

COLD START SYSTEM WITH FUEL DISTRIBUTOR EQUIPPED WITH AN ELECTROINJECTOR APPLIED TO AN FLEX FUEL VEHICLE

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***Abstract.** The production expansion of flex fuel engines, in Brasil, is the motivation for technology development and research to improve the engine cold start and functioning, when supplied with ethanol. Along the last thirty years one of the challenges is to develop an engine working with ethanol with the same performance and characteristics of gasoline engines functioning at low temperatures. The use of gasoline as an auxiliary in the cold start system is now the main characteristic of these systems. In this work the performance of a new cold start system is analyzed. Tests were performed in a vehicle and the results show the potential of the new technology.*

***Keywords:** cold start, ethanol, fuel injection, internal combustion engine*

1. INTRODUCTION

The international interest for alternative fuels has stimulated the technological development of internal combustion engines and of the essential systems for the perfect functioning at different operation conditions. The increasing in the production of multi-fuel vehicles using ethanol, gasoline or ethanol-gasoline blend, is an evidence of the focus in alternative fuels, especially in Brazil, in the last five years. The perfect engine operation necessity at different operational conditions led to technological development of components and systems related to combustion due to the necessity to decrease emissions and fuel consumption. One important parameter is use of pure ethanol (E100) or a combination with gasoline at any proportion. The consumer has the benefit to use an ecological fuel and an engine with same performance of one using gasoline, mainly in conditions of low ambient temperature.

The flexible fuel vehicles are equipped with a cold start system that introduces the gasoline in the intake system in order to promote start-up and good performance at low temperature, especially when the vehicle is fueled by ethanol only or by a high ethanol proportion blend. In such case use of gasoline at cold start and warm-up is extremely necessary, considering that ethanol presents high latent heat of vaporization and ethanol distillation starts at the temperature around 78° C (Owen, K., and Coley, T., 1995). Under normal conditions, an ethanol fueled engine will not start at a temperature below 13° C (Silva and Sodr , 2000).

The cold start systems are still object of research, aiming at the improvement of vehicle performance (start and drive ability) and exhaust emissions at low temperature. Normally the auxiliary cold start system uses gasoline and consists of a small gasoline tank, an electrical pump and an electrical valve, which adds gasoline into the air intake system through a tube with one or more calibrated holes. Gasoline is added during cold start and warm up acceleration. The amount of injected gasoline is controlled by the engine electronic control module by means of the electrical pump and the electrical valve. The control of the quantity of injected gasoline into the intake manifold and the distribution among the cylinders influences cold start and warm up acceleration, exhaust emissions and fuel consumption.

This work introduces the new cold start equipped with the gasoline flow distributor with the electronic fuel injector applied in a vehicle with the flex fuel engine 1.4 l. The new cold start system used allows for simultaneous gasoline introduction through calibrated orifices in the four conduits of the intake system. This system has an electrical injector (nozzle) that controls the gasoline flow in a fuel distributor, which is connected to an intake manifold. The fuel distributor is composed by one input orifice and four outputs with calibrated holes, meaning that there is one calibrated hole for each engine cylinder. The main difference between the system proposed and the conventional ones is the presence of an electrical injector that allows for a precise adjustment to the gasoline flow according to the engine operating condition. The vantages in comparison with the conventional systems is the possibility of better spray direction (directly to cylinder inlet), avoiding fuel losses at the intake walls and the hole position permit the spray

development. These characteristics are very important in complex intake manifolds. The electrical injector is generally designed with one or more holes in its end. In the system with fuel distributor presented in this paper, the calibrated orifices are displayed in each ramification of the intake conduit. This system was presented by Sales et al (2007) using the numerical and test bench experimental analysis. The researches demonstrate that calibrated holes diameters located in a strategy position in an intake manifold can be used for more uniform distribution atomization of gasoline to the engine cylinders.

Despite the new technologies that use the warm ethanol (Brunocilla M. F. and Lepsch F., 2006) and did not use the gasoline in order to auxiliary the cold start, until now did not demonstrated that is possible promoted the cold start under -5°C without gasoline. This condition is possible in many countries. In USA is used the E85 (blend ethanol with gasoline 15%) in order to avoid the cold start system. Concerning that pure ethanol could be used in this countries the new system proposed in this work will be important and could be use as the simple solution in order to use the gasoline during only a few minutes (during cold start and warm up). The objective of this work is to analyze experimentally the dynamic behavior of this cold start system under low temperatures (-2°C , -5°C and -13°C) by cold start tests using a flex fuel engine operated with ethanol (E100).

2. LITERATURE REVIEW

The use of alternative fuels like ethanol and methanol induced researches to study systems and procedures to minimize problems related to combustion of these fuels at low temperatures. Ethanol has a low vapor pressure (2,3 psi compared with a gasoline range of about 8 to 15 psi) and the high latent heats of vaporization (Owen, K., and Coley, T., 1995). Consequently, the engines operated with ethanol under low temperature presented difficulties to starting and warm-up performance.

Basically, the main strategy used in order to minimize this problem is the use of advices that feed fuel with the blend with more volatile composites. The fuel atomization is another important characteristic that strongly influences the combustion. Annand and Gulder (1980) performed experiments with an engine using ethanol as fuel. The results collected from a carburetor equipped with an atomizer performed showed a quicker cold start in comparison to the conventional carburetor. Kito et al (1998) investigated ethanol dissociation into diethyl ether and water steam to improve cold start. With conversion from 40 to 80% of ethanol into diethyl ether and water, cold start at temperatures much lower than that limit of pure ethanol was obtained. Silva and Sodr  (2000) evaluated the use of methyl tert-butyl ether (MTBE) in ethanol for cold start improvement. Pure ethanol was not able to start up the engine at temperatures below 13°C , agreeing with the observations by Kito et al (1998). A mixture of 75% ethanol and 25% MTBE allowed for cold start at temperatures as low as -6°C .

Same works about the engines operated with methanol demonstrate that the addition of gasoline has constituted the main resource used to improve cold start in ethanol-fueled engines. Researchers have shown that addition of high volumes of gasoline into methanol made possible reduction of the minimum cold start temperature, as was observed in tests performed by Iwai et al. (1981). Haatela and Decker (1989) showed that addition of 10% gasoline in methanol propitiated the engine to reach start up temperatures down to -25°C .

In the vaporization and gasoline research line, Sales and Sodr  (2002) performed comparative tests of conventional cold start system (gasoline addition through a tube with calibrated holes) with a system equipped with an electrical injector in the intake manifold of an ethanol-fueled engine. It was shown that the use of an electrical injector allowed for adequate addition of gasoline to shorter, regular cold start, mainly due to the effect of atomization and better control of the gasoline quantity injected. Cold start and warm up acceleration were performed using a leaner fuel/air mixture (fewer amounts of ethanol and gasoline). Later, Sales and Sodr  (2003) demonstrated it was also possible to reduce considerably the level of air pollutant emission (hydrocarbons, carbon monoxide and aldehydes) from an ethanol-fueled engine during warm up. Nowadays this cold start system with an electrical injector is used in normal production vehicle (Linea 1.9 16V Flex) in Brazil.

Sales et al (2007), demonstrate numerically and experimentally the possibility that use a cold start system equipped with fuel flow distributor with an electronic fuel injector. With a fuel flow distributor is possible, by calibrated holes for each intake conduit, to promote the gasoline atomization controlled by an electronic injector. This system represents a evolution of the system presented by Sales and Sodr  (2002 and 2003), because it allows the gasoline atomization, uniform gasoline flow distribution between cylinders and the correct gasoline flow direction to the intake valve with low fuel losses.

3. METHODOLOGY

3.1. Experimental Apparatus

In this work experimental tests were done using a vehicle equipped with a Flex Fuel engine 1.4 l 8V. The new cold start system proposed was installed in the intake manifold in order to perform tests under low temperatures inside a climatic chamber. Fig. 1 presents the gasoline fuel distributor with the electronic injector and the Figs. 2 and 3 present the intake manifold fixed with the system. In Figs 2 (b) and 3 is possible to see the advantages in comparison with the conventional systems. The possibility of better spray alignment (directly to cylinder inlet) avoids fuel losses at the intake walls and the orifice position permit the spray development. These characteristics are very important in complex intake manifolds. The cold start system with fuel injector and distributor is basically composed by a gasoline tank, an electrical fuel pump, a fuel injector, a modulator for injector opening and closing, a line for gasoline conduction and introduction into the ramifications of the intake manifold through calibrated orifices placed in their respective ends. The orifices diameters used in this work were 0.6 mm. The time modulator of injector was connected at the position of electrical valve used in a conventional cold start system, thus instead of the electrical valve actuation during cold start the time modulator commands the electronic fuel injector. The time modulator of injector opening and closing makes possible the adjustment to the quantity of injected gasoline in the intake manifold. Its voltage should be 12 Volts, constituted by a variable oscillator that defines how long the injector is held open and close in a certain unit of time, by a potentiometer that allows the wavelength modification. The band frequency in which the modulator works is from 70 Hz to 840 MHz, meaning that the time it is held open and close can be adjusted from 14.3 ms to 1.2 s. There is also the possibility of having a steady state flow at a constant pressure. The gasoline flow rate adjustment was done after the test inside the cold camera. In this work the ethanol flow did not modified related the adjustment already done for the conventional cold start system, but if is necessary to do the special adjustment for the blend the ECU (Electronic Central Unit) commands could be used to combine with the gasoline flow. A manometer (measurement band up to 4.0 bar, with resolution of 0.1 bar) were installed to monitor the system during flow verification tests. Figure 4 shows the flow gasoline adjustment procedure and the detailed of the experimental device is showed in the Fig. 5. The temperature range of the test camera could be adjusted at low temperatures and is possible operated the vehicle inside it without open the door. The parameters like rotational engine velocity (rpm), intake air temperature, time, battery tension were obtain by ECU and recorded in a computer.

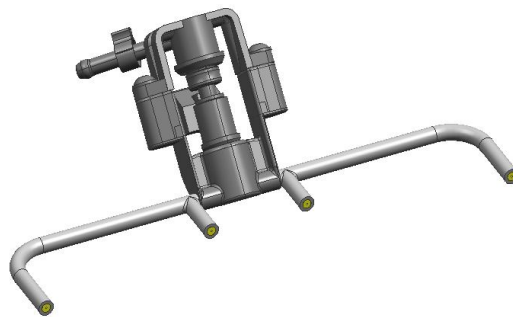


Figure 1 - Detail of fuel distributor with electrical injector.

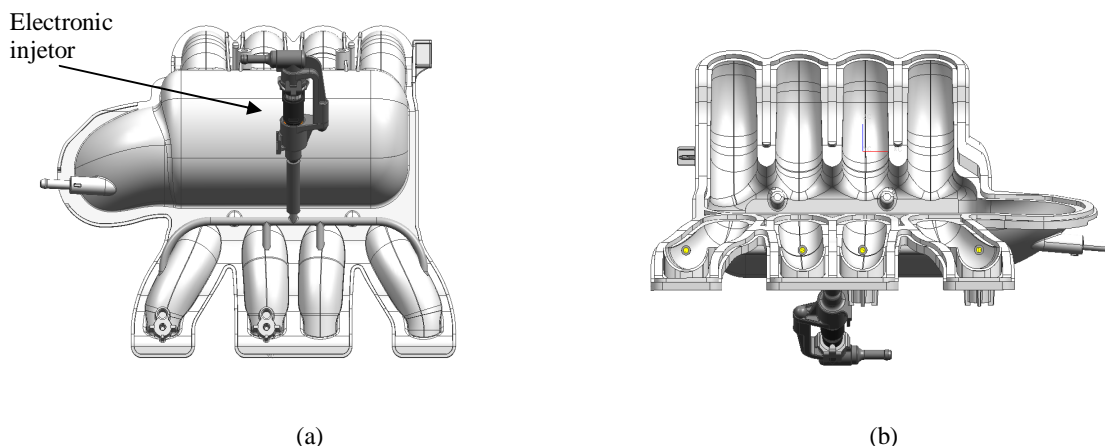


Figure 2 – (a) Posterior view with the fuel distributor with electrical injector coupled in intake manifold and (b) calibrated holes into intake manifolds conduits.

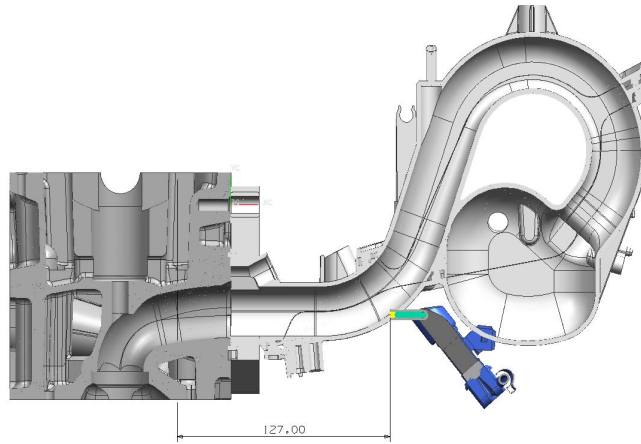


Figure 3 – Side view of intake manifold with the gasoline distributor.

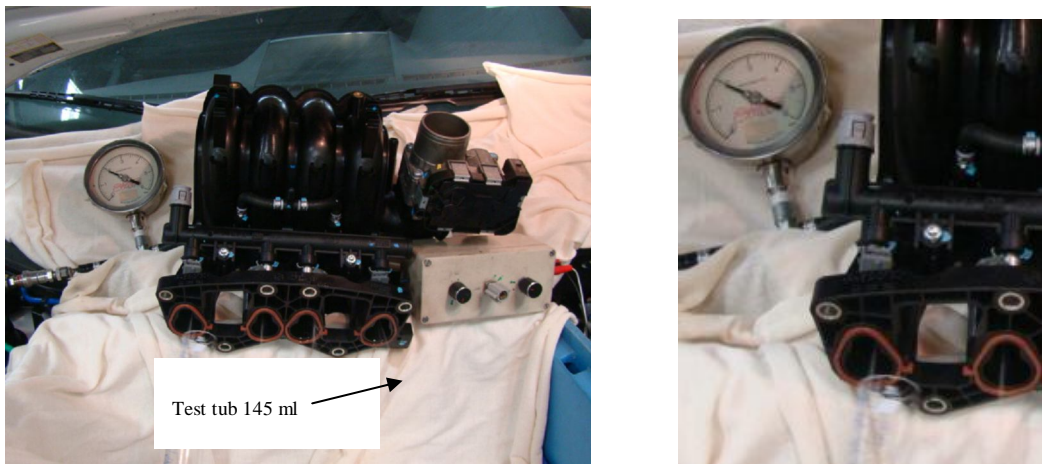


Figure 4 - Flow gasoline adjustment procedure with the collect spray detail into test tub.



Figure 5 – Overview of experimental device in vehicle.

4.RESULTS AND DISCUSSION

4.1. Gasoline flow adjustment

After the cold start tests the gasoline flow was experimentally adjusted. The gasoline flow rate depends on the ambient temperature. Than for the tests under -2°C , -5°C and -13°C the gasoline flow adjusted for approximately 1.2 ml/s (0.00088 kg/s) each orifice. The gasoline flow rate adjustment of the distributor with calibrated holes with 0.6 mm was done with the same procedure that Sales et al (2007) presented in dynamic operation of the electronic injector in the experimental test bench of this same device. The adjustment of the gasoline flow, which is required to cold start and warm up acceleration, can be performed by the control of the opening and closing frequency of the electro injector. The Tab. 1 shows the gasoline volumetric flow rate through calibrated orifices with diameter of 0.60 mm during the dynamic operation of the electronic injector. The measurements of the injected volume in each intake manifold extremity were done every 10 seconds (measured with a resolution of 0.01 s) under a pressure of 2.0 bar at inlet distributor. The volume samples were collected in a 145 ml test tube, with resolution of 1.0 ml. The small between holes can be attributed to small deviations due to the manufacturing process. During the dynamic operation of the electro injector the uniformity in four output holes of the fuel distributor was also verified. The flow control while the uniformity of the flow among the cylinders is guaranteed can make possible the use of the cold start system with electro injector and fuel distributor in many engines using ethanol or “Flex Fuel” technology.

Table 1 - Results (at 25°C) from dynamic operation of the electro-injector.

Samples	Hole 1 (ml/s)	Hole 2 (ml/s)	Hole 3 (ml/s)	Hole 4 (ml/s)
1	1,20	1,30	1,20	1,20
2	1,20	1,30	1,20	1,20
3	1,30	1,20	1,30	1,20
4	1,20	1,20	1,20	1,20
5	1,10	1,20	1,30	1,30
Average (ml/s)	1,20	1,24	1,24	1,20
Average (kg/s)	0,00088	0,00090	0,00090	0,00088

4.1. Cold start tests

In order to demonstrate the new cold start system functionality cold start tests were performed at three different ambient temperatures: -2°C ; -5°C and -13°C . For each configuration was used the same gasoline flow rate adjustment. The results are shown in Figs. 6, 7 and 8, respectively for -2°C , -5°C and -13°C . The diagrams present the mainly parameters that are necessary to be controlled during the cold start tests (intake air flow and coolant temperatures, rotational engine velocity, battery voltage).

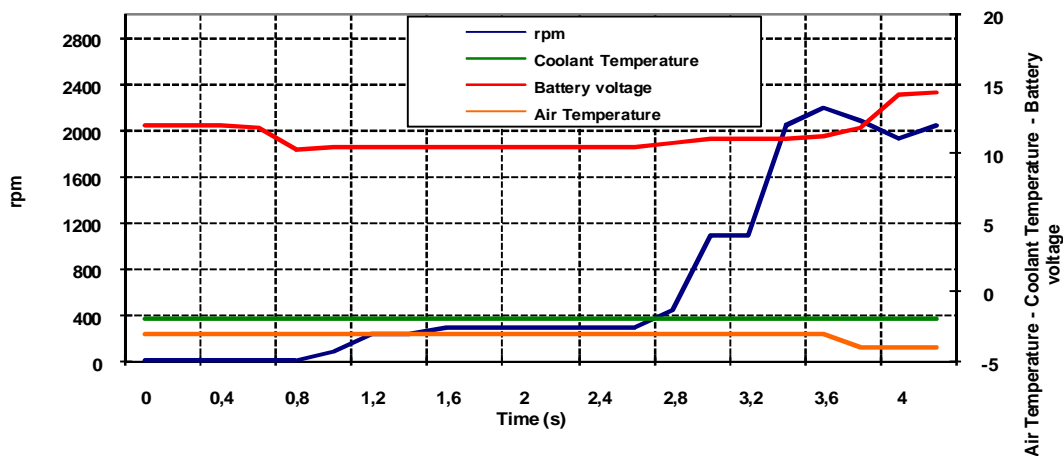


Figure 6 – Cold start test under -2°C with the mainly parameters.

The battery tension goes down (12 to 10 V) when the engine is started. The engine is considered in operation when the rotational engine velocity achieves 800 rpm. The tests under -2°C and -5°C present similarly results (Figs. 6 and 7), in these conditions the cold start mean timing were 2.0s and 2.2s, respectively.

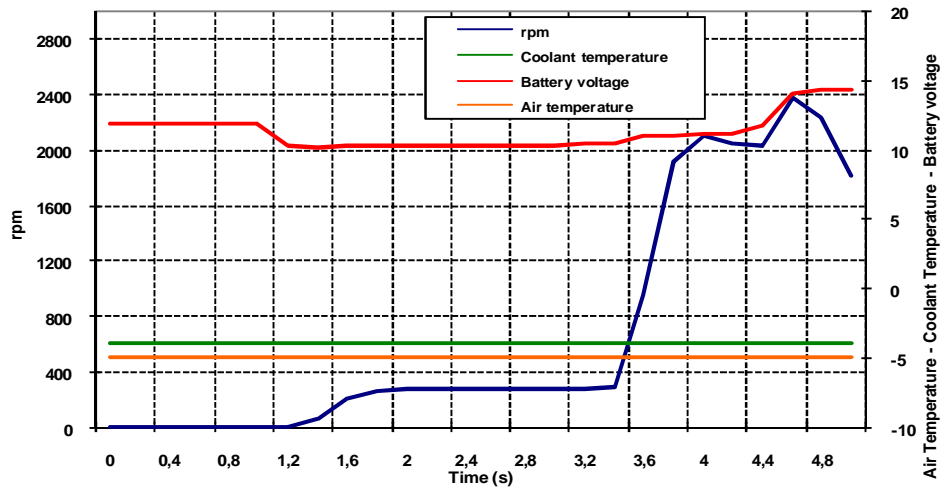


Figure 7 – Cold start test under -5°C with the mainly parameters.

The test under -13°C (figure 8) presented the cold start mean timing was 2.0s and the rotational velocity wasn't increase uniformly. This result could be explained by gasoline flow rate, because is necessary increase the mixture vapor pressure by gasoline rate flow (Haatela and Decker, 1989). Considering that the engine operates with ethanol normally are tested until -5°C , the results close to 2.0s are considered satisfactory, because it is the usually target.

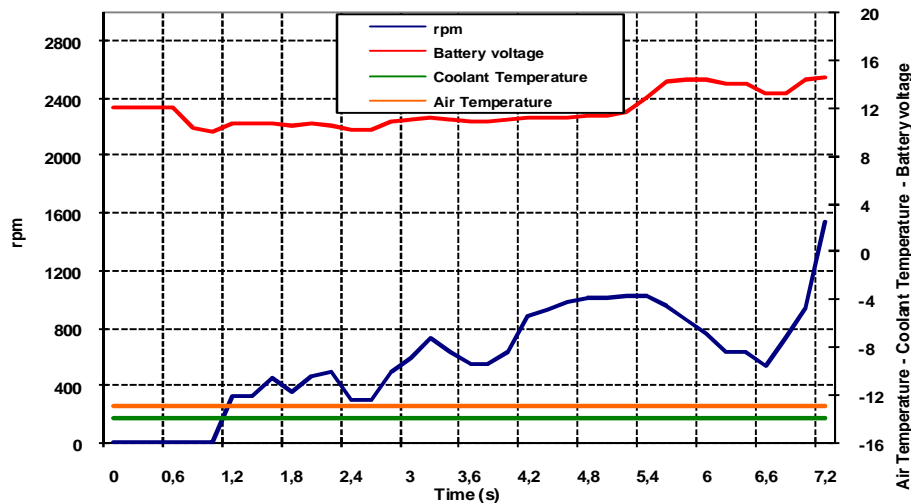


Figure 8 – Cold start test under -13°C with the mainly parameters.

The mainly subject of this work is demonstrate to the functionality of the new cold start system, then for the future works is recommending improve the gasoline flow rate for ambient temperatures below -5°C , in order to optimized the cold start timing and rotational velocity behavior. It is possible because the new cold start system permit the gasoline flow rate adjustment by variation electronic fuel injector frequency.

5. CONCLUSION

The cold start system presented in this work demonstrated that is possible a cold start with ethanol under low temperatures, mainly if is considerate bellow -5°C . This system can be a good alternative to utilization the flex fuel engine in critical climate condition for ethanol. With electronic engine controls and the electronic fuel injector characteristics is possible to adjustment the gasoline flow rate in order to optimized cold start timing. The utilization the

gasoline only during the cold start could be important in order to analyze the impact in exhaust emission and drive ability.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

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