# NEW INNOVATIVE DIRECT DISTRIBUTED INJECTION SYSTEM OF FUEL FOR INTERNAL COMBUSTION ENGINES

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*Abstract:* This paperwork provides via numerical simulation using the software Fluent, the Invention Patent that it is feasible as a viable solution to improve the combustion conditions inside the combustion chambers of the internal combustion Engines. The authors propose a new concept of the direct distributed injection system of fuel for combustion engines. In order to demonstrate the efficiency of the proposed invention, a numerical simulation was conducted following two separate scenarios.

The Invention proposes a shift of the injection paradigm, thus instead of using one central injector to have an injection system which leads to better colliding conditions of the fuel droplets against each-other, with the end of a finer diameter of the resulting fuel droplets which will lead to better combustion conditions.

*Key words:* Fuel injection, internal combustion engines, direct distributed injection system, injection plate, numerical simulation.

## 1. INTRODUCTION

Fuel injection is a system for admitting fuel into an internal combustion engine. It has become the primary fuel delivery system used in automotive engines, having replaced carburetors during the 1980s and 1990s. A variety of injection systems have existed since the earliest usage of the internal combustion engine (Davis, 2010).

The primary difference between carburetors and fuel injection is that fuel injection atomizes the fuel by forcibly pumping it through a small nozzle under high pressure, while a carburetor relies on suction created by intake air accelerated through a Venturi tube to draw the fuel into the airstream.

Modern fuel injection systems are designed specifically for the type of fuel being used. Some systems are designed for multiple grades of fuel (using sensors to adapt the tuning for the fuel currently used). Most fuel injection systems are for gasoline or diesel applications (Holder and Kunz, 2006).

The functional objectives for fuel injection systems can vary. All share the central task of supplying fuel to the combustion process, but it is a design decision how a particular system is optimized. There are several competing objectives such as (Walton, 1957):
-Power output;
-Fuel efficiency;
-Emissions performance;
-Ability to accommodate alternative fuels;
-Reliability;
-Driveability and smooth operation;
-Initial cost;
-Maintenance cost;
-Diagnostic capability;
-Range of environmental operation;
-Engine tuning.

The modern digital electronic fuel injection system is more capable at optimizing these competing objectives consistently than earlier fuel delivery systems (such as carburetors). Carburetors have the potential to atomize fuel better (see Pogue and Allen Caggiano patents).

Operational benefits to the driver of a fuel-injected car include smoother and more dependable engine response during quick throttle transitions, easier and more dependable engine starting, better operation at extremely high or low ambient temperatures, increased maintenance intervals, and increased fuel efficiency. On a more basic level, fuel injection does away with the choke, which on carburetor-equipped vehicles must be operated when starting the engine from cold and then adjusted as the engine warms up (Kendall, 2012).

Fuel injection generally increases engine fuel efficiency. With the improved cylinder-to-cylinder fuel distribution of multi-point fuel injection, less fuel is needed for the same power output (when cylinder-to-cylinder distribution varies significantly, some cylinders receive excess fuel as a side effect of ensuring that all cylinders receive sufficient fuel).

Exhaust emissions are cleaner because the more precise and accurate fuel metering reduces the concentration of toxic combustion byproducts leaving the engine, and because exhaust cleanup devices such

as the catalytic converter can be optimized to operate more efficiently since the exhaust is of consistent and predictable composition (3).

Herbert Akroyd Stuart developed the first device with a design similar to modern fuel injection using a 'jerk pump' to meter out fuel oil at high pressure to an injector. This system was used on the hot bulb engine and was adapted and improved by Bosch and Clessie Cummins for use on diesel engines (Rudolf Diesel's original system employed a cumbersome 'air-blast' system using highly compressed air). Fuel injection was in widespread commercial use in diesel engines by the mid-1920s.

The first use of gasoline direct injection (i.e. injection of gasoline, also known as petrol) was on the Hesselman engine invented by Swedish engineer Jonas Hesselman in 1925. Hesselman engines use the ultra lean burn principle; fuel is injected toward the end of the compression stroke, and then ignited with a spark plug. They are often started on gasoline and then switched to diesel or kerosene (8).

Direct fuel injection was used in notable WWII aero-engines such as the Junkers Jumo 210, the Daimler-Benz DB 601, the BMW 801, the Shvetsov ASh-82FN (M-82FN). German direct injection petrol engines used injection systems developed by Bosch from their diesel injection systems. Later versions of the Rolls-Royce Merlin and Wright R-3350 used single point fuel injection, at the time called "Pressure Carburettor". Due to the wartime relationship between Germany and Japan, Mitsubishi also had two radial aircraft engines utilizing fuel injection, the Mitsubishi Kinsei (kinsei means "venus") and the Mitsubishi Kasei (kasei means "mars").

Alfa Romeo tested one of the very first electronic injection systems (Caproni-Fuscaldo) in Alfa Romeo 6C2500 with "Ala spessa" body in 1940 Mille Miglia. The engine had six electrically operated injectors and was fed by a semi-high pressure circulating fuel pump system (10).

In internal combustion engines, Gasoline Direct Injection (GDI), also known as Petrol Direct Injection or Direct Petrol Injection or Spark Ignited Direct Injection (SIDI) or Fuel Stratified Injection (FSI), is a variant of fuel injection employed in modern two-stroke and four-stroke gasoline engines. The gasoline is highly pressurized, and injected via a common rail fuel line directly into the combustion chamber of each cylinder, as opposed to conventional multi-point fuel injection that happens in the intake tract, or cylinder port.

In some applications, gasoline direct injection enables stratified fuel charge (ultra lean burn) combustion for improved fuel efficiency, and reduced emission levels at low load.

The major advantages of a GDI engine are increased fuel efficiency and high power output. Emissions levels can also be more accurately controlled with the GDI system. The cited gains are achieved by the precise control over the amount of fuel and injection timings that are varied according to engine load. In addition, there are no throttling losses in some GDI engines, when compared to a conventional fuel-injected or carbureted engine, which greatly improves efficiency, and reduces 'pumping losses' in engines without a throttle plate. Engine speed is controlled by the engine control unit/engine management system (EMS), which regulates fuel injection function and ignition timing, instead of having a throttle plate that restricts the incoming air supply. Adding this function to the EMS requires considerable enhancement of its processing and memory, as direct injection plus the engine speed management must have very precise algorithms for good performance and drivability.

The engine management system continually chooses among three combustion modes: ultra lean burn, stoichiometric, and full power output. Each mode is characterized by the air-fuel ratio. The stoichiometric air-fuel ratio for gasoline is 14.7:1 by weight, but ultra lean mode can involve ratios as high as 65:1 (or even higher in some engines, for very limited periods). These mixtures are much leaner than in a conventional engine and reduce fuel consumption considerably.

Ultra lean burn or stratified charge mode is used for light-load running conditions, at constant or reducing road speeds, where no acceleration is required. The fuel is not injected at the intake stroke but rather at the latter stages of the compression stroke. The combustion takes place in a cavity on the piston's surface which has a toroidal or an ovoidal shape, and is placed either in the center (for central injector), or displaced to one side of the piston that is closer to the injector. The cavity creates the swirl effect so that the small amount of air-fuel mixture is optimally placed near the spark plug. This stratified charge is surrounded mostly by air and residual gases, which keeps the fuel and the flame away from the cylinder walls. Decreased combustion temperature allows for lowest emissions and heat losses and increases air quantity by reducing dilation, which delivers additional power. This technique enables the use of ultra-lean mixtures that would be impossible with carburetors or conventional fuel injection (Lindh, 1992), (Olsson, 1990), (3).

• Stoichiometric mode is used for moderate load conditions. Fuel is injected during the intake stroke, creating a homogeneous fuel-air mixture in the cylinder. From the stoichiometric ratio, an optimum burn results in a clean exhaust emission, further cleaned by the catalytic converter.

• Full power mode is used for rapid acceleration and heavy loads (as when climbing a hill). The air-fuel mixture is homogeneous and the ratio is slightly richer than stoichiometric, which helps prevent knock (pinking). The fuel is injected during the intake stroke.

It is also possible to inject more than once during a single cycle. After the first fuel charge has been ignited, it is possible to add fuel as the piston descends. The benefits are more power and economy, but certain octane fuels have been seen to cause exhaust valve erosion.

Swirl injectors are used in liquid rocket, gas turbine, and diesel engines to improve atomization and mixing efficiency.

The circumferential velocity component is first generated as the propellant enters through helical or tangential inlets producing a thin, swirling liquid sheet. A gas-filled hollow core is then formed along the centerline inside the injector due to centrifugal force of the liquid sheet. Because of the presence of the gas core, the discharge coefficient is generally low. In swirl injector, the spray cone angle is controlled by the ratio of the circumferential velocity to the axial velocity and is generally wide compared with nonswirl injectors (Ji-Hyuk Im et al., 2010).

## 2. A NEW DIRECT DISTRIBUTED INJECTION SYSTEM OF FUEL FOR COMBUSTION ENGINES

The Authors propose a new concept of a new Direct Distributed Injection System of Fuel for Combustion Engines. As a general conclusion derived from the above short history, the fuel injection systems that exist and are deployed in practice have an essential shortcoming: the fuel is injected inside the cylinder using a single injector that disregarding the complexity, being placed in a central position, it cannot fill completely the combustion chamber and the mixture rates between fuel-air, due to the fact that the fuel droplets are leaving from a single central point, cannot collide one against other, so that the said fuel-air mixing rates are lower since the dimensions of the fuel droplets are relatively rough.

The Invention is proposing a shift of the injection paradigm, instead of using one central injector to have in place an injection system which is leading to better colliding conditions of fuel droplets against each-other, with the end of a finer diameter of the resulting fuel droplets which in turn will lead to better combustion conditions.
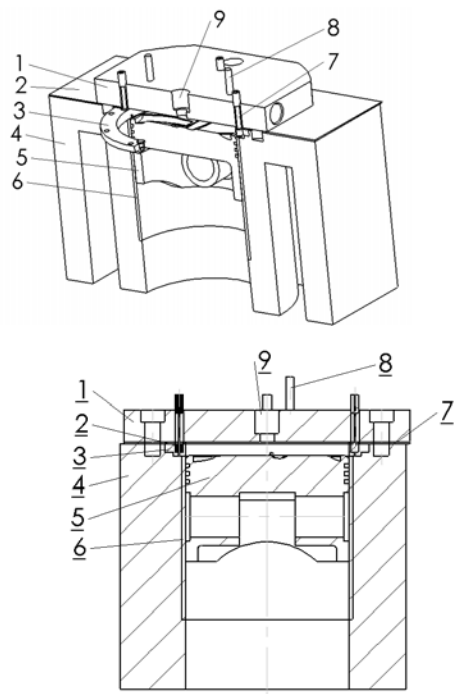


Fig.1. 3D View and Cross-section of a combustion cylinder with Direct Distributed Injection System

In Fig. 1 are given some details regarding the proposed injection system in which: (1)-is the cylinder cover; (2)-the sealing between cylinder cover and crank case; (3)-the injection plate which is the core-component of the system; (4)-crank-case; (5)-the piston with a special design having the upper part machined with guiding grooves for the fuel jet; (6)-piston sleeve; (7)-high pressure duct for fuel; (8)-admission-exhausting valves; (9)-the spark thread.
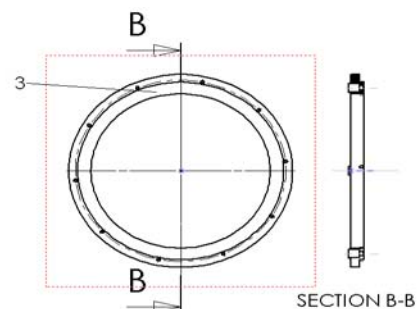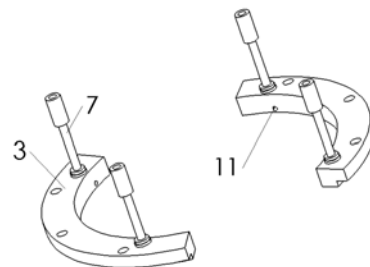


Fig.2.The injection plate (a)



Fig.2.The injection plate (b)

In the above figure, two versions of the Injection Plate (3) are shown which can be made in one piece (Fig.2-a) or out of two separate pieces (Fig.2-b) or put from multiple pieces. If made out of multiple pieces the machining of the fuel injection nozzles (11) is simpler but problems in ensuring the sealing between cylinder cover and the crank case are to be expected whereas if made out a single circular piece the machining of the nozzles is more difficult but more effective in terms of sealing.

The functioning of the system is simple: the fuel is coming via (7)-high pressure duct for fuel to the injection plate (3) that having machined the nozzles (11) will spray the fuel inside the combustion chamber.

A detail of the nozzle (11 penetrating the injection plate (3) is given in the below figure.
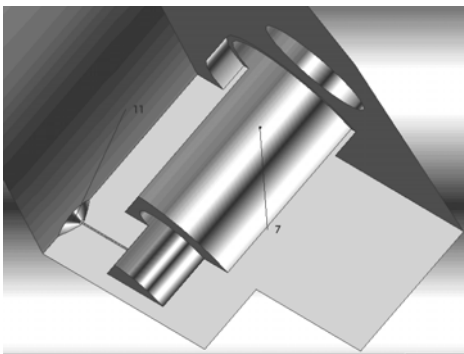


Fig.3. Detail of the nozzle (11) inside the injection plate (3)

Functionally the position of the nozzle (11) against of the center of the combustion chamber is of a paramount importance.
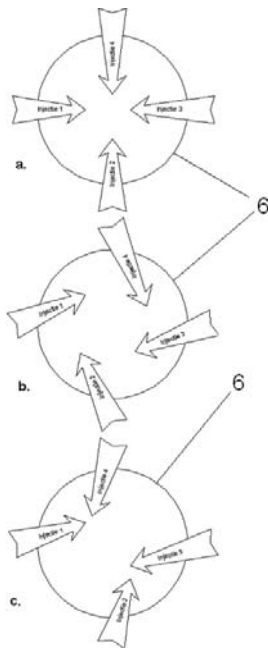


Fig.4. Position of the direction of nozzles (11) against of the center

If as in Fig.4-a, the direction of nozzles are targeting the center then this is the arrangement which is leading to the most intense collision rates between fuel droplets which in turn lead to the best dimensions of droplets due their fragmentation.

If as in Fig.4-b, the direction of nozzles are targeting sidelong equiangular, then a swirl effect may be induced to the fuel jets.

If as in Fig.4-c, the direction of nozzles are targeting sidelong one against the other, then a combination of the two above effects may be induced to the fuel jets.
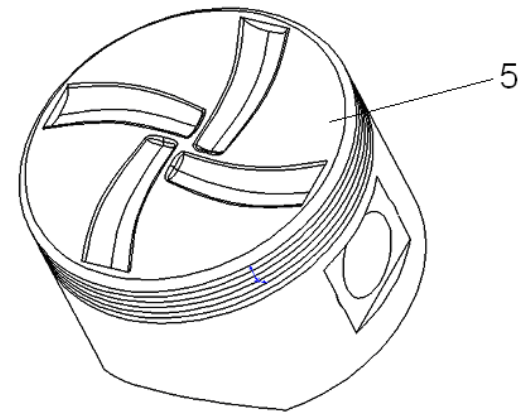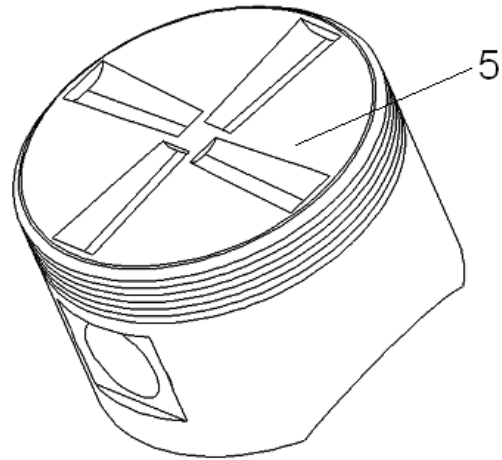


Fig.5. Pistons upper part machined with guiding grooves

As already mentioned the pistons may have a special design having the upper part machined with guiding grooves for the fuel jet (Fig.5). These grooves may lead the fuel jets and ensure enough space for the jets to develop taking into account that at the moment of the injection the width of the combustion chamber is very narrow.

The proposed injection system is not taking into account how and which are the means of pressurizing the fuel before the injection stage. Any system electro-mechanic-hydraulic may be deployed to ensure this function. In plain words the invention is

replacing the Spray Tip of a normal fuel injector with an injection plate, the rest of the injector remaining the same.

## 3. NUMERICAL SIMULATION

In order to demonstrate the efficiency of the proposed invention, a numerical simulation was conducted following two separate scenarios. The geometry of the combustion chamber is given below, the cylinder having the diameter of 200 mm and the height of 15 mm.
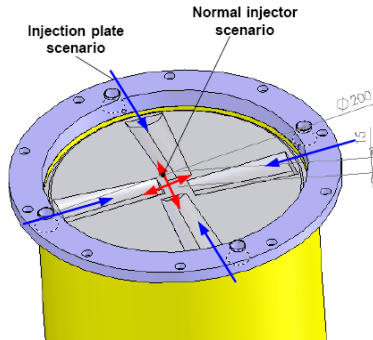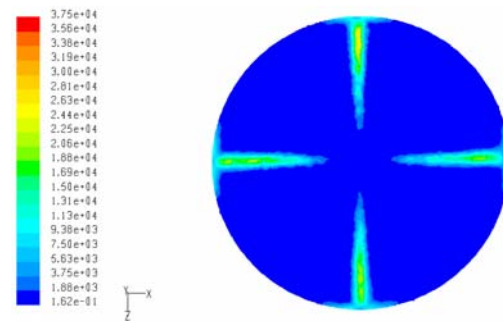


Fig.6. Geometry of the combustion chamber

Keeping constant the geometry and the injection parameters, two scenarios were evaluated; the first scenario is supposing the existence of a normal central injector with nozzles of 0.22 mm and length of 0.006 m. The second scenario is supposing the existence of the injection plate with the same type of nozzles.
The involved software was Fluent.
The model used 133,339 finite volume cells with 27,326 nodes. The fuel was injected via a plain orifice atomizer, with 10 particle streams each, starting to inject the droplets at time 0.0 sec to 0.0026 sec. The calculation followed the evolution of the combustion process from 0.0 sec to 0.065 sec. The flow rate of the injection is 0.013 kg/sec at temperature of 350 0K. The turbulent dispersion was modeled via the stochastic tracking model with the time scale constant of 0.15. The under relaxations factors used were 0.3 for pressure, 1 for density, 1 for body forces and 0.7 for momentum. All the rest of the model settings had pretty much the standard values, the solver used is the segregated-implicit-unsteady-3D one, the viscous model used was k-epsilon standard model. The model was iterated until the convergence was reached.

### 3.1 Computed dynamic and total pressure
As it can be seen in the following figure, the dynamic and total pressure developed for the two scenarios are:
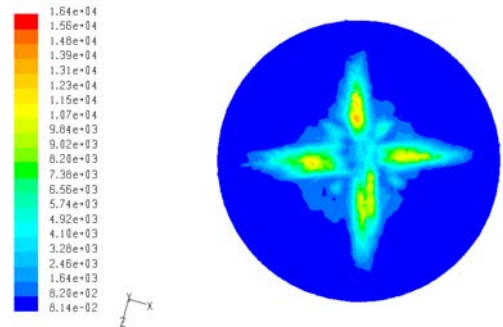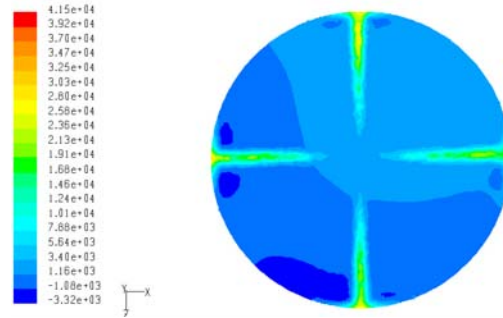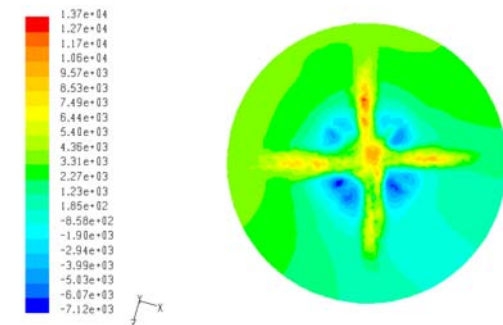


Normal injection (a)



Injection plate (b)
Fig.7. Dynamic pressures for the computed scenarios

• Maximum of 3.75 e4 Pa for the normal injection reached near the walls of the combustion chamber,
• Maximum of 1.64 e4 Pa reached at the center of the chamber.



Normal injection (a)



Injection plate
Fig.8. Total pressures for the computed scenarios

35

• Maximum of 4.15 e4 Pa for the normal injection reached near the walls of the combustion chamber,
• Maximum of 1.37 e4 Pa reached at the center of the chamber.

Judging the pressure distribution after 65 ms from the injection start, for the computed scenarios, is quite visible that the pressures distribution inside the combustion chamber in the normal injection has bigger values with bigger pressure peaks whereas for the plate injection the pressure has a better distribution across the section of the chamber, this being the first clue regarding the superior combustion condition ensured by the injection plate.

## 3.2 Computed velocity

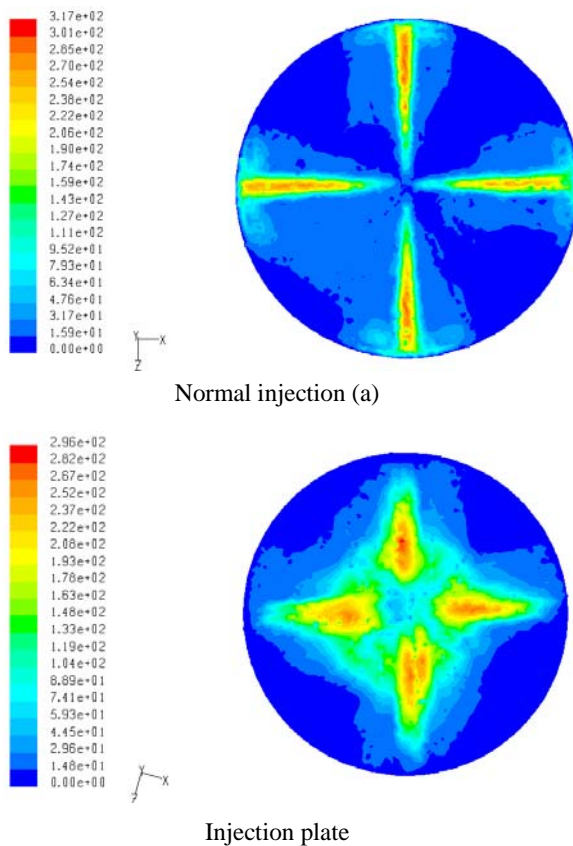As seen in the following figure the velocities fields developed for the two scenarios are:



Normal injection (a)



Injection plate
Fig.9. Velocities for the computed scenarios

• Maximum of 3.17 e2 m/s for the normal injection reached near the walls of the combustion chamber,
• Maximum of 2.96 e2 m/s reached at the center of the chamber.

Once again, it may see that the velocity distribution inside the combustion chamber has a smoother shape.

## 3.3 Computed temperatures

As seen in the following figure, the temperature fields developed for the two scenarios are given in the Fig.10.

• Maximum of 3.25 e3 0K for the normal injection reached near the walls of the combustion chamber,
• Maximum 3.32 e3 0K reached at the center of the chamber.

By now, is quite clear that the injection plate ensure a better combustion condition since the maximum reached temperatures are bigger and the shape of temperatures fields is better distributed inside the combustion chamber.
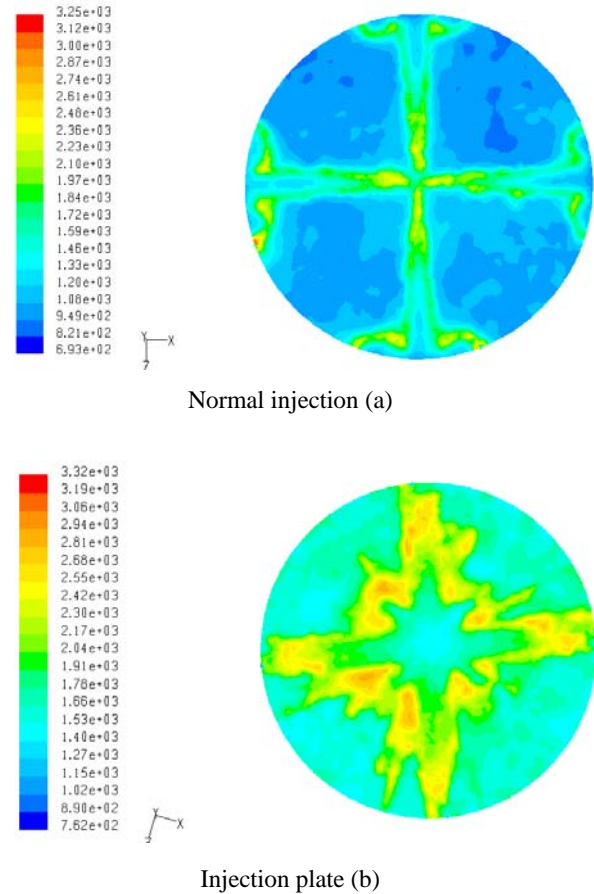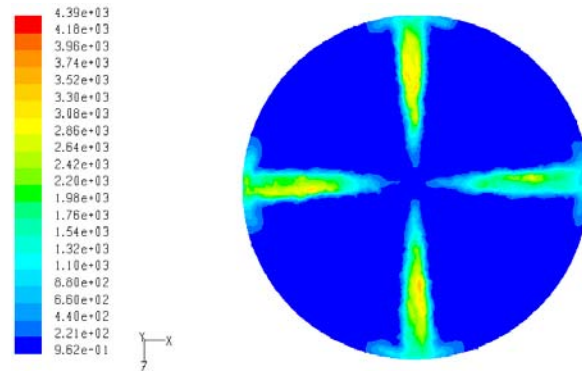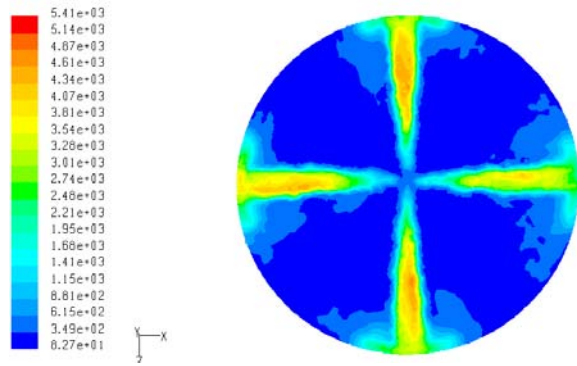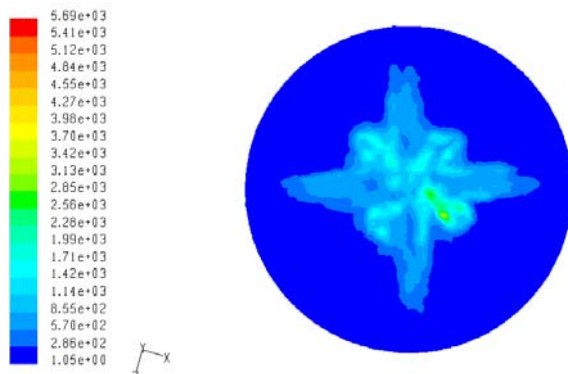


Normal injection (a)



Injection plate (b)
Fig.10. Temperatures for the computed scenarios

## 3.4 Computed turbulence kinetic energy and turbulence intensity
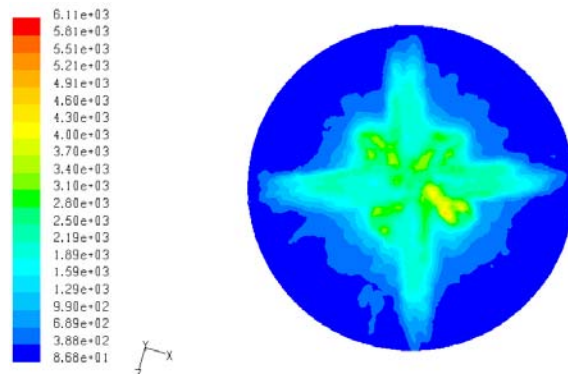
Normal injection (b)



(a)



Injection plate (b)
Fig.11. Turbulent kinetic energy and turbulence intensity
for the computed scenarios

As seen in the figure 11, the turbulent kinetic energy and turbulence intensity fields developed for the two scenarios are:
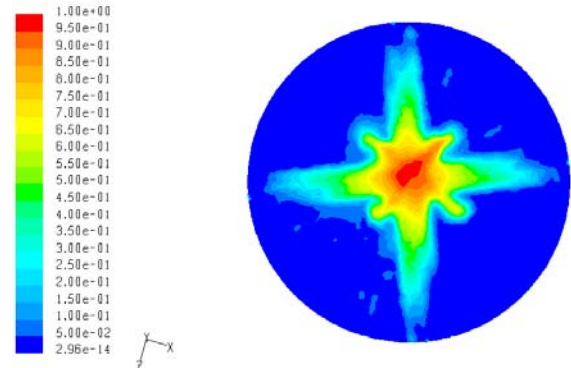•Maximum of 4.39 e3 m2/s2 for turbulent kinetic energy and 5.41 e3 % for turbulence intensity for the normal injection reached near the walls of the combustion chamber,

•Maximum of 5.69 e3 m2/s2 for turbulent kinetic energy and 6.11 e3 % for turbulence intensity reached at the center of the chamber.

**3.5 Computed mean mixture fraction**
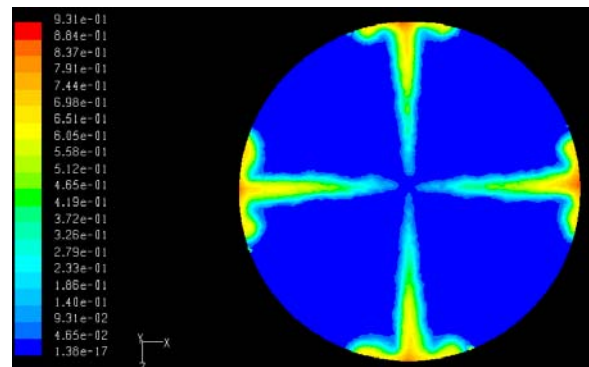


Normal injection (a)



Injection plate (b)
Fig.12. Mean mixture fractions for the computed scenarios

As seen in the above figures, the mean mixture fractions fields developed for the two scenarios are:
•Maximum of 9.31 e-1 for the normal injection reached near the walls of the combustion chamber,
•Maximum 1 reached at the center of the chamber.
The mean mixture fraction is defining the reaction rates developed in the combustion process and as seen the normal injection provide only 10% of the solution proposed via the invention patent.

**4. CONCLUSIONS**

This paperwork provides via numerical simulation using the software Fluent, the Invention Patent that it is feasible as a viable solution to improve the combustion conditions inside the combustion chambers of the internal combustion Engines. The paper proposes a new concept of the direct distributed injection system of fuel for combustion engines. In order to demonstrate the efficiency of the proposed

invention, a numerical simulation was conducted following two separate scenarios.

Fuel injection is a system for admitting fuel into an internal combustion engine. A variety of injection systems have existed since the earliest usage of the internal combustion engine. Modern fuel injection systems are designed specifically for the type of fuel being used. Some systems are designed for multiple grades of fuel (using sensors to adapt the tuning for the fuel currently used). Most fuel injection systems are for gasoline or diesel applications.

The authors propose a new concept of a new Direct Distributed Injection System of Fuel for Combustion Engines.The fuel injection systems that exist and are deployed in practice have an essential shortcoming: the fuel is injected inside the cylinder using a single injector that, disregarding the complexity, being placed in a central position, cannot fill completely the combustion chamber and the mixture rates between fuel-air, due to the fact that the fuel droplets are leaving from a single central point, cannot collide one against other, so that the fuel-air mixing rates are lower since the dimensions of the fuel droplets are relatively rough. The Invention proposes a shift of the injection paradigm, thus instead of using one central injector to have an injection system which leads to better colliding conditions of the fuel droplets against each-other, with the end of a finer diameter of the resulting fuel droplets which will lead to better combustion conditions.

The results presented in the paper are very clear and conducted to the idea that the invention ensures a better combustion case, idea that is well pursued nowadays.

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