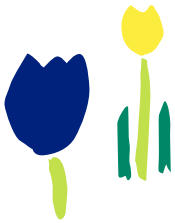

The HPi Engine

Direct Petrol Injection, High Pressure and Stratified Lean Mixture :

True Innovation

Summary

An engine especially well adapted to the expectations of our customers

HPi engine : the industrial tool

1 The HPi engine

is conceived as part of a renewed and ambitious engine policy

1 - Engine policy of the PSA Peugeot Citroën group

The group has undertaken a full renewal of its engine ranges according to three specific objectives :

- Reduce consumption to limit the cost of using a vehicle and control the greenhouse effect.
- Give more torque and power to improve the pleasure of driving at constant engine capacity.
- Control the exhaust emissions to uphold the quality of the air.

The specific objectives are designed to back up the device implemented by the PSA Peugeot Citroën group to meet the objective fixed by the members of the ACEA (Association of European Car Manufacturers) to reduce the emissions of carbon dioxide (CO_2) of new cars before 2 008 to 140 grams per kilometre on average, i.e. an average consumption of ca. 5.6 litres for 100 km.

As of 1998, the group launched the HDI high pressure direct injection diesel engine using the «common rail» technology.
This engine, in 2 litre and 2.2 litre versions, is currently a market reference whether for its dynamic or environmental performances. Compared to a traditional diesel engine, it makes it possible to save 20 % in fuel consumption.

2 - Petrol range and ambitions of the HPi engine

In spring 1999, PSA Peugeot Citroën started renewing its petrol engines by marketing the EW 2 litre indirect injection engine, starting point of a new family. Compared to the XU engine of the former generation, this engine already resulted in a 10 % reduction of the consumption.

Currently, the PSA Peugeot Citroën group presents its brand new HPi high pressure direct injection petrol engine that operates in lean mixture and stratified load.

This new EW10 HPi 16 engine with a 2 litre engine capacity makes it possible to :

◆ strongly reduced consumption

- 10 % compared to the very recent EW 2 litre indirect injection engine ;
- 19 % compared to the XU 2 litre engine.

◆ improve driving pleasure by increasing

- the torque yield at low rating (2,000 rpm) compared to the EW and XU engines, respectively by 9.6 % and 3.6 % ;
- In addition to the improvement of these performances, there is an improvement of the vivacity.

◆ improve the environmental friendliness of the engine

- thanks to a reduction of the CO_2 emissions proportional to the reduction of the consumption ;
- an exemplary pollution control with emissions far below the EURO 3 regulation and compatible with the EURO 4 regulation.

To meet these objectives, the PSA Peugeot Citroën group selected a combustion chamber operating in stratified load with a lean mixture and a new NOx (nitrogen oxides) storage-release pollution control system.

The HPi engine

Innovative technical choices

1 - The HPi engine is the first direct petrol injection engine that operates in stratified load with a lean mixture designed by a European manufacturer.

This engine was fully developed by PSA Peugeot Citroën in 121 weeks. As the choices made in 1998 were close to certain solutions adopted by Mitsubishi, the group signed an agreement with this company to use the patents, certain parts of which were likely to be opposable due to the intellectual copyright.

This specific technique consists of concentrating an inflammable air/petrol mixture in the direct vicinity of the sparking plug and to fill the rest of the combustion chamber with air. To that end, it is mandatory to use direct injection, i.e. to position the petrol injector in the combustion chamber (and not in the intake as is currently the case) in order to inject the fuel in a very accurate and controlled manner at each operating point of the engine.

This technique, further to the improvement of the combustion efficiency, makes it possible to reduce the loss of energy at filling, commonly referred to as pumping losses thanks to its operation with an excess of air, and consequently with a wide open air choke.

This specific principle is the only one that guarantees significant reductions of fuel consumption. The operation of an engine in a stratified load and lean mixture is possible up to a rating or 3,500 rpm and at mid-load. Beyond these conditions the engine operates at stoechiometry.

2 - Innovative technological solutions

The HPi engine required the implementation of innovative technological solutions : an engine architecture based on a new combustion chamber with a deviated jet, new engine strategies and new monitoring components and a pollution control system, with NOx storage-release catalysis.

◆ An engine architecture based on a new deviated jet combustion chamber

The HPi engine utilises the base of the EW 2 litre engine with the aluminium cylinder housing, the fixed connecting rod lengths, the cast iron crankshaft, water and oil pumps.

In contrast, the upper part is totally specific.

- A new deviated jet combustion chamber

The injector was placed directly in the combustion chamber between the two admission ducts in an inclined lateral position to inject the petrol slantwise inside the combustion chamber.

The sparking plug is placed vertically in a central position.

The piston features an off-centre bowl positioned opposite the injector, that helps direct the petrol towards the sparking plug.

- Admission ducts to give a specific motion to the air

The straightening out of the admission ducts and their specific shape make it possible to create a rotation motion of the air referred to as «reverse tumble» (opposite side from that of indirect injection engines).

Therefore, during the admission phase, the air is put into rotation around an axis square to the cylinder in a duct-injector-piston-sparking plug sequence.

Upon completion of the compression phase, the petrol is sprayed in the chamber by the injector in a pre-established zone and mixed with the air. The mixture so obtained is then brought into the direct vicinity of the sparking plug thanks to the specific internal aerodynamics, and to the shape and motion of the piston. This concept is referred to as a «deviated jet».

- A combustion referred to as a «stratified load»

The above-mentioned devices make it possible to concentrate an inflammable mixture of air/petrol around the sparking plug and to fill the rest of the chamber with air. Therefore, it is possible to perform a combustion with an excess of air compared to the petrol within a ratio which can reach 30/1.
The same quantity of fuel equally distributed in the combustion chamber would give a physically non-inflammable air + fuel mixture.

- A reduction of the «pumping losses» favourable to engine efficiency

In addition to all the efforts implemented to optimise the combustion of the HPi engine, special attention was paid to reduce the effort required for the admission of the air within the combustion chamber, often referred to as the «pumping losses» :

The operation with the throttle butterfly wide open significantly improves the filling of the air in the combustion chamber.

In addition, by recycling up to 30 % of the exhaust gases towards the admission, the Exhaust Gas Recirculation valve notably makes it possible to reduce the pumping losses and improve engine efficiency.

Thanks to the recovery of these exhaust gases, it is also possible to reduce the temperature of the flame thus reducing the production of nitrogen oxides during the operation in lean stratified mixture.

3 - New engine monitoring components and new strategies

As for the HDI engine, it is the engine management system that controls the operation of the HPi engine and the associated pollution control system.

The HPi engine benefits from a completely new engine monitoring developed jointly with Siemens.

The result is a highly improved engine efficiency and well-controlled exhaust emissions.

◆ The engine management system to steer the engine strategies as a whole

It controls the operation in stratified mode, the engine strategies during the changeovers of operating mode, the pollution control system, the diagnostic functions (EOBD - European On Board Diagnosis) and the operating safety.

In addition, it controls the engine strategies and associated components as a whole :

- Injectors

Injectors have a jet cone angle of 70°. The petrol is put into rotation (swirl) around the axis of the injector.

They operate under a variable pressure ranging from 30 to 100 bar (in a traditional petrol engine, injectors operate under a pressure of 3.5 bar). The duration and pressure of the injection are controlled and adapted by the computer at each operating point of the engine.

The petrol is finely sprayed (70 bar in idle mode, 100 bar at full load) to obtain the best combustion efficiency throughout the operating ranges as a whole.

The pressure of the petrol is also adjusted to obtain the smoothest possible driving (30 bar in the transition phases).

Therefore, this fine control of the injectors results in a low fuel consumption and an enhanced driving pleasure.

- High pressure injection pump

The injection pump is totally new. It is based on an original and unique concept developed within the Siemens - PSA Peugeot Citroën joint venture. It is manufactured at the Asnières plant in Paris.

The pump works on two stages : the first level consists of a hydraulic pump placed in an oil bath ; the second corresponds to the distribution level, it delivers the petrol and returns the excess.

The design of this two-stage high pressure injection pump is a true innovation.

Compared to existing technologies, it offers the following benefits :

- All mechanical parts in motion are in oil, without contact with the petrol thus ensuring a high service life and a good operation at high pressure that makes it possible to use standard materials.

- Pumping is performed by three pistons that are driven by an inclined rotating plate. This plate is placed on a hydrostatic bearing and driven by the camshaft. This provision limits the internal friction and the driving torque.

- The axial piston layout selected made it possible to design the most compact and lightest pump on the market. With a weight of 900 grams, it is twice as light as existing pumps.

- Ignition

Engine monitoring controls the ignition coil that supplies three energy levels to the sparking plug, adapted to the various operating modes of the engine.

- A high energy level (100 mJouls) for the operation in stratified load.
- Two gradually lower energy levels for the operating modes in homogeneous mixture (70 mJouls for the intermediate loads and 50 mJouls for the full load).

- The motorized throttle butterfly unit

The driven throttle butterfly unit manages the quantities of air admitted in the combustion chamber during the changeovers of the engine operating modes imposed by the driving pleasure or pollution control system.
Therefore in stratified mode, the throttle butterfly is wide open so that the combustion can take place with an excess of air.
For example, in idle mode, it is already open at 20° whereas on an indirect injection engine it is only open from 8 to 10°.

During transition from the stratified load to a homogeneous mode, in the acceleration or NOx release phases, the engine management system actuates the throttle butterfly so that these various operations take place in a transparent manner for the driver.

4 - A specific after-treatment device for the nitrogen oxides (NOx)

The HPi engine that operates in lean mixture generates an excess of oxygen. This led PSA Peugeot Citroën to develop a specific after-treatment system capable of treating both the carbon monoxide (CO), the unburned hydrocarbons (HC) and the nitrogen oxides (NOx), under these specific conditions.

At source, nitrogen oxides were reduced in a significant manner thanks to a high rate of EGR at 30 % (exhaust gas recirculation).

Considering the excess of air, it is impossible to treat the remaining nitrogen oxides on a permanent basis with the traditional three-way catalyst.

PSA Peugeot Citroën developed jointly with the DMC^2 company (Degussa-Hüls) a sequential treatment device that features an NOx storage and release function.

◆ Description of the after-treatment device

It is constituted of a 0.8 litre pre-catalyst located in the vicinity of the exhaust collector whose purpose is to activate itself in a timely manner to treat the CO and HC.

Another 3 litre catalyst located under the floor of the car ensures an NOx storage and release function and a traditional three-way function.

The storage function is ensured by a salt derived from the Barium alkaline-earthy metal that has a specific chemical affinity for nitrogen oxides.

- NOx storage and release function

The active coating of the catalyst is, amongst others, impregnated with platinum, palladium and rhodium, as well as barium salts.

When the engine operates in lean mixture, the nitrogen oxides, fully oxided in nitrogen dioxide (NO_2) on the platinum, are stored in the form of nitrates on the barium-based materials.

Periodically, on average for three seconds every minute, the NOx collected by the catalyst is released by briefly increasing the richness of the combustion mixture.
This operation increases the concentration of CO and HC that act as reducers. The nitrogen oxides are then released and chemically reduced into nitrogen (N_2) on the rhodium.

This storage – release sequence is controlled by the engine management system. It takes place in two fully transparent stages for the driver :

- The engine management system evaluates the saturation state of the storage - release catalyst on a permanent basis. It activates the release of nitrogen oxides (by increasing the richness of the mixture) when the barium salt is saturated.
- When a variation of the oxygen content is detected, corresponding to the moment when all the nitrogen oxides were treated by the CO and HC in excess, the engine management system changes the engine operation, to return to a combustion in stratified load with lean mixture.
  The catalyst can then return to its storage function.

■ Position of the catalyst in the exhaust line and optimum operating window

The treatment of the nitrogen oxides in lean mixture depends on the temperature of the exhaust gases. Beyond 500°C the efficiency of the nitrogen oxide storage – release catalyst is strongly reduced.

Therefore, the catalyst was placed within the exhaust line at a position that ensures a temperature range from 300 °C to 450 °C, window that corresponds to the urban use and during which the system treats more than 90% of the nitrogen oxides. Therefore, the control of urban pollution is especially well taken into account.

On the road, when the temperature exceeds 500 °C, the engine management increases the richness of the mixture that makes it possible to return to an exhaust gas composition that is treated by the traditional three-way catalyst.

3 An engine

especially well adapted to the expectations of our customers

1 - A significant reduction in consumption and in CO_2 emissions

The PSA Peugeot Citroën group designed the HPi engine by selecting the most efficient technological solutions to obtain significant fuel consumption reductions and therefore reduce the releases of carbon dioxide (CO_2) as they are directly linked to fuel consumption.

The reduction of the consumption (in mixed cycle) is 10 % compared to the new EW engine and 19 % compared to the former generation XU engine. In the city, urban cycle (ECE) these reductions are raised to 11 % and 21 % respectively.

◆ The smoother the driving in the city, the lower the consumption

The combustion in stratified load and lean mixture is currently the only solution that makes it possible to obtain significant reductions of the consumption.

The operation in the stratified load is possible up to the mid-load of the engine and up to 3,500 rpm.

This range of use actually nearly covers the urban use as a whole.

Therefore, the smoother the driving in the city, the higher the reduction of the consumption.
On the contrary, if the driving is interrupted by strong accelerations, the engine management system will impose an increase of the richness of the combustion mixture to obtain the requested power.

◆ The influence of the sulphur rate on consumption

The sulphur in the fuel is oxided, during the combustion, into sulphur dioxide (SO_2). The sulphur dioxide SO_2 behaves in the same way as the nitrogen oxides with the barium salt (present in the catalyst). It fixes itself to it and turns into barium sulphate that is chemically more stable than barium nitrate.

The SO_2 causes a gradual loss of efficiency of the catalyst.
To solve this problem, the engine management must periodically activate a regeneration of the catalyst by jointly increasing the temperature and the richness of the exhaust gas.

This operation gives rise to a temporary increase of the consumption whose level is directly linked to the quantity of sulphur in the fuel.

The 10 % consumption reduction of the HPi engine is obtained with a fuel whose sulphur content is of ca. 150 ppm (parts per million), a level that corresponds to the current European regulation.

The reduction of the sulphur content to less than 10 ppm, a level advised by all car manufacturers, will make it possible to space out the desulphation sequences of the catalyst thus preventing a penalisation of the consumption reduction and improving the efficiency of the HPi further.

2 - An increase in the torque and power for more pleasure

At similar engine capacity, the HPi engine provides services enhanced in terms of consumption, torque and power compared to the XU and EW engines.

On a 100 base	Consumption	Torque at low rating	Power
XU 2-litre engine	100	100	100
EW 2-litre engine	90	104	103
HPi 2-litre engine	**81**	**110**	**106**

These good results are notably obtained thanks to :

- The direct injection that made it possible to improve the combustion, efficiency and vivacity of the engine.
- The solution of a distribution with a variable timing of the camshaft that can vary by up to 20°.
- The compression ratio that was raised to 11.4 in order to privilege consumption reduction and performances.

3 - Well controlled exhaust emissions

In conditions of approval, releases of the HPi engine are far below the Euro 3 European regulation that will be enforced in January 2001.

g/km (mixed cycle)	CO	HC	NOx
Euro 3 standard in 2001	2,3	0,2	0,15
HPi Engine	**0,5**	**0,075**	**0,06**
Euro 4 standard in 2005	1	0,1	0,08

These results also show that it is compliant with the Euro 4 regulation that will be enforced in 2005.

HPi engine :
the industrial tool

The HPi engine was designed in 121 weeks and required a budget of FRF 420 million including the studies and industrial investments.

Creation of a new versatile cylinder head machining workshop

The HPi engine will be manufactured in the engine plant of the PSA Peugeot Citroën group at Trémery (Moselle) in Eastern France.

This site already produces diesel engines of the HDI family and petrol engines of the EW indirect injection type whose base is fully utilised by the HPi engine.

In order to ensure a maximum flexibility of the production tool, a new workshop was created to machine the cylinder heads of the HPi engine and of the HDI engines indifferently.

This workshop that required an investment of FRF 300 million is constituted of 48 totally digital fast machining centres.

60 people working in three shifts will be assigned to this workshop to produce 1,400 cylinder heads per day.

The manufacturing of the HPi engine is a good illustration of the group's objectives to increase the flexibility and versatility of the petrol and diesel engine manufacturing lines.

HPi engine :

key figures and characteristics

Number of cylinders	4
Engine capacity	1,998 cm^3
Boring x race	85 x 88 mm
Cylinder head	4 valves per cylinder
Volume ratio	11.4
Torque at 2,000 rpm	170 Nm
Maximum torque	192 Nm
Maximum power	103 kW i.e. 143 bhp at 6,000 rpm

Investment	FRF 420 million
Production	200 engines/day
Marketing	second half year 2000