Computational Analysis of the Scavenging of a two-stroke Opposed Piston Diesel Engine

Francisco Brójo, António Santos, Jorge Gregório

Abstract— **After the great success of the opposed piston engines in the second World War, their use has been reduced due to pollutions levels. These engines have the highest specific power, what given them advantages when the weight is an important factor (aircraft engines) and consequently the interest in these engines is nowadays high. The scavenging process has a high importance in the pollution levels, in the combustion process efficiency and in the engine thermal efficiency. To improve the scavenging it is needed knowledge about its behaviours. For the purpose it was designed an engine based on a commercially available one and the scavenging process was studied numerically using a commercial software (FLUENT). It was created a three-dimensional model of the engine and several scavenging geometries and physical parameters were tested to verify the combination that obtained the best values for the performance parameters.**

Index Terms— **Opposed piston, scavenging, two-stroke, engine.**

I. INTRODUCTION

The construction of alternative engines with opposed pistons started in 1850 with the construction of engines with one cylinder following the 2 or 4 stroke cycles. Due to its geometrical construction, this type of engines offered an easy alternative for the dynamic equilibrium of the engine. The construction was also easier since it eliminated the need of the engine head and gasket. Several inventors and engines from that time can be mentioned: Giles of Cologne (1874), Wittig (1878), T. H. Lucas (1881), Robson (1890), Ochelhauser and Hugh Junkers (1888).

At the beginning of the XX century were built successfully several engines for stationary and sea use. In what concerns aircraft applications, Hugo Junkers at 1930 dedicated exclusively to its development, designing the Jumo 205, 206, 207, 208, 209 and 218. The 205 was the first to be produced industrially, while the 207 was used by the German air force in high altitude applications.

This type of engines, consuming diesel fuel, produced high specific power values at low rpm, what allowed their use for the propulsion of trains and ships (1950).

Due to its high specific power, were developed more recently several engines. As examples can be mentioned the engine developed in 1987 by Bonner Engineering, Lda. (UK) for Africar, the engine developed in 1995 by Air Airship Industries (UK) and the engines developed by Fairbanks Morse, Kharkiv Morozov, Diesel Air and Gole Motor.

Actually, due to petrol prices, the interest in these engines increased and some possible applications could be light aircrafts and helicopters, where the power/weight ratio, efficiency, simplicity and safety are advantages enough to justify its use.

For the 2-stroke cycle, there is just one power stroke per revolution of the crankshaft, being the power produced twice the power of a 4-stroke engine with the same dimensions, operating at the same conditions. The opposed piston engine has two pistons per cylinder allowing the obtention of 3 to 4 times more power than the power obtained with a 4-stroke engine with similar size and weight. This power to weight ratio turns this engine very attractive to aeronautical applications.

The mechanical simplicity of these engines is also a great advantage, making the production and maintenance very easy. The drawbacks are based on short-circuit fuel losses during scavenging and high pollution levels. Several approaches to reduce these drawbacks have been suggested and can be cited: variable valves/ports times [1][2], exhaust collector control [3]-[5], stratified scavenging [6]-[8], direct injection after the closing of the valve/port [9]-[12], combustion with high charge [13]-[15], air assisted injection and delayed injection [16]. These solutions look very promising. Nevertheless, none was made thinking in the specific case of opposed piston engines.

Research on scavenging processes started very long ago. In 1938 Rogowski et al [17] studied the scavenging process of a compression ignition engine, where was reported the effects of several geometries for the admission and exhaust ports and opening and closing times. With the results of this study the efficiency of the engine increased 23%. Nevertheless, only data was obtained and the behaviours of the processes were still unknown. At the end of the sixties (XX century) were made the first attempts to visualise the scavenging process in a 2-stroke engine [12]. Nowadays, the methods used at the time can be considered obsolete. Nevertheless, they allowed the designers to build more efficient engines. Other methods of visualisation used laser Doppler anemometry [4][18]. More recently, advances in computational resources allowed the simulation of the scavenging process [13][15][16][19]. Computational Fluid Dynamics (CFD) look very attractive, due to the high resources needed to experimentally test several configurations.

Manuscript received March 24, 2010.

Francisco Brójo is with the Department of Aeronautic Sciences of the University of Beira Interior, Portugal (phone: + 351 275 329 957; fax: + 351 275 329 768, e-mail: brojo@ ubi.pt).

António Santos, is with Dassault Systems, Providence, USA (e-mail: antoniosantoz@gmail.com).

Jorge Gregório is with the Technology and Management School of Guarda of the Polytechnic Institute of Guarda, Portugal (e-mail: jgregorio@ipg.pt).

II. COMPUTATIONAL RESTRAINTS

A. *Geometry*

The engine designs were based on the geometry of the PRD FIREBALL RK125cc WC and several three-dimensional models of a single cylinder with two and four admission ports and one exhaust port were created.

In Fig. 1 can be seen one representation of the internal geometry of the engine made using the software CATIA and in Table I is presented the geometrical specifications of the engine.

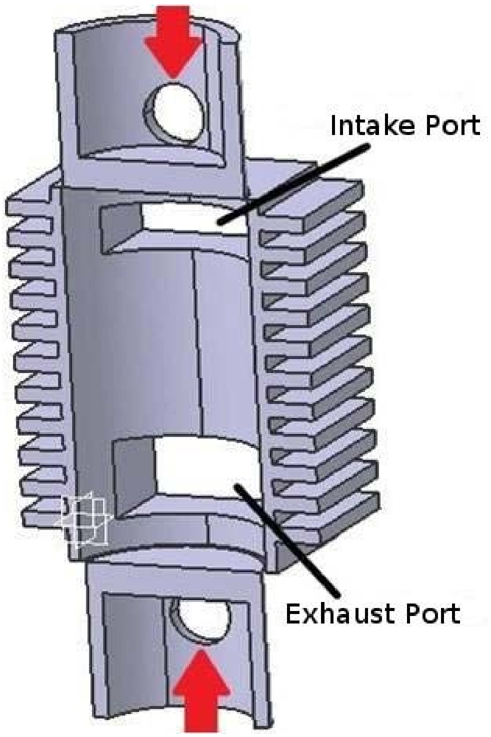


Figure 1 – Internal geometry of one of the models of the engine.

Table I – Geometrical specifications of the engine.

Parameter	**Dimension**
Volume	250 cc
Stroke	53.68 mm
Bore	54 mm
Connecting rod length	100 mm
Admission ports	2
Exhaust ports	1
Clearance volume	22 cc
Compression ratio	3
Opening angles	
Admission ports	178
Exhaust ports	178

B. *Mesh Generation*

The mesh was generated using FLUENT mesh generator Gambit and after exported to FLUENT. The first model built (two admission ports and one exhaust port) was symmetrical, what allowed cutting the geometry and the construction of a mesh with only 29,298 cells. This reduced the computational needs and the calculation time. The second model with four admission ports and one exhaust port had 112,667 cells. Two plane surfaces were modelled for the pistons heads. The scavenging process was simulated from the instant the first port opens until the moment the last one closes, allowing to preview the behaviours of gas exchange processes.

In the case of numerical studies, the mesh quality and size must always be adequate to the phenomena studied. If the mesh is too small, computational resources and time are wasted. Nevertheless, if the mesh is too large, the physical phenomena could not be satisfactorily modelled and the results can in this case be meaningless.

The piston moves through the process and was used the In-Cylinder model of FLUENT to determine the piston position based on the crankshaft angle, connecting rod length and stroke.

A structured grid was placed adjacent to the piston, occupying the volume along the piston movement. A technique called layering was then used to add or remove layers of cells according to the piston position. If the cell height gets smaller than a pre-determined value (collapse factor) it will be removed and fused with the adjacent layer. A similar process is used to add layers of cells using a split factor. If the cell height gets higher than a pre-determined value (split factor), the cell will be split, creating another one. The ideal cell height for fusion or split should be in accordance to the mesh size used.

Associated to this dynamic mesh layering is the opening and closing of the admission and exhaust ports. Since it is the movement of the piston that opens and closes the ports, it will be needed to incorporate these events in the simulation. FLUENT allows the creation of events to create interfaces (sliding interfaces) between the mesh inside the cylinder and the meshes in the admission and exhaust ducts. In Table II are presented the needed events.

TABLE II – Events needed for the simulation

Event	Angle	Command
Open exhaust port	96	Create Sliding Interface – Exhaust
Open admission port 1	120	Create Sliding Interface – Admission 1
Open admission port 2	120	Create Sliding Interface – Admissiuon 2
Open admission port 3	120	Create Sliding Interface – Admission 3
Open admission port 4	120	Create Sliding Interface – Admission 4
Close admission port 1	240	Delete Sliding Interface – Admission 1
Close admission port 2	240	Delete Sliding Interface – Admission 2
Close admission port 3	240	Delete Sliding Interface – Admission 3
Close admission port 4	240	Delete Sliding Interface – Admission 4
Close exhaust port	2264	Delete Sliding Interface – Exhaust

C. Computational Methods and Boundary Conditions

Turbulence is a very complicated phenomena and none of the models created until now can be considered superior to the remaining in the simulation of all the types of physical phenomena. Several turbulence models should always be tested and compared with experimental results, in order to check which one simulates more closely the experimental reality. Nevertheless, the choice of the turbulence model depends always on several considerations as:

- physical behaviours,
- established practice for a specific class of problems,
- level of precision wanted,
- available computational resources and time.

Accordingly, the model used was the one established by practice for the simulation of scavenging processes in an engine cylinder (k-ε Standard) [4]-[8].

The boundary conditions were defined in order to allow the recreation of conditions close to reality. For the intake, it was defined constant pressure with values ranging from 1 to 1.4 atmospheric pressure. For the exhaust it was assumed the atmospheric pressure in all the cases. The initial pressure inside the cylinder was assumed to be 44.5 bar and the initial temperature 1000 K [5].

The algorithms used were PRESTO for pressure interpolation, PISO for the velocity coupling and Second Order Upwind Scheme for the discretization of the momentum equation.

III. NUMERICAL RESULTS

The scavenging process in 4-stroke engines is helped by the movement of the piston during two of the strokes, during which the exhaust gases are pushed out of the cylinder and the fresh mixture is pulled in.

For 2-stroke engines that is not the case and the exhaust port is opened first, allowing the blowdown and after that the intake port is opened and the inertia of the gases and eventually the higher pressure on the admission let the scavenging to take place. This makes the scavenging of 2-stroke engines a more complicated phenomena, where the short-circuit fuel losses and high pollution levels can easily happen.

In what concerns the parameters used to measure the performance of the scavenging process, the choices were the [11]:

- Delivery Ratio (compares the mass of air inducted per cycle with a reference mass – usually the trapped cylinder mass),
- Trapping efficiency (indicates from the air mass inducted in the cylinder, the fraction really retained),
- Scavenging efficiency (indicates the efficiency of the substitution of combustion gases by the new air mass inducted).

The results for the models are presented in Tables III and IV.

Table III – Performance parameters for the Model 1.

Pressure	**Parameter**	**Value**
1 Patm	Delivery ratio	0.0062
	Trapping efficiency	0.6580
	Scavenging efficiency	0.0043
1.1 Patm	Delivery ratio	2.7481
	Trapping efficiency	0.2739
	Scavenging efficiency	0.8914
1.2 Patm	Delivery ratio	3.9398
	Trapping efficiency	0.1956
	Scavenging efficiency	0.9096
1.4 Patm	Delivery ratio	5.7727
	Trapping efficiency	0.1373
	Scavenging efficiency	0.9098

Table IV – Performance parameters for the Model 2.

Pressure	**Parameter**	**Value**
Patm	Delivery ratio	0.0013
	Trapping efficiency	1.0000
	Scavenging efficiency	0.0014
1.1 Patm	Delivery ratio	2.2790
	Trapping efficiency	0.3287
	Scavenging efficiency	0.9523
1.2 Patm	Delivery ratio	3.3249
	Trapping efficiency	0.2281
	Scavenging efficiency	0.9710
1.4 Patm	Delivery ratio	4.8751
	Trapping efficiency	0.1587
	Scavenging efficiency	0.9892

In Figs 2 to 8 are presented visualizations of the substitution of the gases inside the cylinder (in blue) by the fresh charge (in red) for several angles of the crankshaft and cases of model 1 and 2.

IV. CONCLUSION

From the analysis of Figs 3 to 8 can be said that for model 1 the scavenging process is higher close to the cylinder wall where the exhaust port is and having some difficulty in substituting the exhaust gases in the opposite side. Model 2 don's reveal this problem, since the admission ports on this model are not at 90º to the cylinder wall but have an angle of 20º. The generated swirl cleans more uniformly the cylinder.

In what concerns the admission pressures, in both cases, the pressure allowing better scavenging is 1.1 times the atmospheric pressure, since it has a scavenging efficiency close to the others, but with higher fresh charge retention. For the same admission pressure, model 2 presents better results than model 1, then showing that an angle for the ports promoting the swirl is always desirable.

Figure 5 – Scavenging for crankshaft at 240º (model 1)

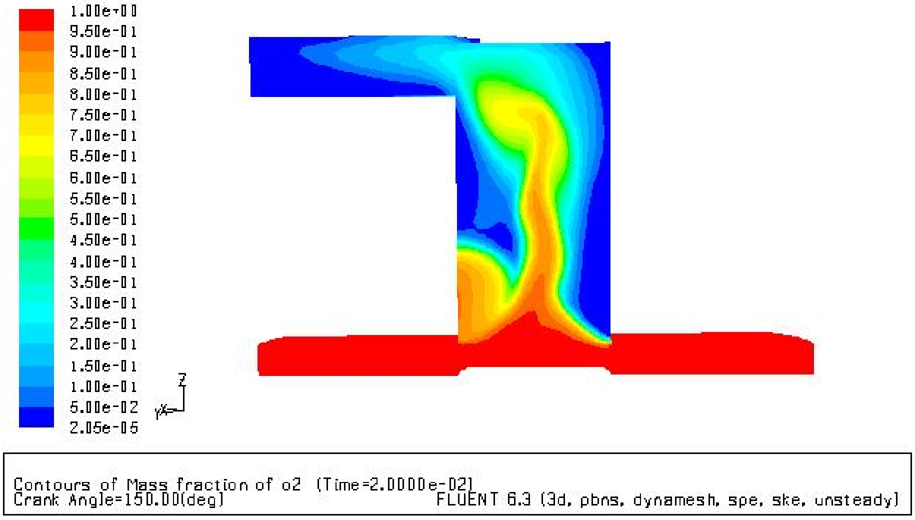


Figure 3 – Scavenging for crankshaft at 150º (model 1)

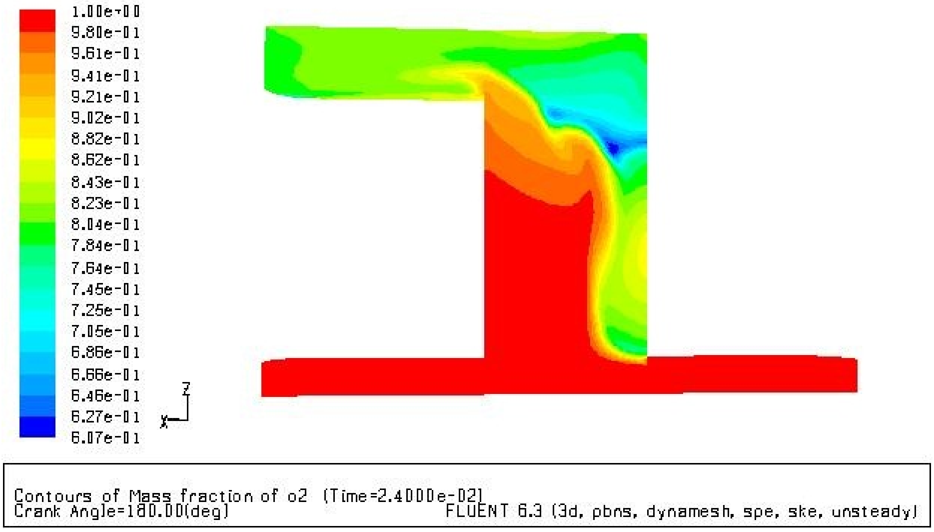
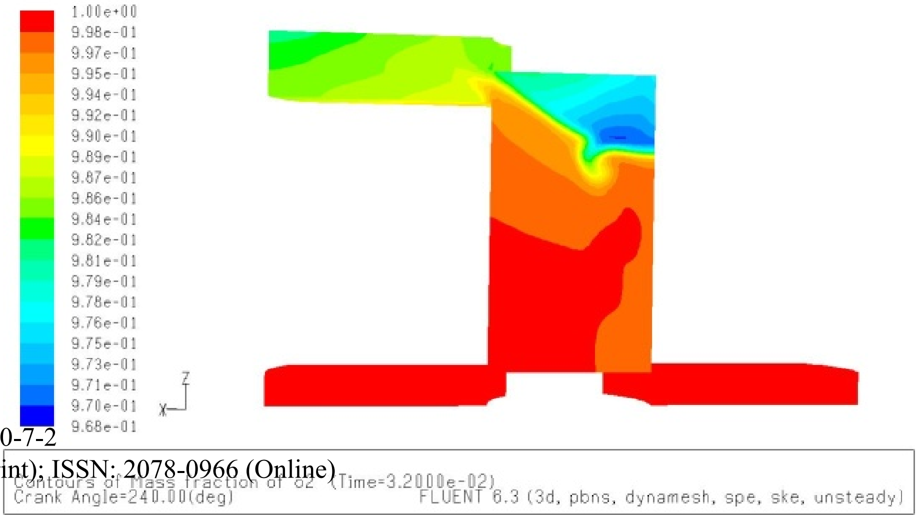


Figure 4 – Scavenging for crankshaft at 180º (model 1).



ISBN: 978-988-18210-7-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

Figure 8 – Scavenging for crankshaft at 240º (model 2).

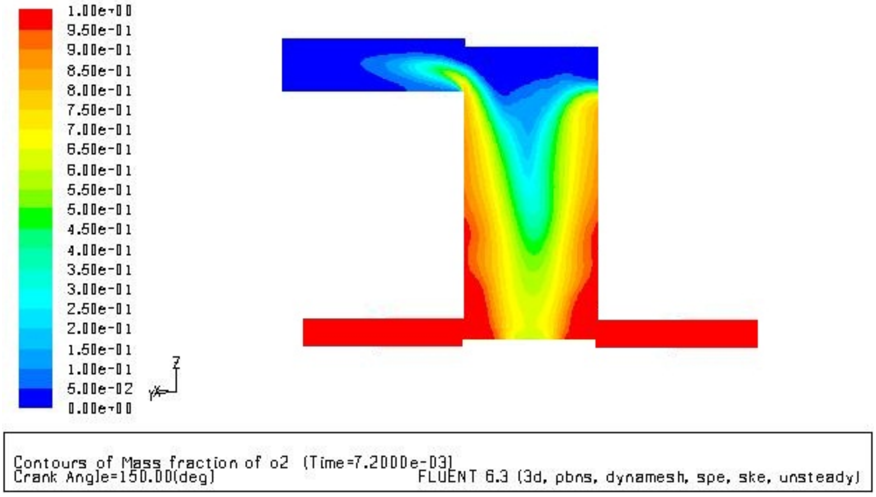


Figure 6 – Scavenging for crankshaft at 150º (model 2).

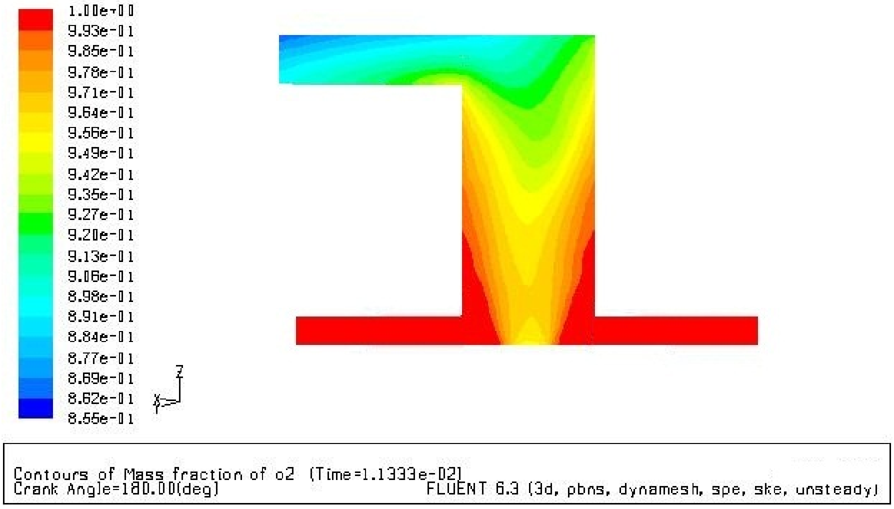
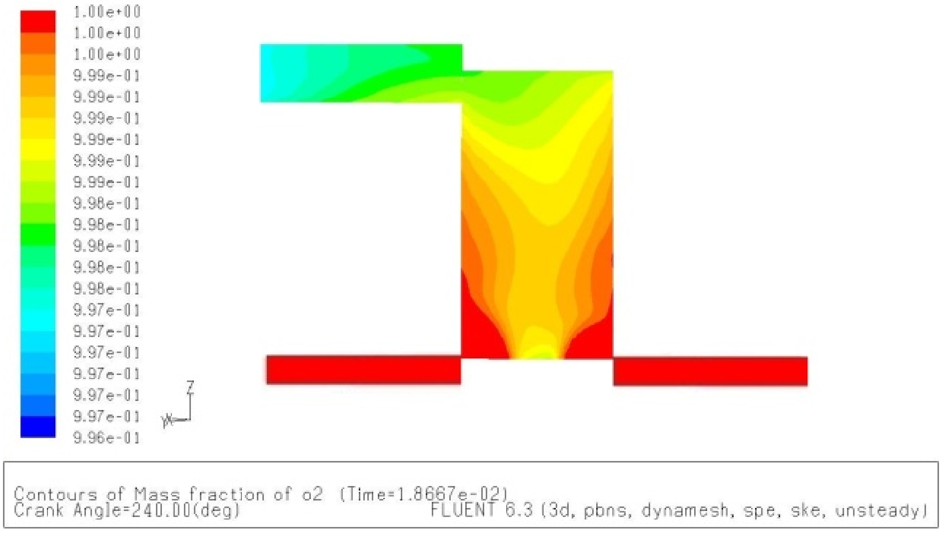


Figure 7 – Scavenging for crankshaft at 180º (model 2)



REFERENCES

[1] Benson R.S., Whitehouse N.D., "*Internal Combustion Engines*", Vol. 2, Pergamon, Oxford, 1979.

[2] Blair G.P., "*The Basic Design of Two-Stroke Engines*", Society of Automotive Engineers, Inc., 1990.

[3] Cebeci T., Shao J.R, Kafyeke F., Laurendeau E., "*Computational Fluid Dynamics for Engineers*", Horizons Publishing Inc., 2005.

[4] Chehroudi B., Schuh D., "*Intake-Port Flow Behavior in a Motored and Fired Two-Stroke Research Engine*", Experimental Thermal and Fluid Science 1995, 10:86-100.

[5] Ferguson C.R, Kirkpatrick A.T., *Internal Combustion Engines*, 2nd Edition, Wiley & Sons, Inc., 2001.

[6] . Inc., 2001. *Fluent 6.0 Dynamic Mesh Manual,* Cavendish Court, Lebanon.

[7] Fluent Inc. *Fluent vs 6.1 User's guide manual*, 2003.

[8] Dr. Gaterstädt, "*Development of the Junkers-Diesel Aircraft Engine*", Automobiltechnische Zeitschrift, 1930.

[9] Green R.M., "*An Optical Research for the Study of Two-Stroke Cycle In-Cylinder Phenomena*" International Symposium COMODIA 90 (1990): 347-352.

[10] Goldsborough S.S., Van Blarigan P., "*Optimizing the Scavenging System for a Two-Stroke Cycle, Free Piston Engine for High Efficiency and Low Emissions: A Computational Approach*", Society of Automotive Engineers, Inc., 2003.

[11] Heywood J.B.,"*Internal Combustion Engine Fundamentals*", McGraw-Hill, Inc., 1988

[12] Jante A., *Scavenging and Other Problems of Two-Stroke Cycle Spark-Ignition Engines*, 1968

[13] Mukund K., Arun M., Srinivas N.B., Appushame A.S., Rudramoorthy R., "*Cold Flow Simulation in Internal Combustion Engines Using Dynamic Mesh*", Department of Production Engineering, PSG College of Technology Peelamedu, Coimbatore, Tamil Nadu, India

[14] Nallasamy M., "*Turbulence Models and their Applications to the Prediction of Internal Flows: A Review*", Computers & Fluids, vol. 15, pp. pp. 151-194, 1987.

[15] Oliver P.J., "*A Numerical Investigation of the Scavenging Flow in a Two-Stroke Engine With Passive Intake Valves*", Queen's University Kingston, Ontario, Canada, 2008.

[16] Payri F., Benajes J., Margot X., Gil A.,"*CFD modeling of the in-cylinder Flow in direct-injection Diesel engines*", CMT-Motores Térmicos, Universidad Politécnica de Valencia, Camino de Vera s/n, 46022 Valencia, Spain, Computers & Fluids 33 (2004) 995–1021

[17] Rogowski A.R., Bouchard C.L., "*Scavenging a Piston-Ported Two-Stroke Ctlinder*", National Advisory Committee for Aeronautics – Technical Notes No. 674, 1938.

[18] Smyth J.G., Kenny R.G., Blair G.P., "*Motored and Steady Flow Boundary Conditions Applied to the Prediction of Scavenging Flow in a Loop Scavenged Two-Stroke Cycle Engine*", SAE Paper No, 900800, SAE Int. Cong. And Exp., 1988.

[19] VanGerpen J.H., "*A Two-Stroke Diesel Engine Simulation Program*", Iowa State University, NASA Report No. CR-185155, 1990.