A COMPUTATIONAL FLUID DYNAMICS ANALYSIS ON STRATIFIED SCAVENGING SYSTEM OF MEDIUM CAPACITY TWO-STROKE INTERNAL COMBUSTION ENGINES

by

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The main objective of the present work is to make a computational study of stratified scavenging system in two-stroke medium capacity engines to reduce or to curb the emissions from the two-stroke engines. The 3-D flows within the cylinder are simulated using computational fluid dynamics and the code Fluent 6. Flow structures in the transfer ports and the exhaust port are predicted without the stratification and with the stratification, and are well predicted. The total pressure and velocity map from computation provided comprehensive information on the scavenging and stratification phenomenon. Analysis is carried out for the transfer ports flow and the extra port in the transfer port along with the exhaust port when the piston is moving from the top dead center to the bottom dead center, as the ports are closed, half open, three forth open, and full port opening. An unstructured cell is adopted for meshing the geometry created in CATIA software. Flow is simulated by solving governing equations namely conservation of mass momentum and energy using SIMPLE algorithm. Turbulence is modeled by high Reynolds number version k-ε model. Experimental measurements are made for validating the numerical prediction. Good agreement is observed between predicted result and experimental data; that the stratification had significantly reduced the emissions and fuel economy is achieved.

Key words: *SI engines, scavenging, engine emissions, computational fluid dynamics*

Introduction

The civilization of any county depends on the number of vehicles used by the public. For heavy duties, diesel engines are preferred, while for individual transport, a small duty, two-stroke petrol engines are being employed. However, from the beginning, two-stroke engines have suffered from high emissions and poor fuel economy compared to the larger, heavier but more efficient four-stroke engines. The major pollutants emitted from these two-stroke spark ignition engines are carbon monoxide and unburnt hydro carbons (UBHC). Breathing of these emissions causes detrimental effects on human, animal, and plant life besides environmental disorders. Hence globally, stringent regulations are made for permissible levels of pollutants in the exhaust of two- and four-stroke spark ignition engines. A two-stroke engine is recently receiving a renewed interest in the automotive industry due to its lower weight and volume resulting in a more compact body and twice in power compared to four-stroke engines of same cubic capacity.

The short circuiting loss of fresh charge has been known ever since two-stroke engines were first made more than a century ago by Sir Dugald Clerk in 1879 equally old are all the innovative technologies and concepts that have been proposed or attempted in order to circumvent the short circuiting loss of fresh charge, as stratified scavenging through air head, exhaust gas recirculation, air assisted fuel injection, compressed wave injection (CWI), direct or indirect fuel injection, *etc*.

The charge stratified engine discovered by Rosskemp [1], Blair, [2] and Hill [3] are in another interesting design disclosed by Jackson *et al*. [4] stratification occurs in three phases air, air-fuel mixture, and air which improves trapping of fresh charge. In the year 1995 the patent work of Woolf and others [5] used poppet valve in a uniflow crankcase scavenged and carbureted two-stroke engine.

In another interesting design more or less similar to today's air head scavenging system is the invention by Douglas and Stephenson [6] and Sher [7], in which he fitted poppet valve which is fitted at the top of the transfer passage to fill the transfer passage with air during the upward stroke of the piston, poppet valve closes when the piston approaches top dead center (TDC) and fuel and air mixture is admitted into the crankcase through piston controlled intake port.

These are some of the improvements suggested and successfully implemented but only suitable for the small capacity engines. Engine manufacturers have commercialized some of the technological advancements as air-head scavenging particularly Komatsu-Zenoah [8] of Japan. An automatic ball valve admitting air from outside to the top of transfer passage for a 240 cm^3 engine is also attempted by some authors [9-12] the number of patents issued or applied for indicates the research activities pertaining to the design and application of such engines.

Experimental program

The tab. 1 shows the specifications of the single cylinder engine used for the experimentation; fig. 1 shows the modifications done to conventional spark ignition engine used for the experimentation. The two-stroke engine is altered in the basic design as another port is created in the transfer port in the vicinity of the port entrance into the cylinder and is provided with a reed valve to have unidirectional flow into the cylinder along with the charge from the crankcase and a part of exhaust gas is re circulated into the cylinder.

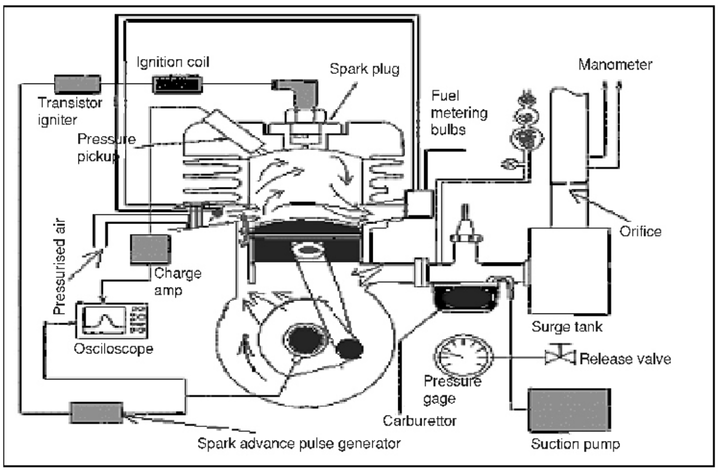


Figure 1. Experimental setup

Table 1. Engine specifications

Type	Single cylinder, air cooled, crankcase compressed schnurle loop scavenged
Bore stroke [mm]	57.5 58
Displacement [cm^3]	152
Spark timing [deg bTDC]	22 1
Ignition type	Electronic
Compression ratio	8:1
Intake port	Opens 115 deg bTDC; Closes 55 deg aTDC
Transfer ports	2
– Width height [mm]	22 12
– Timing, deg bTDC and aTDC	132
Exhaust port	1
– Width height [mm]	30 18
– Timing, deg bTDC and aTDC	103
Lubrication	Petroil mixture (3.2% 2T oil)

aTDC – after top dead centre; bTDC – before top dead centre

As the exhaust gas and the fresh air are also accommodated into the cylinder the quality of the charge that is supplied to the cylinder is too changed to have a proper and better combustion in the chamber. As the fresh air and exhaust gases are being pumped into the cylinder the fresh charge that is entering into the cylinder through the crankcase may be diluted. The carburetor is provided with the suction pump to have a rich mixture when it is needed to overcome the above problem. A filter is provided to filter the particulate matter which may reenter the cylinder. The pollutants of CO and HC emissions are recorded with Netal Chromatograph CO/HC analyzer. The photographs are shown at the end of the paper.

Modeling in CFD

The combustion chamber and the ports are modeled using CATIA. The in cylinder is meshed using Gambit and exported to Fluent 6.2.2. The flow analysis is done in Fluent 6.2.2 the commercial computational fluid dynamics (CFD) software and the results are compared with the experimental results.

The grid generated is shown in fig. 2 and the vector plot of the simulated cylinder is shown as fig. 3. The basic three equations *i. e.* conservation of mass, momentum, and the energy equations are solved and the residuals are plotted as shown in fig. 3. Here and to the good convergence is

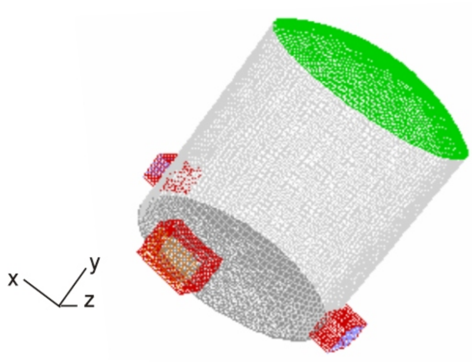


Figure 2. Computational grid of the cylinder (color image see on our web site)

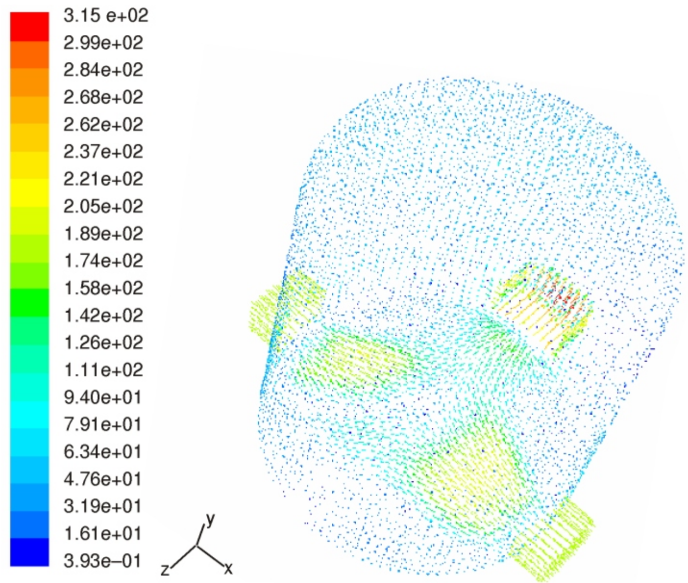


Figure 3. Velocity vectors in cylinder (color image see on our web site)

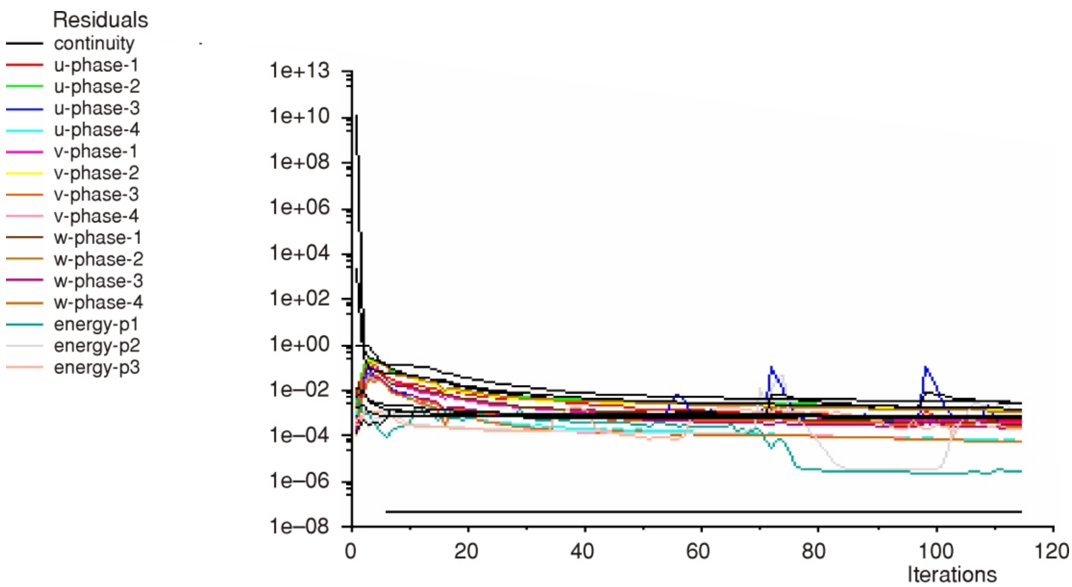


Figure 4. Residuals showing convergence (color image see on our web site)

reached. The grid is of 187,000 elements. The inlet is velocity boundary condition and the exhaust is pressure boundary condition with moving grid method. Chemical kinetics is included in the CFD analysis.

The velocity profiles are as shown in fig. 5(a) and the behavior of the heat that is transferred is as shown in fig. 5(b). The velocity contours of the fluid flow after the combustion is shown in fig. 6. As the pressurized mixture is leaving the transfer port and entering the cylinder

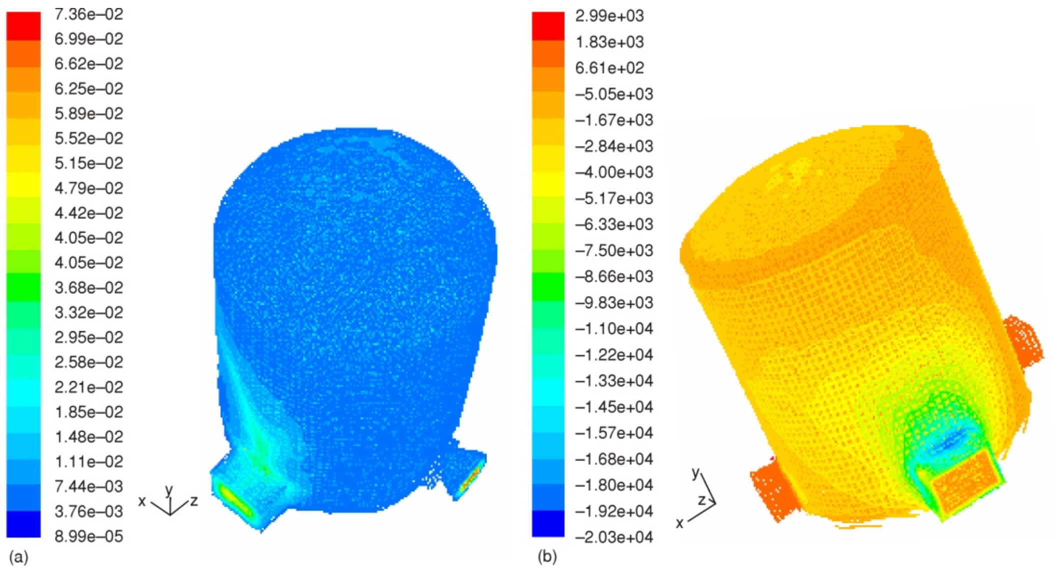


Figure 5. Internal energy profile (color image see on our web site)

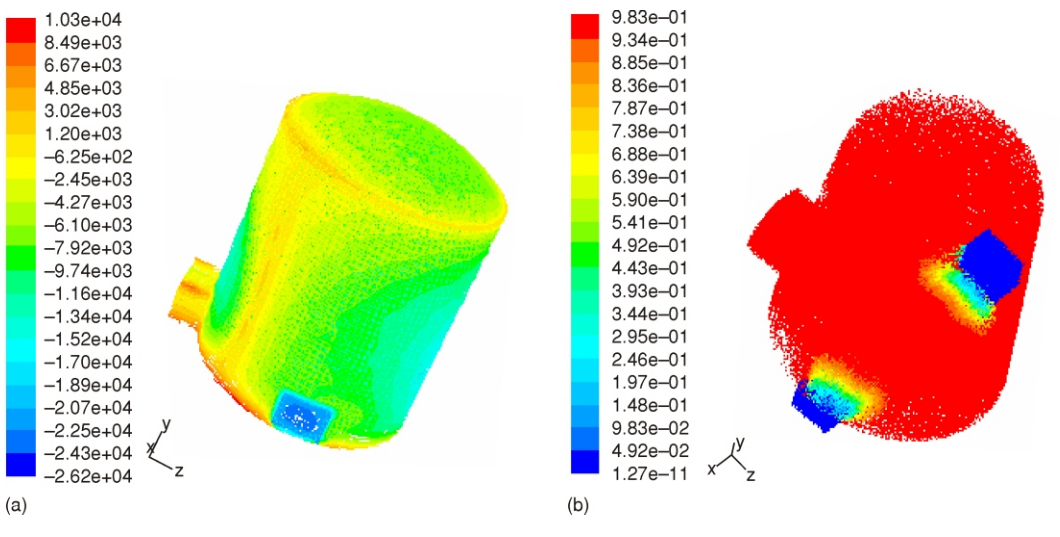
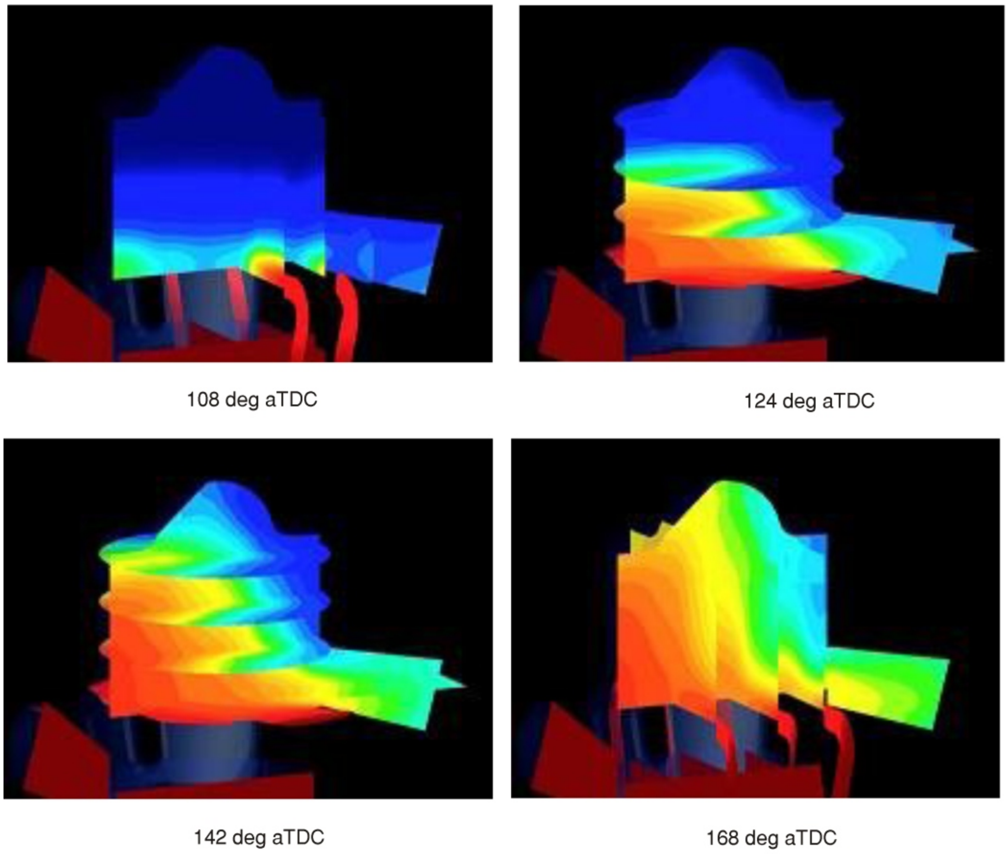


Figure 6. Pressure distribution and velocity contours (color image see on our web site)

the velocity profile will show us the distribution of the mixture in the cylinder and how efficiently it will throw out the burned gases out is clearly be estimated from the velocity and pressure distribution in the cylinder.

Figure 5 shows the internal energy of the cylinder before the combustion and fig.6 shows the pressure distribution and also velocity contours.

Charge flow into cylinder at various crank angles are given in fig. 7. The pressurized air is able to drive the flue gases out as shown in the simulations in fig.7. As the piston moves from the TDC to BDC (bottom dead center) releasing the power after burning the fuel the charg-



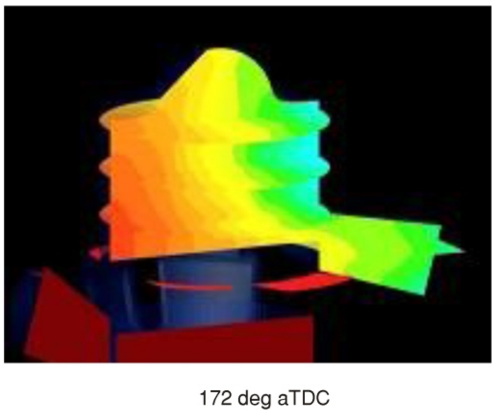


Figure 7. Simulation sketches of the scavenging process in the engine
(color image see on our web site)

ing as well as the scavenging are to take place and this is clearly observed in the data of the CFD simulations given in fig. 7. The red color indicates the fresh charge entry into the cylinder through transfer ports and the blue color indicates the burned gases.

The emissions are measured and the readings are comfortably substantiating the CFD program.

In fig. 7 it is to be understood that the burned gases are thrown out by the pressurized air in a better way compared to the scavenging without the stratification and pressurized air.

Results and discussion

Figures 8 and 9 show the variation of UBHC and CO with fresh charge delivery ratio at different equivalence ratios, respectively. It is observed from the fig. 8 as fresh loss ratio increases HC decrease.

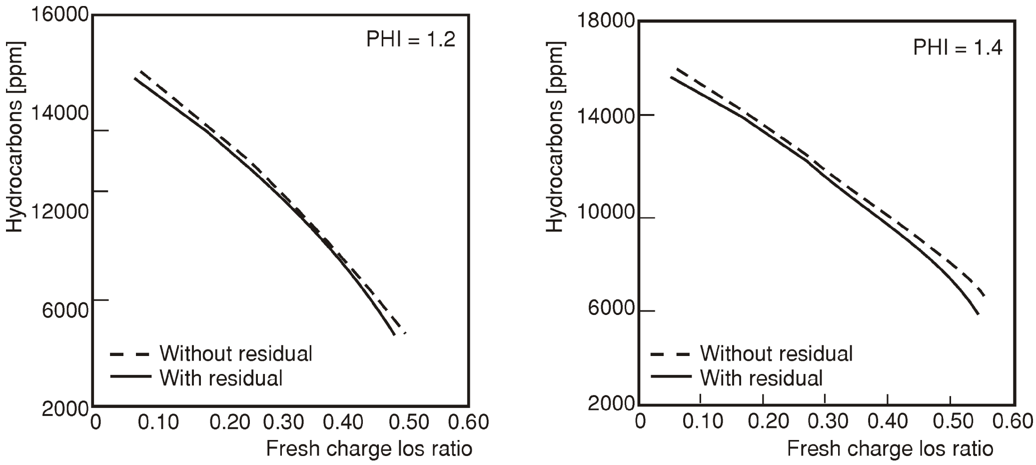


Figure 8. Effect of fresh charge loss ratio on HC concentration at different equivalence ratio (PHI Φ)

The trends are observed to be same for both residual and non residual cases. As the re circulated gas which is sand witched between fresh air and fresh charge as the scavenging processes begins the fresh air pushes the burned gases out from the chamber and before the fresh charge enters the cylinder the re-circulated gas acts as an artificial piston to throw away the flue gases out completely leading to reduction in HC emissions. From fig. 9 it is observed that CO emissions decrease as the fresh charge loss ratio increase at all equivalence ratios and it is more pronounced at lower equivalence ratios.

The CO emissions decrease due to the better oxidation and combustion reactions because of the admission of air into the combustion chamber. Similar trends are observed for both residual and non residual cases. The trends are quite consistent for the large number of cases and the CFD results that are obtained are trusted after the marginal error analysis as shown in tab. 2.

Table 2. Error of CFD analysis in comparision to experimental data

Parameter	Experiment	CFD results	Error	%
HC (g/h)	14.8	15.4	0.6	4.1
CO [g/h]	7.19	6.72	–0.47	6.5
NO [g/h]	9.84	9.01	–0.83	8.4
Brake specific fuel consumption in g per horse power hour	56.1	58.8	1.8	3.2
Fuel [kg/h]	13.6	14.2	0.6	4.4
Power [kW]	32.8	32.8	0	0

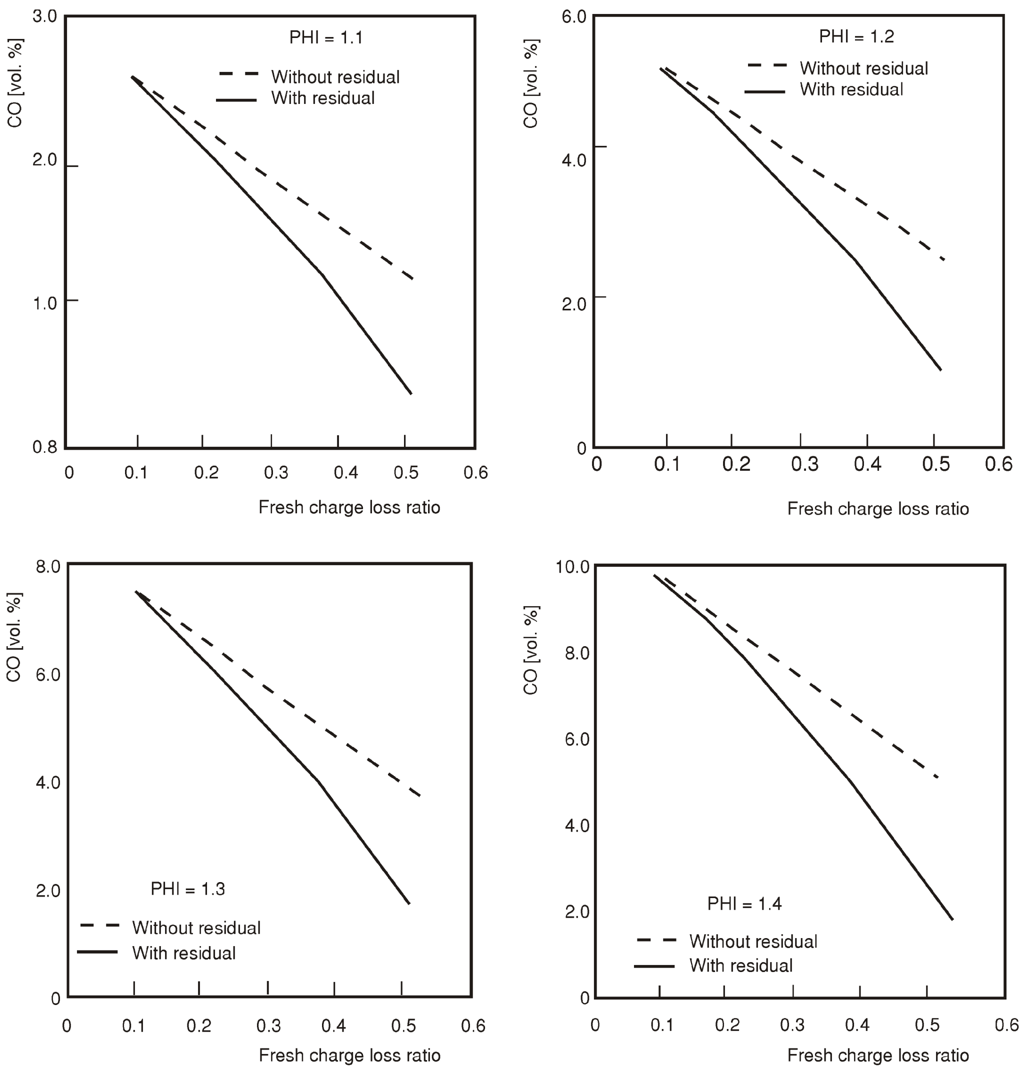


Figure 9. Effect of fresh charge loss ratio on CO concentration at different equivalence ratio (PHI Φ)

Conclusions

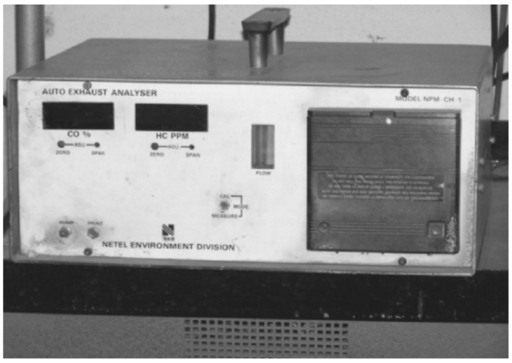
Based on the CFD investigations on a two-stroke stratified scavenged engine with extra port volume to provide the pressurized air through transfer port the pre and post combustion gases are clearly analyzed and found that the scavenging and trapping efficiencies are strong functions of delivery ratio and the stratification of the scavenging is improving the performance of the two-stroke engine with little modifications.

The reduction of HC emissions is found to be 34-38% when compared with conventional engine.

The CO emissions are decreased by 22-25% with stratified engine compared with non stratified engine.

Instruments

NO_x analyzer



CO and HC analzer

AVL smoke meter

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