Low Exhaust Emission System for Small Two-Stroke Cycle Engines

Yoshio Kobayashi*1 Kazuyuki Uenoyama*1
Yukiteru Yoshida*1 Kazunori Kudo*2
Hiroyuki Endo*3

Emission regulations for small utility, lawn, and garden equipment engines went into effect in 1995 in the U.S. Tier 2 standards of the California Air Resource Board (CARB) went into effect in 2000. Reducing emission of small two-stroke cycle engines is thought to be difficult due to incomplete scavenging. Two-stroke cycle engines have many features favoring handheld equipment, so we studied new scavenging system to meet emission standards. We found that hydrocarbon (HC) emission could be reduced to about one third that of conventional engines, meeting the standard. This paper describes the new scavenging technology and the development of 5 new TLE series engine models.

1. Introduction

In recent years, the request for low exhaust emissions and high thermal efficiency has become stringent in many countries for the purpose of environmental protection. In the State of California, USA, Tier 2 emission regulations went into effect in 2000. Because of their simple structure, light weight, high output, and freedom of operating attitude, small two-stroke cycle engines have been widely used mainly for handheld-power equipment. Due to incomplete scavenging, however, conventional two-stroke cycle systems emit greater HC emissions than the four-stroke cycle engines, and have difficulty meeting emission regulations. In order to solve this problem, a new scavenging system capable of remarkable reduction in HC emission was developed.

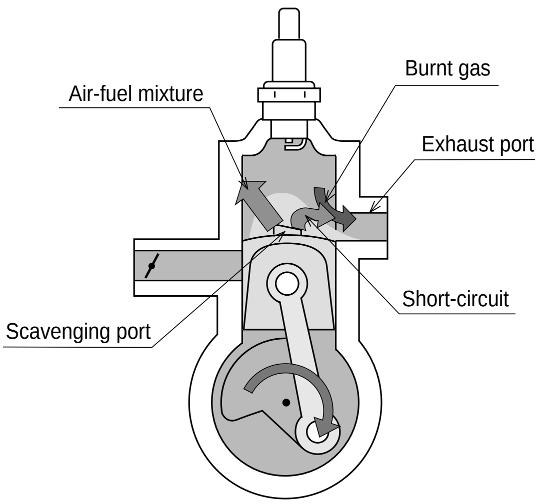

Fig. 1 Schematic drawing of scavenging flow of conventional two-stroke engine
When the scavenging port is opened, the air-fuel mixture flows into the combustion chamber. However, a part of the mixture is short-circuited out the exhaust port together with the exhaust gas.

2. Trends of exhaust emission control

In the State of California USA, emission regulations went into effect in 1995. In 2000, Tier 2 emission regulations, allowable level about one-third the conventional level, started. **Table 1** shows the standard. The Environmental Protection Agency (EPA) in the USA will also start implementing Tier 2 emission regulations in 2002, and the EC will also start implementing the regulations in 2002.

3. New scavenging system

The scavenging system of conventional two-stroke cycle engines is so called the schnurle scavenging system, and its structure and description are given in **Fig. 1**. While the air-fuel mixture compressed in the crankcase during the downward stroke of the piston is being supplied from the scavenging port into the combustion chamber, the burnt gas inside the com-

Table 1 Emission standard of CARB (California Air Resource Board) for hand-held engine

Regulation (implementation)	Engine displacement	Durability periods (h)	HC (g/kW-h)	NOx (g/kW-h)	CO (g/kW-h)	PM (g/kW-h)
Tier 1 regulation (1995−1999)	< 20 cc	-	295	5.4	804	-
	20 - 50 cc	-	241	5.4	804	-
	> 50 cc	-	161	5.4	603	-
Tier 2 regulation (2000−)	≦ 65 cc	50, 125, 300	72		536	2*

*: Applicable to two-stroke cycle engines

*1 Industrial Machinery Division
*2 Nagoya Research & Development Center, Technical Headquarters
*3 Nagasaki Research & Development Center, Technical Headquarters

bustion chamber is expelled out the exhaust port. As shown in the figure, a part of the fresh charge is unavoidably short-circuited to the exhaust port. **Fig. 2** shows the instantaneous fuel concentration of the exhaust gas passing through the exhaust port, measured by the optical method(1). In conventional two-stroke cycle engines, high density fuel components come out immediately after the scavenging port was opened, which indicates that the major short-circuiting occurs at very first stage of scavenge process.

The principle of the new scavenging system is described in **Fig. 3**. The new engine has two different intake systems, one leads the fresh air containing no fuel to the scavenging passage through the reed valve, and the other charges the mixture to the crankcase through the intake port of which opening is controlled by the piston stroke. Fig. 3(a) shows that, when the piston is near its top dead center, fresh charge is sucked from both intake systems into the crankcase decompressed to a negative pressure by the upward movement of the piston. Fresh air passes into the side passage through the reed valve, and thus, its last portion occupies the scavenging port when intake flow ceased. Fig. 3(b) shows the latter stage of the expansion stroke immediately after the scavenging port is opened. As the scavenging flow from the crankcase, compressed by the downward movement of the piston, blows into the combustion chamber, it is the fresh air (head air) in the passage that enters the chamber at first. Therefore, even if a part of it is mixed with the burnt gas and short-circuited out the exhaust port, HC will not be exhausted because it does not contain the fuel component. After that, the air-fuel mixture in the crankcase takes place as scavenging gas, to be charged in the combustion chamber. This system as described above, use of two kinds of gas in the scavenging process, is referred to as stratified scavenging.

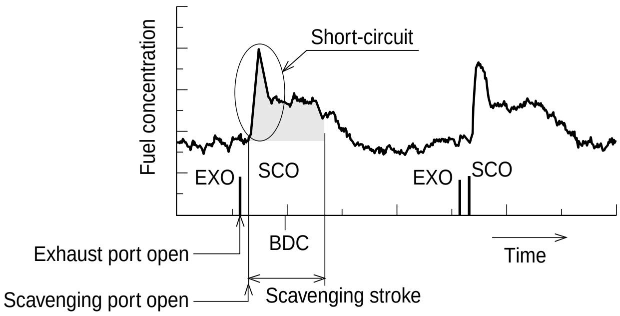

Fig. 2 Measurement of instantaneous fuel concentration at exhaust port of conventional two-stroke engine

The high density fuel components are exhausted immediately after the scavenging port is opened.

4. Scavenging flow calculations

4.1 Calculation methods

In order to calculate the scavenge and exhaust characteristics of two-stroke cycle engines, two calculation methods were used in association with each other.

4.1.1 One-dimensional performance calculation

A performance simulator for the stratified scavenging engine having two different intake systems has been developed. The simulator calculates the quantitative gas exchange at each port, caused by the pressure and the temperature change due to the piston stroke and combustion in the cylinder. The pressures and temperatures in the crankcase at the

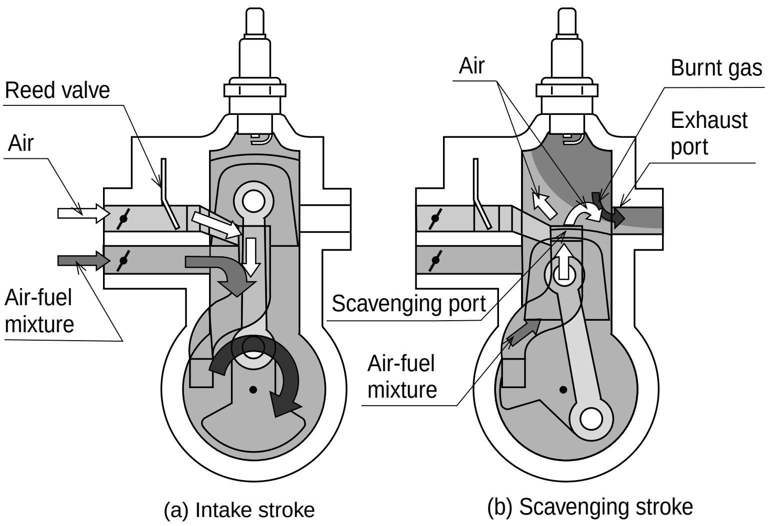

Fig. 3 Schematic drawing of gas exchange process of stratified scavenging system

The stratified scavenging system has two intake systems, one for fresh air and the other for air-fuel mixture. In the initial stage of the scavenging stroke, the fresh air at the scavenging port first flows into the combustion chamber.

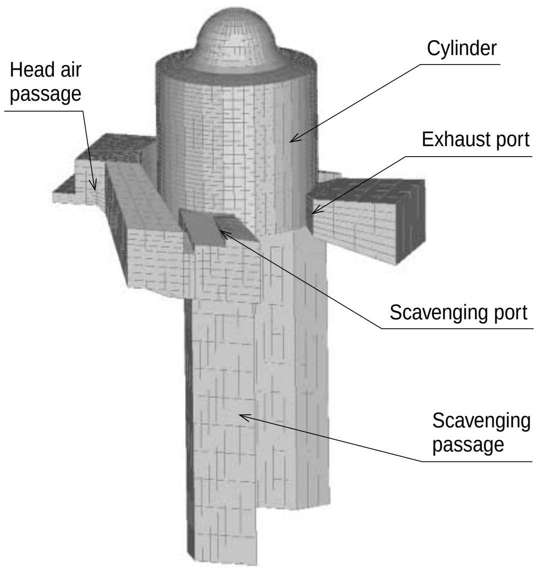

Fig. 4 Calculation model for three dimensional CFD of stratified scavenging system

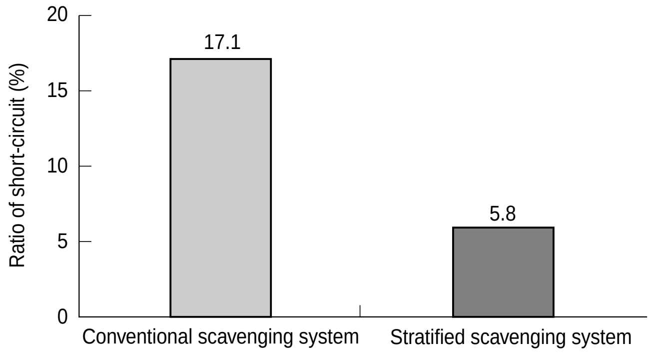

Fig. 6 Comparison of predicted scavenging performance
As compared with the conventional system, the stratified scavenging system can expect a remarkable decrease in the short-circuiting of the air-fuel mixture.

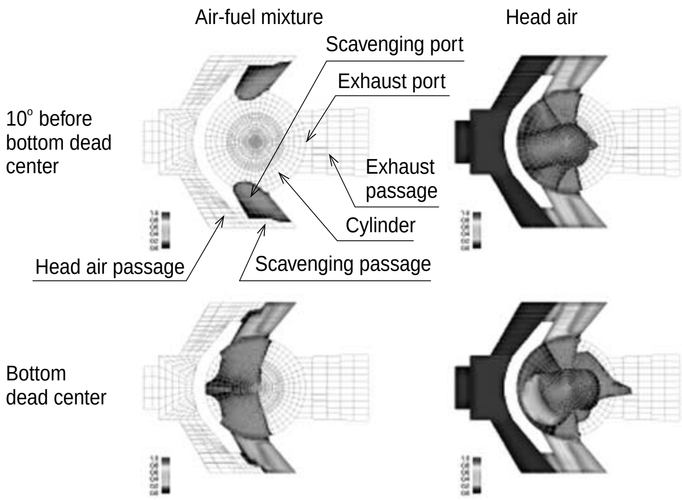

Fig. 5 Predicted distribution of mixture and head air in cylinder
Short-circuiting of the mixture is suppressed because head air short-circuites to the exhaust passage ahead of the mixture.

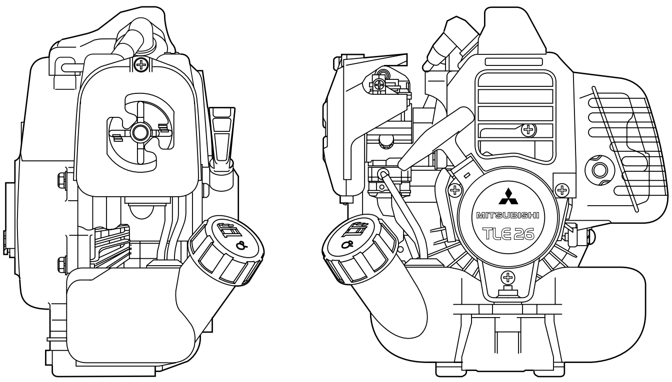

Fig. 7 External appearance of test engine

intake and exhaust ports thereby calculated were used for the boundary conditions of the three-dimensional CFD analysis in the next paragraph.

4.1.2 Three-dimensional CFD

The flow characteristics in each port and in the cylinder were predicted by adopting the three-dimensional CFD .

KIVA3V code[(2)] was used for CFD. Some modifications of the Code, such as continuous multi-cycle calculations or simplified blow down modeling of the burnt gas to the scavenging passage was made, for the analysis of two-stroke cycles engines. **Fig. 4** shows the calculation model.

4.2 Results of calculations

By the view from the upper side of the cylinder, the time history of air-fuel mixture and head air distribution is shown in **Fig. 5**. It can be well understood that the head air flows into the cylinder in earlier stage of scavenging process, and short-circuits to the exhaust passage. Because the air-fuel mixture flows into the cylinder following after the head air, the possibility of short-circuiting can be reduced remarkably.

Using this three-dimensional analysis, the volume of short-circuited air-fuel mixture of the conventional system was compared to that of the stratified scavenging system. The results are as shown in **Fig. 6**. A remarkable increase in trapping efficiency of air fuel mixture can be expected by the stratified scavenging system as compared with the conventional system.

5. Test results

5.1 Test engine

Using a test engine of 26 cc displacement, the performance, exhaust gas emissions, and applicability for hand-held power equipment were evaluated. **Fig. 7** and **Table 2** shows the external appearance and the major specifications of the test engine. The lubricating oil is mixed with fuel in a tank, and supplied to the engine by a carburetor. Two intake systems, one for air fuel mixture, and the other for head air, are controlled incorporated by throttle valves in each passage. For the ignition device, a CDI (Condenser

Table 2 Specifications of test engine

Type	Crankcase compression type
Cylinder number	1
Bore (mm)	33
Stroke (mm)	30
Displacement (cc)	25.6
Geometric compression ratio	10
Crankcase compression ratio	1.4
Ignition timing	40° (before top dead center/8 000 min^{-1})
Lubricating system	Mixed oil lubrication (Fuel to oil ratio 50:1)
Fuel feed system	Diaphragm type carburetor
Intake system	Two intake system (Fresh air: reed valve, Mixture: piston)

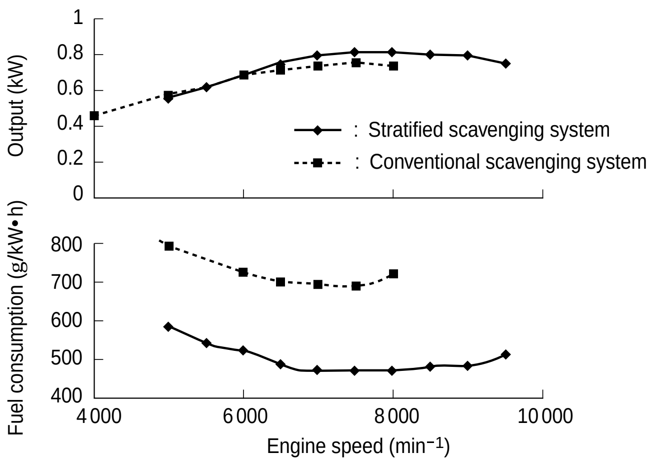

Fig. 8 Comparison of performance characteristics
By the stratified scavenging system, a remarkable reduction in fuel consumption could be obtained while an output equivalent to a conventional engine is assured.

Discharge Igniter) having spark advance function was adopted.

5.2 Performance characteristics and exhaust emission

Figs 8 and **9** show the comparisons in performance characteristics and exhaust emissions between the conventional engine and the test engine, respectively. The new stratified scavenging engine obtains an improvement in fuel consumption of approx. 35% while maintaining the same or higher output level over the entire speed range. The exhaust emissions are reduced to one-third or less for HC+NOx, and to approximately half for CO. The reduction in HC+NOx is due to a reduction in the quantity of short-circuited fuel component. On the other hand, the reduction in CO is caused by the carburetor calibration, the air-fuel ratio set to slightly leaner side. And also, as described later, the reduction in short circuiting gas, thus less dilution of burnt gas contributes to the reduction of CO, even though the CO concentration of exhaust gas is about same. **Fig. 10** compares the trapping efficiencies of air and the fuel mixture. The trapping efficiency of air is obtained from the oxygen

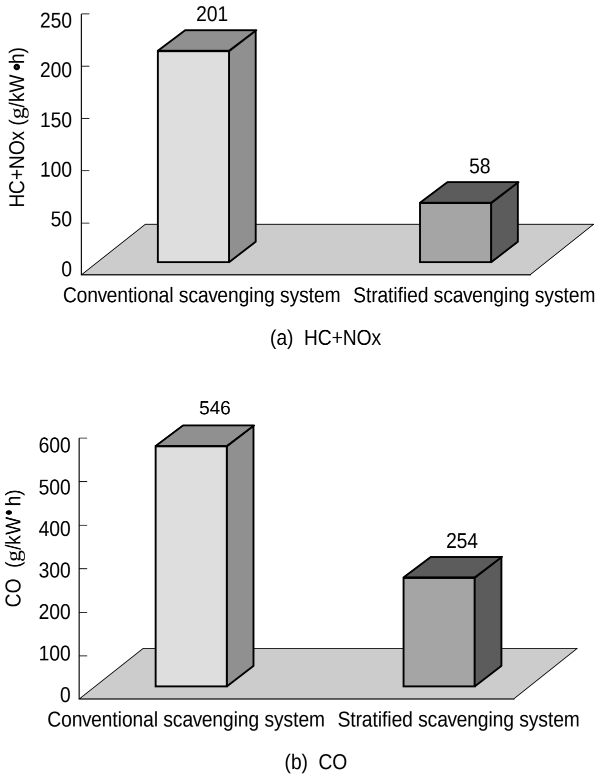

Fig. 9 Comparison of emission level
The stratified scavenging system reduces the HC+NOx by approximately one third and CO by approximately a half.

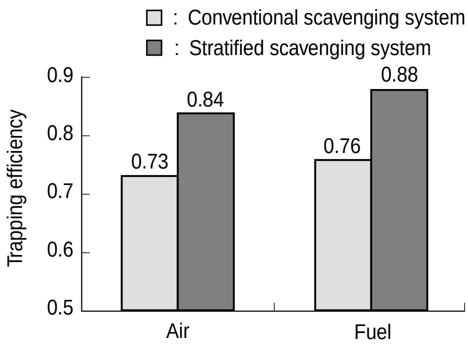

Fig. 10 Comparison of trapping efficiency of air and mixture
The stratified scavenging increases both the trapping efficiency of the fuel mixture and the trapping efficiency of the air.

concentration in the exhaust gas, and that of the fuel mixture, from the HC concentration and the fuel flow rate. From the figure, it can be found that, not only the reduction in short-circuited fuel mixture, causing the reduction in HC emission, but also the reduction of air itself was achieved about 10% or more.

6. Series of newly developed models

Stratified scavenging engines of 20 to 43 cc have been developed as a series of five models. They are named as TLE series. **Table 3** shows the major specifications of each model, and **Fig. 11** shows the appearance. Each model reduces both exhaust emis-

Table 3 Specifications of TLE series engines

Model			TLE20FD	TLE20VD	TLE23FD	TLE26FD	TLE33FD	TLE43FD
Type			Air cooled, stratified scavenging, crankcase compression, 2-cycle					
Displacement		(cc)	19.8	19.8	22.6	25.6	32.6	42.7
Max. output		(kW)	0.6	0.6	0.7	0.85	1	1.27
Fuel		(*l*)	Lubricating oil-mixed fuel (Mixing ratio 50:1)					
Fuel tank capacity			0.4	0.4	0.6	0.6	0.8	0.9
Ignition plug			NGK BPMR8Y or equivalent					
Dry weight		(kg)	2.25	2.2	2.6	2.6	3.3	4
Engine dimensions	Length	(mm)	151	128	162	162	165	174
	Width	(mm)	207	208	226	226	246	252
	Height	(mm)	225	230	240	240	256	266

TLE20FD TLE43FD

Fig. 11 Photographs of TLE series engines

sions and fuel consumption remarkably, while assuring easy handling same as conventional engines. All these models except TLE43 have already been certified by CARB.

7. Conclusion

(1) A new stratified scavenging two-stroke cycle engine has been developed. The HC emissions and fuel consumption of the engine has been reduced remarkably comparing with conventional engines.

(2) It was confirmed by the CFD and exhaust gas measurements that, in the stratified scavenging system, the short-circuiting of the mixture compositions at the time of scavenging was suppressed.

(3) As a series of the stratified scavenging two-stroke cycle engine, five models of 20 to 43 cc displacement engines have been developed.

References

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(2) Amsden, A. A., KIVA-3V: A Block-Structured KIVA Program for Engines with Vertical or Canted Valves or Canted Valves, Los Alamos National Laboratory Report, LA-13313-MS (1997)