter, the liquid film became thin gradually. Moreover at low flow rate, the fuel flows in the form of thicker liquid film at the lower part of the pipe than at the upper part.

(2) The test for the newly devised Eco-Ring was found to be very effective for breaking up the liquid film flow of fuel in the intake manifold. And the author could increase the atomization rate of the fuel spray remarkably in the inside of the intake pipe by optimally choosing the shape of the Eco-Ring. In case of using the Eco-Ring of T1-80-36 type, the rate of atomization was higher than that of the system without Eco-Ring.

(3) The distribution of mixture is affected by the throttle opening and its shape. The liquid film is uniformly reached the manifold circling along the intake mainfold in the downstream rear of the carburetor. By mounting the Eco-Ring at the optimum position near the carburetor, the author can obtain the useful result of better atomization rate as well as the improvement of homogeneous distribution of mixutre in the manifold by rejecting the liquid film fuel.

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