Agronomy Research Biosystem Engineering Special Issue 1, 55-74, 2012

Study of prior art of spark ignition engine fuel supply system

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Abstract. The technical development of contemporary fuel supply systems is vast. Reasons for development include improving the economical parameters of engines as well as decreasing the concentration of exhaust fumes. The aim of this particular article is to define, firstly, the technical standard of the fuel supply systems of spark ignition combustion engines, and secondly, the validity of the given patent. For these purposes, a literature-based overview of the engines' fuel supply systems, their developments and most pertinent parts will be provided. The structural specialties of fuel supply systems are analyzed and their suitability for using bio fuels will be reviewed. Innovative solutions for upgrading the fuel supply systems so that liquid bio fuels could be used in spark ignition engines will be given.

Key words: mono injection, multipoint injection, manifold-injection, direct-injection, FSI, HCCI, D-jetronic, bifuel-motronic.

Introduction

One of the most important parts of a combustion engine is its fuel supply system. The functions of a fuel supply system include forming the air fuel mixture and directing it into the cylinder. Several types of fuel supply systems are used in spark ignition engines. One of the first widely-spread elements of a spark ignition engine's fuel supply system was the carburetor where, due to the effect of underpressure, the mixture is formed by combining the fuel being sucked through the nozzle head and the air passing through the choke. The fuel level in the carburetor is maintained by a float which regulates the amount of the fuel going into the carburetor according to the fuel consumption of the engine. (Pulkrabek, 2009; Taylor, 1985). Carburetors were constantly developed to higher standards; however, the drawback of a carburetor is the complicated controlling of the air fuel mixture's forming process. Adding electronic components to the carburetor did not demonstrate the anticipated results and the construction of the carburetor became extremely complicated. Therefore, injection systems which made it possible to control the forming of the air fuel mixture in a more precise manner were taken into use. The first injection systems were called 'Jetronic' systems which was also the initial trade mark of gas engine injection systems. Injection systems had been used earlier as well – in the 1930's – in aviation and motor sport. Despite this fact, Robert Bosch GmbH has categorized the development of injection systems according to their use in consumer vehicles. The particular categorization is given in Table 1.

Table1. The injection systems of spark ignition engines according to Robert Bosch GmbH (Robert Bosch GmbH, 2006)

Year	System	Features
1967	D-Jetronic	Analog-technology; Multi-point injection system intermittent fuel injection; Intake-manifold-controlled
1973	K-Jetronic	Mechanical-hydraulic multi-point injection system; Continuous fuel injection
1973	L-Jetronic	Electronic multi-point injection system, initially analog later digital technology; Intermittent fuel injection; Air-flow sensing
1981	LH-Jetronic	Electronic multi-point injection system; Intermittent fuel injection; Air-mass sensing
1982	KE-Jetronic	K-Jetronic with electronically controlled additional functions
1987	Mono-Jetronic	Single-point injection system; Intermittent fuel injection; Air-flow calculation via throttle-valve angle and engine speed
	Motronic	
	M-Motronic	Mechanically regulated throttle valve; The positioning sensor of the throttle valve
	ME-Motronic	Electronically regulated throttle valve; Potentiometer-type of gas pedal
	DI-motronic	Direct injection
	Bifuel-Motronic	Dual fuel system

The 'Motronic' trade mark stands for the control systems of gas engines which compare all the necessary parameters for the engine to work and control the work of subsystems. The conducted subsystems include the injection system, ignition system, the control system of exhaust fumes, etc. Contemporary gas engines are all equipped with a 'Motronic' control system. The fuel that is most commonly used in the previously mentioned fuel supply systems is either gasoline or ethanol fuel E85. In addition, the control system is able to control the work of an engine equipped with a biogas fuel supply system. (Robert Bosch GmbH, 2006; Robert Bosch GMbH, 1998).

Subsequently, the article provides an overview of spark ignition engines' fuel supply systems, their constructional specialties and issues. Trends in developing new fuel supply systems will be given and different options in upgrading the fuel supply systems for using liquid biofuels in spark ignition engines will be provided. The main aim is to come up with innovative solutions for advancing the additional fuel supply systems. More precisely, the idea is that the engine would have two fuel supply systems – firstly, the main fuel supply system for using a standard fuel, and secondly, an additional fuel supply system for using bio fuels in the engine. (Bedoya, et al., 2009).

Material and methods

The following databases were used to search for patents – Espacenet and Google patents (over 70 million and over 8 million patent documents). During the research, it became evident that due to searching for keywords throughout the patent documents, Google patents provides more results. The retrospective of patent search is 45 years.

Table 2. Characteristics of fuel supply systems

Characteristic	Jetronic		Jetronic	Jetronic		Motronic	Jetronic	Motronic	Motronic		
	K	KE	D	L	LH	M	mono	mono	ME	DI	BiFuel
	US4257375		US4696275	US4481928			US4782806		US20040011326		US5890459
Hydraulic injection system	+	-	-	-	-	-	-	-	-	-	-
Electro-hydraulic inj. syst.	-	+	-	-	-	-	-	-	-	-	-
Electronic injection syst.	-	-	+	+	+	+	+	+	+	+	
Multi-point injection	+	+	+	+	+	+	-	-	+	+	+
Mono-injection system	-	-	-	-	-	-	+	+	-	-	-
Indirect injection system	+	+	+	+	+	+	+	+	+	-	-
Direct injection system	-	-	-	-	-	-	-	-	-	+	+
Constant injection system	+	+	-	-	-	-	-	-	-	-	-
Separated injection system	-	-	+	+	+	+	+	+	+	+	+
Injection control:											
Mono:	-	-	-	-	+	+	+	+	+	+	+
Dual:	-	-	+	+	-	-	-	-	-	-	-
Complex:	+	+	-	-	-	-	-	-	-	-	-
Air flow measuring by a pressure sensor	-	-	+	-	-	-	-	-	-	-	-
Flat, mechanically dosing air flow measuring device	+	+	-	-	-	-	-	-	-	-	-
Flat, electronic air flow measuring device	-	-	-	+	-	-	-	-	-	-	-
Hot wire/hot film air flow measuring device	-	-	-	-	+	+	-	-	+	+	+
Karman Vortex type of air flow measuring device	-	-	-	-	-	+	-	-	+	+	+
’close loop‘ lambda control	+	+	+	+	+	+	+	+	+	-	-
Broadband lambda	-	-	-	-	-	-	-	-		+	+
Analog technology	+	+	+	+	+	-	-	-	-	-	-
Digital technology	-	-	-	+	+	+	+	+	+	+	+
Mechanical throttle valve	+	+	+	+	+	+	+	+	-	-	-
Electronic throttle valve	-	-	-	-	-	-	-	-	+	+	+
Stratified air fuel mixture formation	-	-	-	-	-	-	-	-	-	+	+
Volumetric air fuel mixture formation	+	+	+	+	+	+	+	+	+	+	+
Dual fuel supply systems	-	-	-	-	-	-	-	-	-	-	+

Some countries that are included in the patent search systems include USA (US), Australia (AU), Canada (CA), Switzerland (CH), Germany (DE), United Kingdom (GB), France (FR), Russia (RU), et al., During the patent search, Table 2 was drawn up. It provides the main characteristics of spark ignition engines' fuel supply systems, furthermore, the fuel supply systems that share similar characteristics have been drawn together. In the table, '+' marks an existing characteristic whereas '-'marks an absent characteristic. Based on the abovementioned table, key words for patent search were listed. The results of the patent search using these key words are given in Table 3.

Table 3. Results of the patent search from databases using key words

Type	Key word	Espacenet results	Google patents results
K and KE-jetronic	Internal combustion engine; Spark ignition; Fuel injection; Mechanical air flow meter; Injection system; Multi injection	**24**	**147**
D-jetronic	Fuel injection; Intake manifold pressure sensor; Atmospheric pressure	**8**	**38**
L, LH, M jetronic, motronic	Internal combustion engine; Intake air flow meter; Fuel injection system; Engine, fuel; Multi injection	**55**	**626**
Mono jetronic, motronic	Internal combustion engine; Mono injection; Intake manifold; Fuel supply system; Rate and timing	**5**	**65**
ME, DI motronic	Internal combustion engine; Downstream nozzle; Direct injection; Spark ignition	**3**	**5**
BiFuel	Spark ingnition; Dual fuel; Direct injection	**3**	**133**

When conducting a similar search, the fact that several search engines of different databases look for keywords in the full texts of the patent documents should be kept in mind. For this reason, the number of results may increase drastically. One of the solutions to avoid this problem is to limit the search. The keywords provided in Table 3 were used in different combinations to decrease the number of results. The patent search rendered numerous results from which many did not conform to the characteristics in Table 2 (information pollution). For this reason, only some of the patents that characterize different fuel supply systems and their supplements were chosen. These particular patents are given in Table 2 and the subsequent analysis is based on them. The working principle and categorization of fuel supply systems and their more important subsystems is then given.

Description

Throughout the development of spark ignition engines, the fuel supply systems have become more complicated. One of the first fuel supply systems was a multipoint system (US4257375) characterized by a hydraulic fuel dosing principle. In this system, the amount of fuel is regulated by a precise plunger which is operated by a force arm connected to the flat of the air consumption measuring device. The amount of fuel dosed depends on the pressure created in the fuel distributor. The fuel distributor contains two chambers separated by a membrane whereas the pressure in the lower part of the membrane is used to regulate the fuel influx into the injectors. If the pressure under the membrane is higher than above the membrane, the influx into the injectors is blocked by a valve on the membrane. Fuel injection is a constant process, according to the position of the air consumption measuring device. In the previously mentioned system, flat air consumption measuring devices were used. According to the patent document US7958866, newer systems took advantage of the electronic lambda control systems (close loop type). What is more, an electronic sensor for measuring the air consumption was added as well as the electronic pressure regulator to regulate the pressure in the fuel distributor. This system was widely used in the aviation and car industries. (Robert Bosch GmbH, 2006).

The hydraulic fuel supply system developed into an electro-hydraulic fuel supply system, where the mechanical pressure regulator in the fuel distributor was replaced with an electronic pressure regulator (Robert Bosch GmbH, 2003).

The pressure regulators of liquid fuel supply systems have developed from mechanical into electro-mechanical. Mechanical pressure regulators are mainly comprised of a frame, a compression spring, a membrane and openings for influx and outflow (US4235211). Different options for regulating the pressure in electro-mechanical pressure regulators are used. One of these options is to change the position of the nozzle or the plate using a solenoid winding or an electric engine (US20110000463). Regulating the pressure is made possible by changing the distance of the nozzle/plate in relation to the fuel influx or outflow opening. (Robert Bosch GmbH, 2001). The wider the opening, the smaller the pressure is in the system. Some issues of such a system include the electronically complicated control system and achieving the stability of the fuel pressure in rapid changes of the working modes. To solve these issues, the pressure regulators began to be controlled using pulse-width modulation. (US20110220066). The fuel flow is mostly regulated using pistons or needle valves that move on the frequency ~1 kHz. Pressure regulation happens when the fill factor of the pulse-width modulation is changed on the given frequency. The bigger the fill factor, the longer the piston/needle valve stays in a closed position and the bigger the pressure in the system (Robert Bosch GmbH, 2006). Such regulators are mostly used in high pressure lines, but they could also be applied in the previously mentioned fuel supply systems. The wearing parts of these regulators are the piston and the needle valve. Once they wear out, the fuel will flow into the outflow opening even if the regulator is in the closed position.

The main drawbacks in these types of fuel supply systems were the breaking of the pressure regulating membrane in the fuel distributor and the clogging of the sieve of the reflux opening. The reason for the breaking of the membrane is the impact of the gasoline and the formation of paraffin on the membrane.

For the more accurate dosing of the fuel, electronically controlled fuel supply systems were designed. The principle of forming the air fuel mixture in the first electronically controlled fuel supply system was based on measuring the underpressure in the intake manifold (US6276341). The amount of the fuel injected is defined according to the signal measured from the sensor. Each cylinder has a separate injector; however, injection takes place on two injectors at one time. Nevertheless, the amount of fuel calculated on the basis of the pressure sensor signal is not always accurate. It depends on the changes in air humidity, density and temperature. To solve this, the pressure sensor was replaced with an electronic air consumption measuring device, which was substantially more reliable and enabled a more precise control of the forming of the air fuel mixture. Furthermore, the first injection systems included flat air consumption measuring devices. In the hydro-mechanical and electro-hydraulic fuel supply systems, the amount of the fuel injected is controlled by changing the position of the flat of the air consumption measuring device. The force arm of the air consumption measuring device regulates the position of the plunger in the fuel distributor. The amount of the fuel depends on the position of the plunger. Such a solution (US4403588) could be called a flat air consumption measuring device which also has the function of dosing the precise amount of fuel (Fig. 1a). In case of electronic fuel supply systems, a flat-type air consumption measuring device (US4481928) is used whereas the position of the flat is proportional to the amount of air (Fig. 1b) (Soodla, 2010). In fact, a flat-type air consumption measuring device inhibits the influx of air into the engine. The resulting charge ratio characterizes the filling of the cylinders with the air fuel mixture in engines. All in all, constructing flat type air consumption measuring devices is complicated as well as costly.

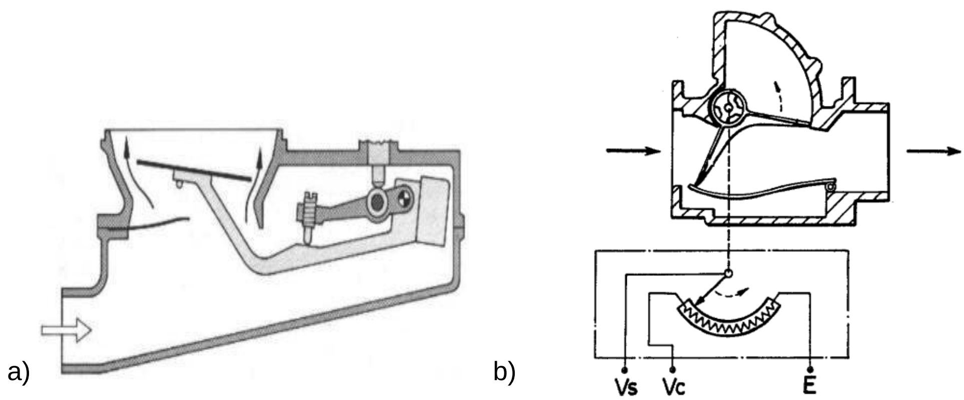


Fig. 1. Flat air consumption measuring devices: a) a flat type with the function of dosing the precise amount of fuel (Robert Bosch GmbH); b) a flat type electronic air consumption measuring device.

Flat air consumption measuring devices were replaced by hot wire air consumption measuring devices, which measure the mass of the airflow (US4986115). The platinum wire is heated 100°C above the surrounding temperature. In the proximate distance from the heater, there is a temperature sensor. During the motion of the airflow, the heater is being cooled down which causes an increase in the current being directed through the heating element. This secures the constant temperature of the heating element. As the cooling effect is directly dependent on the air temperature, humidity and density, the current flow permeating the heater is proportional to the air mass going into the engine. The hot wire element is sensitive to soiling. That is the reason why heating modes of a high temperature (~1,000 °C) are used to clean the element. (Robert Bosch GmbH, 2002; Heisler, 1995). According to the patent document US6701781, an analogue to the hot wire element is a hot film element. A hot film element is not as sensitive to soiling and does not require cleaning modes. When using the hot film element, the temperature maintained is ~70°C above the surrounding temperature. The principle schemes of hot wire and hot film air consumption measuring devices are demonstrated on Fig. 2 (Soodla, 2010).

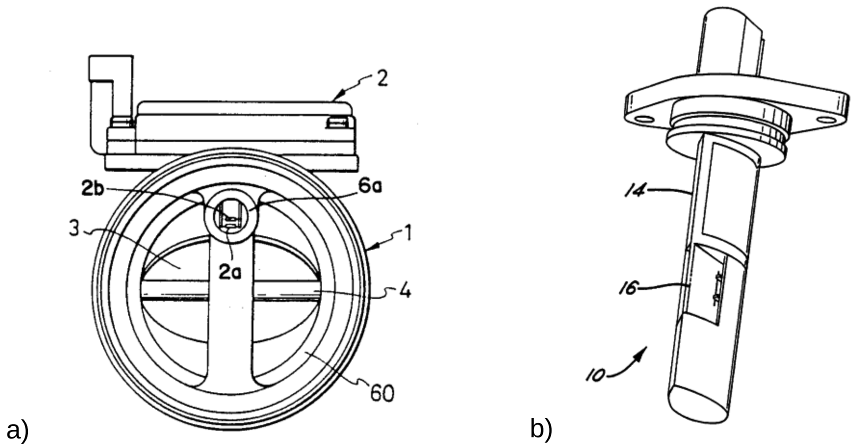


Fig. 2. Air consumption measuring devices with a heating element: a) a hot wire air consumption measuring device; 1) the frame of the measuring device; 2) an electronic control system; 2 b) a hot wire element; (US4986115) b) a hot film air consumption measuring device; 14) the frame; 16) a hot film element; 10) a hot film sensor (US6701781).

Nevertheless, hot film air consumption measuring devices can be direction-sensitive to the airflow (US2003/0070494). While the intake valves close, some air might exit by the intake manifold. Measuring the air that exits may provide an opportunity to define the air-fuel ratio in the cylinder more accurately. The working principle of the sensor is based on the heating element that heats the temperature sensors. If the airflow is directed into the engine, the temperature sensor which is placed after the heating element is heated. The voltage of the sensor depends on the temperature. If the airflow is directed out of the engine, the temperature sensor placed before the heating element is heated due to the airflow. According to the changes in temperature, the air mass is determined.

Fig. 3 depicts the relation between the voltage of the sensor of the hot film air consumption measuring device and the air mass. Most often, the voltage and the frequency are used as the output signals of the sensor.

Parallel to the hot wire and hot film sensors, the Karman-Vortex type of air consumption measuring devices were also developed. Some advantages of these include the small resistance to the airflow, the simplicity of the construction, faster reaction and little sensitivity to soiling. The working principle of the sensor is based on creating turbulence behind a stationary object. The airflow increases simultaneously with the turbulence. The changes in turbulence can be measured in several ways. To measure the change in the pressure behind the object causing the turbulence, a LED, a mirror and a light-sensitive sensor are used. The mirror is attached to an elastic and delicate spring and is placed by the opening, which causes the reflection of the light (that is directed from the LED to the mirror) on a photo sensor. The vibration of the mirror generates a digital signal on the photo sensor (US4836016). The increase of its frequency is linear to the increase in the air flow speed (Soodla, 2010; Zhang, et al., 2006).

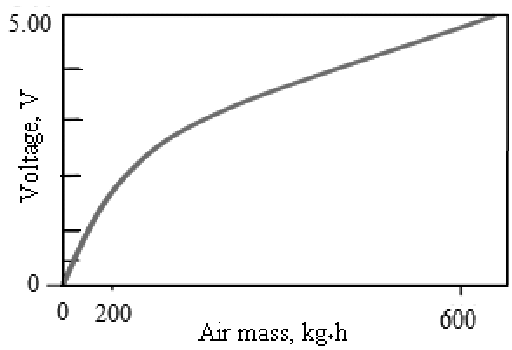
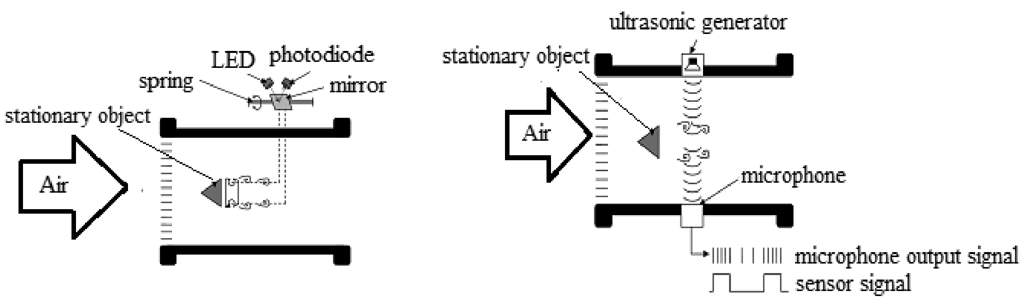


Fig. 3. The relation between the voltage of the sensor of the hot film air consumption measuring device and the air mass (Soodla, 2010).

When using an ultrasound method, a small speaker sends an ultrasound of consistent frequency through the microphone of the turbulence area. As the airflow increases, the turbulence increases as well, thus, the bigger the interference of the signal. The control block of the sensor interprets the interference of the signal as a frequency signal, which in turn is in immediate relation to the airflow mass. The frequency signal is converted into a voltage of 0….5 V. The higher the sensor voltage, the greater is the mass of the airflow (US4392385, 5398548). The principles of the optical and ultrasound sensors are given in Fig. 4.



a) b)

Fig. 4. Karman-Vortex type of air consumption measuring devices (Soodla, 2010): a) light-sensitive sensor; b) ultrasound sensor.

For the purpose of forming the air-fuel mixture more precisely, oxygen sensors were taken into use. Air consumption measuring devices enable to determine the amount of fuel required in the engine at any given time; however, for the more precise forming of the air-fuel mixture, it was necessary to measure the amount of residual oxygen in the exhaust fumes. Lambda is a mathematical expression that characterizes the ratio of air and fuel. Lambda is expressed in the formula (Soodla, 2010):

$$\lambda = \frac{A_{actual}}{A_{theoretical}}, \qquad (1)$$

where A_{actual} – the actual ratio between air and fuel mass;
$A_{theoretical}$ – the theoretical mass ratio of air and fuel needed to burn the fuel.

$\lambda < 1$ characterizes a rich air-fuel mixture whereas $\lambda > 1$ characterizes a lean air-fuel mixture. Moreover, oxygen sensors can be divided into narrow-band and broad-band devices. Narrow-band sensors can in turn be divided into zirconium and titan sensors according to their working element. The first of these consists of two porous platinum electrodes and the ceramic zirconium oxide electrolyte between them. The sensor generates a low voltage (100…900 mV) depending on the concentration of oxygen in the exhaust fumes. Basically, the oxygen in the exhaust fumes is compared to oxygen in the air. What is more, the sensor provides consistent information on the concentration of oxygen in the exhaust fumes. When the engine is running, the concentration of oxygen in the exhaust fumes changes constantly. This is caused by the continuous changing of the fuel amount to ensure the stoichiometric air-fuel mixture in the cylinder (e.g. US5277781 and US4266979), (Tiitsu et al., 2004).

The distinctive feature of the titan sensor is the changing of the measuring element's resistance according to the concentration of oxygen in the exhaust fumes. The sensor does not need air oxygen to work, which, thus, makes it less accurate than the zirconium sensor. Nowadays, titan sensors are mostly used on vehicles working in extreme conditions (power vehicles).

The broad-band oxygen sensor's working characteristic is substantially different from those of titan and zirconium sensors (US6978655). The broad-band oxygen sensor is able to measure the excess-air coefficient in the range of 0.7... ∞. At this point, infinity marks measuring the amount of air oxygen. This means that a broad-band oxygen sensor can be used to define how rich or lean the air-fuel mixture is. The functioning of the broad-band sensor is based on a narrow-band zirconium sensor, which is connected to the pump element and the diffusion chamber. The pump element is able to consume oxygen or burn fuel particles in the cavities of the pump element, depending on the direction of the pump current. While the sensor is working, a small amount of exhaust fumes pass through the diffusion opening into the pump element. Depending on the air-fuel mixture, the comparison element generates the voltage. Therefore, if the air-fuel mixture is rich, the voltage generated is higher than the comparison voltage. The control system generates a pump current of certain polarity according to the voltage. The process is reversed in case of a lean air-fuel mixture. In the balanced position of the sensor, the pump current is a value characterizing lambda (Soodla, 2010).

To continue, another development stage of the fuel supply systems was the mono injection system (US4782806). These were mostly used in four-cylinder engines to ensure the identical air-fuel mixture in the cylinders. The most important sensor of this system was the oxygen sensor – its signal was the basis for the control module to regulate the air-fuel mixture in the cylinders. The main problem with this particular system was the dependence of an engine's work on the oxygen sensor. Mono injection systems did not enable regulating the amount of harmful components in the exhaust fumes accurately enough and they were soon replaced with multipoint injection systems (Robert Bosch GmbH, 2006).

In the development of multipoint injection systems, one of the most important innovations was applying the method according to which the injectors were controlled one by one. This enabled to increase the efficiency of the engine and to form the air-fuel mixture in each cylinder separately. In addition, it enabled to compensate for the inequalities in the engine's work due to the wearing of the engine. A solution like this was possible because of the microprocessors and digital electronics being taken into use in car industries. The microprocessors made it possible to save information which was necessary for controlling the work of the injection system and the ignition system of the engine. The constructional part of the multipoint injection systems has not developed much in the last 20 years. Mostly, the constructions of the sensors and the actuators have been improved as well as the electronic components of the control modules and the software (Robert Bosch GmbH, 2006).

Nowadays, direct injection systems (US20040011326) are used in gasoline engines. The working principle of the system is based on a high pressure common rail. The pressure in the common rail is created by a high pressure pump (~ 120 bar). High pressure enables to inject fuel directly into the cylinder. For injecting the fuel, injectors controlled by electromagnets are used. The amount of the air entering the engine is regulated by an electronic throttle valve. Engines with direct injection systems work on three different air-fuel mixtures: 1) a lean air-fuel mixture, lambda is higher than one; 2) a homogeneous air-fuel mixture, and lambda equals one; 3) a rich air-fuel mixture, lambda is less than one. Forming the air-fuel mixture in the cylinder is of great importance as the efficiency of the engine and the concentration of harmful components in the exhaust fumes depend on that.

The air-fuel mixture is formed on two modes. The principle of the fuel stratified injection (FSI) mode is based on directing the injected fuel spurt to the spark plug electrode. Two layers will form in the combustion chamber. The first layer consists of compressed air whereas the second layer is the concentrated air-fuel mixture. The latter is directed to the proximate distance of the spark plug electrode and ignited. When analyzing the ratio of air and fuel, it could be said that there is substantially less fuel than could be burned in the sucked air (Soodla, 2010).

In the volumetric forming of the air-fuel mixture, the fuel and the air have mixed in the whole combustion chamber. Lambda equals one; however, in case of the concentrated homogeneous air-fuel mixture it is less than one. When the fuel is ignited, the flame spreads from the electrode of the spark plug to the piston, causing differences in temperature in different parts of the combustion chamber. This, in turn, causes the increase in the harmful components in the exhaust fumes. To solve the problem, a homogenous charge compression ignition (HCCI) (US20090025679) has been taken into use, which stands for the multipoint ignition of the air-fuel mixture in the cylinder.

This particular solution is mostly used in diesel engines. The ignition effect is caused by the fast and effective burning of the air-fuel mixture. To form the volumetric air-fuel mixture, one of the options is forming the mixture in the intake manifold. However, the process where the air-fuel mixture sucked into the cylinder is ignited on the effect of compression is rather difficult to control. The main problems arise due to the timing of the ignition since the fuel ignites too soon and most of the fuel burns before piston's top dead centre. One of the possibilities is to control the process by chemical components (Starck, 2010; Wang 2006).

Discussion

In the following analysis, possible solutions for using biofuels in the existing fuel supply systems will be tackled. What is more, innovative solutions for improving these systems will be proposed by the authors. In most cases, one improvement is suitable for several types of fuel supply systems. For this reason, the types of the fuel supply systems in Table 2 have been categorized on the basis of certain characteristics. As the characteristics of different types of fuel supply systems overlap, one example patent for these types of systems is provided. The fuel supply systems are regarded both as standard fuel supply systems and biofuel supply systems. To simplify the analysis of patents in Table 2, Table 4, which summarizes the characteristics of the fuel supply systems described in the given patents, has been compiled.

In the sample patents of hydraulic and electro-hydraulic fuel supply systems (US4187821 and US4257375), the intake manifold has been improved by complementing it with an additional canal and an air flow stabilizer for the suction of the air. This enables the smooth running of the engine in the neutral position and on light load (provided that the throttle valve is closed). To improve the starting of the engine, the fuel distributor of the fuel supply system may be improved by an electronic start valve. When it is applied, the position of the dozer is regulated. When the engine is started, the air that is sucked into the engine regulates the position of the air flow sensor. Due to little underpressure, not enough fuel is dosed into the cylinder as the air flow sensor has been calibrated to work in conjunction with the dozer to ensure a specific air fuel mixture where the ratio between engine gasoline and air is 1:14.7 and 1:9 in case of bio ethanol (Schifter, 2011). To start up the engine, a concentrated air fuel mixture is needed. The concentration of the air fuel mixture is ensured by the magnetic valve. When it is applied, the lever of the dozer's position is regulated, irrespective of the position of the air flow sensor. If the magnetic valve has not been applied, the position of the dozer is regulated by the motion of the air flow sensor. The metal rod of the magnetic valve is connected to the regulating lever of the dozer. The metal rod has free motion inside the magnetic valve, without inhibiting the regulating lever of the dozer's position. Such a solution compensates for the deficiencies of underpressure caused by the wearing of the engine that in turn influences the starting of the engine. The system does not require a cold start-up nozzle as the concentration of the air fuel mixture is conducted by the main nozzles. The principle scheme of the system is given on Fig. 5.

Table 4. Technical characteristics of fuel supply systems

Patent	Aim	Technical characteristics	Difficulties
1	*2*	*3*	*4*
US4257375	The injection of fuel into the intake manifold of a spark ignition combustion engine, behind the intake valve by using the air that is sucked into the engine to dose the fuel. The dosing of the fuel depends on the air temperature and pressure.	1. The amount of fuel is regulated by the air flow. 2. The regulation of the amount of fuel according to the temperature of the engine happens due to changing the settings of the system's pressure regulator. 3. To start a warm engine, there is a regulating valve in the air bypass canal which ensures the sufficient amount of air while the throttle valve is closed.	1. Inhibits the air flow into the engine. 2. The fuel distributor is sensitive to water, solid parts and acidic engine fuels. 3. Different air flow measurement devices cannot be used without changing the construction of the system. 4. Highly sensitive to changes of fuel pressure in the system. 5. A complicated construction. 6. The start-up and running of the engine when the throttle valve is in a closed position.
US4696275	To regulate the amount of fuel by changing the opening time of the injector and using the difference of the pressure and air pressure in the intake manifold to form the air fuel mixture.	1. Injecting the fuel into the intake manifold of the engine. 2. By changing the opening time of the injector, the amount of fuel is regulated. 3. The internal pressure of the injection system is constant. 4. By comparing the underpressure and air pressure in the intake manifold the forming of the air fuel mixture in the cylinder is regulated.	1. Determining the amount of air is not precise. 2. Sensitive to changes in the fuel pressure in the system 3. Inaccuracies in forming the air fuel mixture caused by the temperature of air.

Table 4 continued

1	*2*	*3*	*4*
US4481928	The decreasing of the swaying of the flat type electronic air flow sensor on rapid changes of the throttle valve's position.	1. A control module equipped with a processor and an analogue/digital convertor. 2. The opening time of the fuel injector is determined with a coefficient that is fixed on the basis of all the signals from the engine sensors and by taking the given etalon values into account.	1. The flat type air flow sensor inhibits the air flow. 2. The measuring of the air backflow caused by the work of the intake valves is complicated.
US4782806	A method and the device for forming a pre-prepared air fuel mixture and directing it into a combustion engine.	1. Mono injection system 2. Two injectors 3. To be used on V-engines 4. Indirect injection system 5. The injector is positioned before the throttle valve in a special chamber in the intake manifold.	1. The distribution of the fuel between the cylinders. 2. Regulating the amount of the air fuel mixture.
US20040011326	To inject the air fuel mixture in a direct injection engine to the proximate distance of the spark plug electrode that is positioned in the middle of the combustion chamber's ceiling	1. The injector equipped with two injector tips and an injector nozzle. 2. Injecting the air fuel mixture around the electrode of the spark plug.	1. The injector is technically complicated. 2. Synchronizing the injectors.
US5996558	To inject liquid and gas fuels into a combustion engine through an injector.	1. An injector tip with two nozzles. 2. An injector running on two fuels. 3. Forming a mixture of the two fuels in the combustion chamber. 4. An injector tip with parallel injection canals.	1. Regulating the duration and timing of the injection irrespective of the angle of rotation of the cam shaft. 2. Complicated construction.

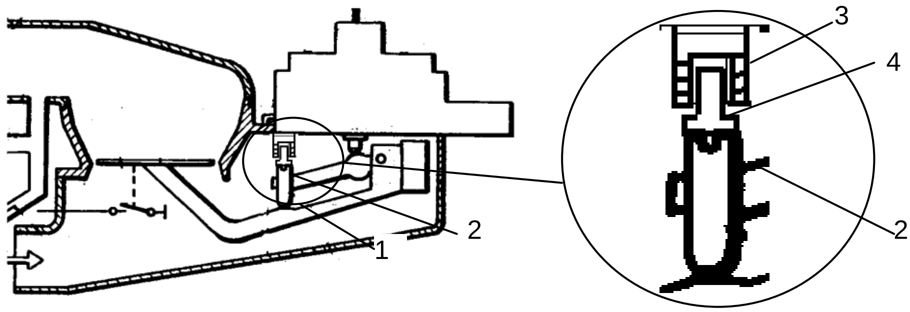


Fig. 5. The principle scheme of a start valve: 1) the air flow sensor; 2) the regulating lever of the dozer; 3) the magnetic valve; 4) the metal rod.

When looking at these different types of fuel supply systems on a broader scale, it can be said that they could also be used as additional fuel supply systems. However, to use biofuels, it is reasonable to make some changes in their construction. The main drawback of the hydraulic and electro-hydraulic fuel supply systems is the fuel distributor, as the precise nodes are sensitive to bio fuels. To solve this problem, the fuel distributor should be replaced with an electronically controlled fuel dozer. The aim in indirect multipoint injection systems is, firstly, to doze the fuel amount, and secondly, to direct it into the injectors. The system is made up of a control module, a dozer, a current source, a fuel pump, a pressure regulator, injectors and a gas pedal with an electronic position sensor.

The control module is made up of a signal generator and a transistor-controlled system (Fig. 6). The signal generator measures the voltage from the gas pedal position sensor and converts the fill factor of the pulse-width modulation accordingly on the basis of which the opening time of the magnet valve in the dozer on a frequency of 1…10 Hz is calculated. The dozer consists of an electro-magnetic valve and a fuel distributor. The pump sucks the fuel from the fuel tank and directs it through the fuel filter into the pressure regulator. The function of the pressure regulator is to regulate the pressure in the system. The pressure of the fuel is regulated according to the density, viscosity, calorific value, etc of the fuel. The higher the pressure in the system, the more fuel is directed through the dozer and the greater the fuel feed. The fuel pressure may vary in the range of 1…5 bar. The excess fuel is directed from the pressure regulator along the backflow line back to the fuel tank. The fuel is directed along the suction line to the suction opening of the dozer. By regulating the opening time of the electro-magnetic valve, a certain amount of fuel is directed into the distribution canal and then to the injectors. The dozer of the fuel is able to ensure a sufficient fuel feed for the cold start of the engine. The advantage of the system is the small number of parts that are sensitive to fuel and wearing. These can affect the reliability of the fuel supply system. The system is mostly designed for using alcohol fuels in internal combustion engines.

At first, the underpressure of the intake manifold was used to determine the air fuel mixture in common rail type of fuel supply systems. This method is known from the patent document US4696275. For the more precise forming of the air flow mixture, a method was taken into use that was based on comparing the atmosphere pressure and the underpressure of the intake manifold. The advantage of this particular method is the more precise calculation technique of the amount of air which is based on determining the air density by means of the atmosphere pressure. To improve the solution in the particular patent document, it is also necessary to take the air temperature in the intake manifold into account. By doing so, the determining of the amount of air would be even more precise. In the next generations of common rail fuel supply systems, mostly the measurement devices of air consumption, injectors, pressure and temperature sensors, the software of the control module and electronics were improved. An example here would be a common rail fuel supply system equipped with an air flow measuring device (US4481928). However, in this case, a problem arises as some malfunctions of the air flow measuring device come about on the rapid changes in the engine modes that inhibit the correct forming of the air fuel mixture. This particular problem is common in flat type air flow measurement devices. The problem is tackled by smoothing the signals of the air flow measurement device and comparing them with the etalon signals. Signal processing was one of the pertinent stages in developing fuel supply systems and this particular solution enabled the more precise measuring and controlling of the analogue signals.

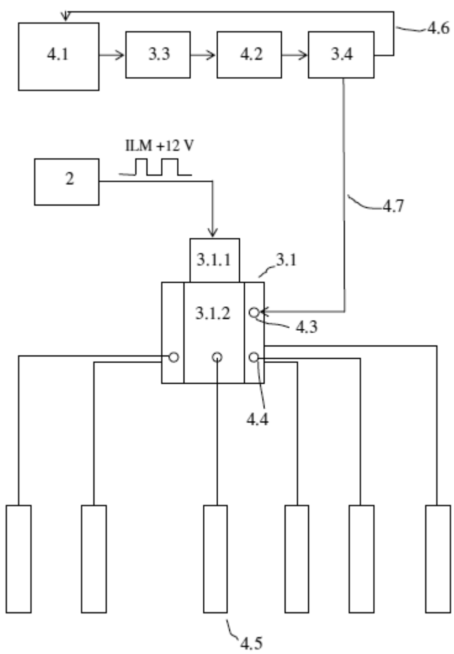


Fig. 6. The principle scheme of an additional fuel supply system: 2) a control module; 3.1) a dozer; 3.1.1) an electro-magnetic valve; 3.2.1) a fuel distributor; 3.3) a fuel pump (+12 V); 3.4) a fuel pressure regulator; 4.1) a fuel tank; 4.2) a fuel filter; 4.3) a suction opening; 4.4) an outlet channel; 4.5) an injector; 4.6) a backflow line; 4.7) a suction line.

Furthermore, another type of fuel supply systems is the mono-injection system. It was mostly used on in-line four-cylinder engines. Its usage on V-engines was, however, more problematic as the distribution of the air fuel mixture between cylinders was not equal. This problem has been solved in the patent US4782806. The solution to the problem is based on the injection system installed into the intake manifold. This injection system consists of a common fuel distributor, two injectors and their control system. One injector must ensure that one cylinder line of the V-engine is supplied with fuel. Nevertheless, the problem of this solution is the equal distribution of the air fuel mixture between cylinders as the throttle valve directs the air fuel mixture into the intake manifold unevenly. To improve the running of the fuel supply system, the working principle of the throttle valve should be changed, or the intake manifold that is situated after the throttle valve should be lengthened. However, a longer intake manifold takes up a lot of space, which is limited in case of many motor vehicles. In this particular system, it would be necessary to use a throttle valve that does not rotate as a whole in the intake manifold. For doing so, a throttle valve of two parts should be constructed so that its parts could be moved irrespective of each other. In principle, this would be a butterfly valve which principle scheme is given on Fig. 7.

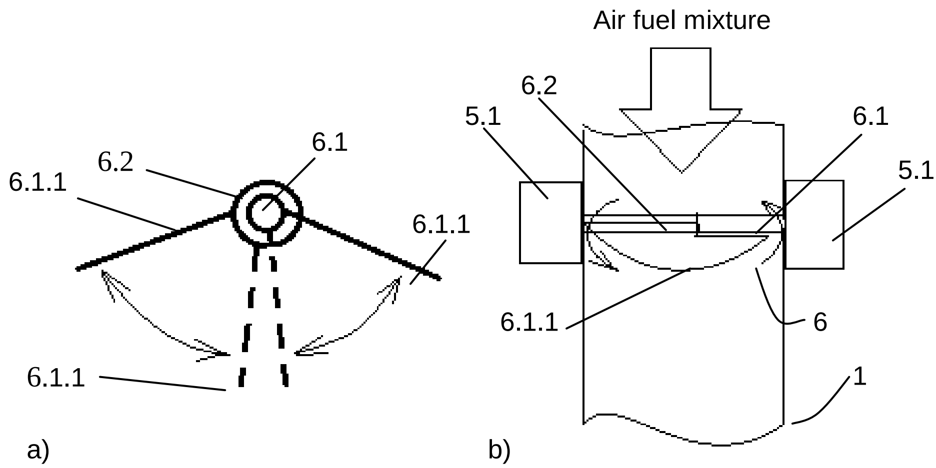
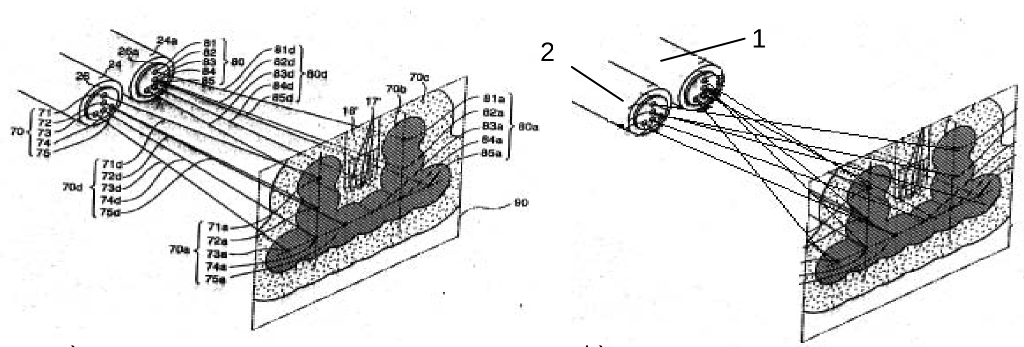


Fig. 7. The principle working scheme of a throttle valve: a) the working principle of a throttle valve; b) the position of the throttle valve in the intake manifold; 1) the intake manifold; 6) a throttle valve; 5.1) a step motor; 6.1) the inner shaft of the throttle valve; 6.2) the outer shaft of the throttle valve; 6.1.1) a regulating valve.

The throttle valve is actuated by two step motors that regulate the rotation angle of the valve depending on the position of the gas pedal. The running of the step motors is synchronized by the engine's control module that controls the throttle valve based on the given data. The step motors rotate the throttle valve's (6) inner (6.1) and outer shaft (6.2) in opposite directions. As a result, more air fuel mixture is sucked into the cylinders. This particular solution evens the distribution of the air fuel mixture between the cylinders. As it is also possible to regulate the work of only one step motor apart from the other, it is therefore possible to regulate the air fuel mixture separately between the cylinder lines in case of V-engines. This means that the fuel feed on one cylinder line can be regulated by one side of the throttle valve and one injector.

Fuel supply systems have developed from indirect injection systems to direct injection systems (US20040011326). The latter enable the stratified forming of the mixture and as a result the fuel consumption and the amount of harmful compounds in the exhaust fumes decrease. The decreasing of the exhaust fumes is conditioned by the low combustion temperature and the small amount of fuel. In the previously mentioned solution, for example, a fuel injection has been designed that enables to inject the fuel around the spark plug electrode in the middle of the cylinder, which ensures the proper environment for the air fuel mixture to ignite. The drawback of this particular solution is the large injector that takes up a lot of space in the cylinder head and the combustion chamber of the engine. In addition, the injector has many wearing parts. It is more reasonable to use injectors with one injector tip in case of one fuel so that the geometric locations of the tip openings would determine the directing of the injection spurts in the cylinder (Basshuysen, 2001). The advantage of an injector with two injector tips is the possibility to use a standard and a biofuel at the same time. For example, using a methanol fuel decreases the amount of harmful compounds because the combustion temperature in the cylinder is lower than in case of standard fuels (Gong, 2011). The principle problem is the forming of the air fuel mixture as in the previously mentioned solution the air fuel mixture is formed by means of two injector tips on both sides of the spark plug electrode (see Fig. 8). When using two fuels, it is important to form a homogeneous air fuel mixture. For doing so, it is necessary to change the locations of the injector tip openings and the timing of the injection (see Fig. 8). In case of two fuels, two injectors cannot inject at the same time because the injection spurts are located crosswise. Therefore, the fuels are injected separately – first the standard fuel and then the biofuel.



a) b)

Fig. 8. A method for forming the mixture in a direct injection engine: a) forming the mixture in the cylinder using a standard fuel (US20040011326); b) forming the mixture in the cylinder using a standard and a biofuel: 1) the injector of a standard fuel; 2) the injector of a biofuel.

The proposed solution is basically a fuel supply system running on two fuels. Engines that run on two fuels enable, firstly, a significant economizing on fossil fuels, and secondly, environment conservation in general. The principle development trends in the field are injection devices with parallel canals where two fuels are injected from one injector (for example, US5890459). Similar solutions enable the space saving in engines; however, they also make the construction of the injection system significantly more complicated.

Furthermore, using biofuels decreases the amount of harmful compounds in exhaust fumes. In case of alcohol fuels, the effect is based on a lower combustion temperature and the small number of compounds. To achieve a low combustion temperature, a HCCI (Homogeneous Charge Compression Ignition) method is being developed. As a result, the air fuel mixture in the cylinder would ignite because of the pressure. In case of HCCI, direct injection systems can be replaced with indirect injection systems as the forming a volumetric air fuel mixture would also be effective in direct injection systems. What is more, indirect injection systems are easier in construction and also cheaper. The main drawback is the complicated controlling of the combustion process, more precisely, the timing of the self-ignition. Nevertheless, the self-ignition temperature of gasoline can be lowered by chemical compounds. Self-ignition can be timed by regulating the pressure in the cylinder. The pressure is related to the cubic content of the cylinder. If the volume of the combustion chamber was changed, it would also be possible to regulate the moment of the air fuel mixture's ignition. When taken into account that the inner temperature of a cylinder in a combustion engine changes constantly, it would make the timing of the ignition inaccurate. To solve the problem it would be necessary to measure the temperature of the cylinder wall in different places to ensure the even ignition of the air fuel mixture. Nowadays, HCCI is one of the most relevant development trends and its usage would end the development of spark ignition engines.

Conclusion

Fuel supply systems have been developed to be more and more effective in the last 45 years. The main aims of the development are, firstly, improving the efficiency parameters, and secondly, decreasing the harmful compounds in the exhaust fumes. The main purpose of a fuel supply system is forming a high-quality air fuel mixture. This means that the fuel particles in the air fuel mixture need to be microscopic to ensure their quick and effective combustion. When forming the air fuel mixture, other important parts besides the fuel supply system are also the intake manifold and the combustion chamber. Many solutions for using biofuels have been worked out that enable to use biofuels in combustion engines together with standard fuels as well as independently. The main problem of fuel supply systems is their durability to biofuels. For example, using untraditional biofuels (e.g. a 70- per-cent alcoholic bio ethanol) is complicated. A fuel like that contains a lot of water which causes corrosion in the fuel supply system. On the other hand, producing a 70-per-cent ethanol would be cheaper than the 100-per-cent ethanol used in engines today. In addition, the fuel supply systems do not enable using different types of biofuels in one fuel supply system (for example, alcohol and herbal oils). This is due to the low-quality forming of the air fuel mixture as in case of fuels with different viscosity, different techniques are used. To use biofuels more effectively, it would be necessary to design a fuel supply system that would guarantee the high-quality forming of the air fuel mixture in case of different biofuels and would not be sensitive to the chemical and physical properties of biofuels.

To use biofuels in engines with the existing fuel supply systems, it is important to change the precise nodes of the fuel supply systems to reduce their wearing and ensure a good injection quality. An example also given in this article would be the electro-hydraulic fuel supply system which injector tip has been replaced with an electronic dozer. This reconstructed fuel supply system is suitable for injecting alcohol fuels into the intake manifolds of spark ignition engines. In case of direct injection systems, it is reasonable to use two fuel injectors to mix the standard fuel and the biofuel inside the cylinder. The solution provided in the article enables to inject the standard fuel and bioethanol directly into the engine's cylinder, forming a suitable air fuel mixture around the spark plug electrode. To increase the durability of fuel supply systems' precise work surfaces, using teflon and nano-composite material work surfaces is recommended.

All in all, using HCCI without a direct injection system in the future is possible by adding ignition improvers to fuel or regulating the inner pressure of the cylinder during the running of the engine. Furthermore, using liquid biofuels in the nearby future has prospects in engines with dual fuel supply systems as producing biofuels is costly and using them without standard fuels requires further research. This particular article provides an overview of the prior art of the existing fuel supply systems as well as of their characteristics on the basis of which it is possible to determine the validity of the given patent and identify additional fuel supply systems with innovative features for using biofuels in engines.

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