



## SYSTEM OF THE ICE GAS-WATER FUEL SUPPLY

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### ABSTRACT

The paper develops the principle of alternate fuel utilization for motor vehicles. The proposed solution improves fuel and economic figures of the internal combustion engine and reduces hazardous substances in exhaust gases. The principle of the gas-water mixture utilization with the distributed injection is taken as a basis to develop the ICE fuel feed system. The paper presents the numerical scheme of the gas-water fuel mixture combustion procedure in ICE cylinders and the results of its computer modeling in MathCad. Mathematical analysis of the obtained results proves thermal process parameter variations and determines the optimal concentration of water in the fuel mixture.

**Keywords:** internal combustion engine, gas mixture, water, numerical scheme, processes, modeling, structure.

### 1. INTRODUCTION

Expansion in the number of motor vehicles against the backdrop of a global energy crisis, and their transition to gas fuel are of great relevance. This is due to the fact that deterioration of the world ecological situation and the urgent need for diesel fuel and gasoline economy [7]. Gas application as an alternative fuel type not only limits use of oil products but also brings down vehicle operating costs. It should be also noted that the ICE gas fuel does not demand additional chemical processing.

Motor fuel uses liquefied natural gases (LNG) and compressed natural gases (CNG).

Despite all kinds of authors' opinions, gas fuel takes undoubted precedence over liquid. It can be proved by power efficiency. For gas engines in a wide range it reaches 38-40% and for the petrol engine this coefficient does not pass 30-35% [1]. Another confirmation is presented by the data of the Ford enterprise. When testing the automobile LNG-operated engine, following the results of the mileage of 55 thousand miles, it was noted that its capacity is 10% more than the similar gasoline-operated engine has (respectively 74 and 66 kW) and the monoxide carbon content in exhaust gases of LNG-operated engines was 5 times lower (respectively 0.21 and 1.2%) [2].

Also it should be remembered that fire gases of the majority of applied fuel materials have some shortcomings. The loss of barring dynamics, the decrease in full speed (5-8%) and the capacity reduction due to the decreased ratio of compression (10-15%) are the main shortcomings.

Unlike the classical gas-gear fuel supply system, the distributed gas injection system allows to stabilize the engine performance, to achieve car economy and to raise dynamic characteristics of the engine [1]. This fuel supply system meets the requirements of modern ICE the most as it is identical to petrol systems which the modern engine-building is focused on.

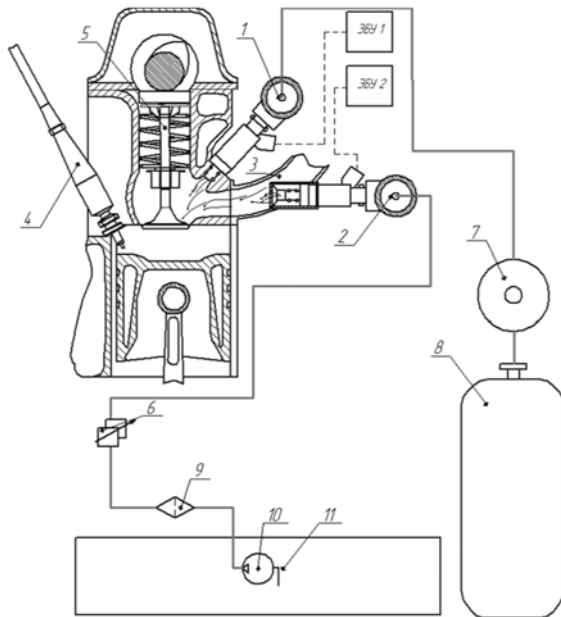
Water application as a fuel agent to combustible gas is the radical solution as it gives a chance to increase effective capacity and the full-road curve indicators in general.

### 2. SYSTEM OF THE ICE GAS-WATER FUEL SUPPLY

The gas-water mixture development needs the two-flow scheme. Gas fuel and water are fed by different nozzles and their mixing happens in cylinders.

In fuel combustion microscopic water drops intensively start evaporating from the surface of heated details. This process is followed by the considerable pressure increase (that later will do compression work) and the insignificant decrease of temperature in a combustion chamber. Thanks to the decrease in peak burning temperature (2000 C°) detonating velocity slows down, burning more fuel [1]. In the process of the fuel mixture injection at high temperature some water decomposes to oxygen and hydrogen which also participates in the burning process. As a result of such fuel mixture burning, engine capacity increases.

Figure-1 presents the scheme of the distributed gas injection system with water supply to cylinders. The ICE eight-valve petrol that has a number of constructive completions is taken as a basis [4].



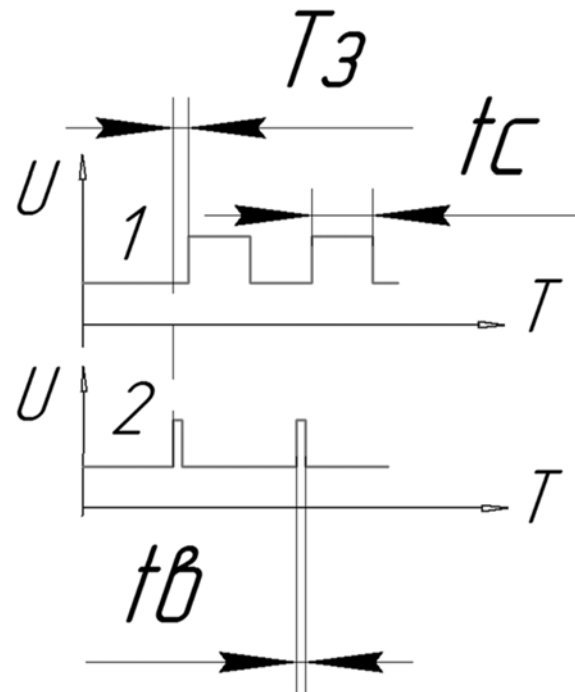
**Figure-1.** Scheme of the distributed gas injection system with water supply in cylinders: 1- a fuel rail; 2- a water rail; 3- an air manifold; 4- a spark plug; 5- an inlet valve; 6- a water pressure regulator; 7- a gas pressure regulator; 8- a gas bag; 9- a water filter; 10- a water-circulating pump; 11- a water tank.

The regular fuel system is built up by the additional nozzles and a fuel rail, a water rail, a filter and a pressure regulator. The correcting condition signal on the nozzles is generated by the additional ECM. Water is supplied through a nozzle directly to an inlet manifold. An electronic control module is used to control operation modes of the water nozzles. The operation of two electronic modules is synchronized by a crankshaft position sensor.

As the quantity of water fed to the engine is less than the total quantity of injection fuel, the switch on time of a water nozzle should be less than the switch on time of a fuel nozzle.

To provide better air-gas carburation, at first a water nozzle is connected in each cycle of the cylinder operation and then after a while a fuel nozzle is connected. Figure-2 presents the schedule of a delay of control signal injection of a fuel nozzle.

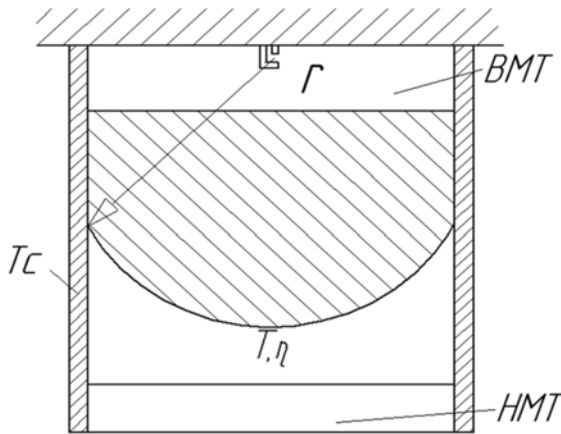
It should be noted that the on-delay control signal time is determined by various distances between water and fuel nozzles and an inlet valve opening.



**Figure-2.** Scheme of control signals of fuel (1) and water (2) nozzles: 1- a fuel nozzle control signal; 2 - a water nozzle control signal;  $T_3$  - the on-delay fuel nozzle time;  $t_c$  - the fuel nozzle control signal duration;  $t_b$  - the water nozzle control signal duration.

### 3. MATHEMATICAL MODEL OF THE GAS-WATER MIXTURE COMBUSTION PROCEDURE

According to the thermal theory, flame spreading in a cylinder can be described by the system of two equations [3, 6, 16, 17, 19]. Proceeding from the corresponding initial and final boundary conditions which determine the severity of the working medium exposure on physical and chemical parameters of the operating procedure, this system of equations describes a change of these parameters under the steady-state combustion mode. This system of equations is also quite good to describe the combustion procedure of alternative fuel types as it is fair for all cases when boundary conditions are fixed. Figure-3 shows the analytical model of the gas-water mixture combustion in the engine cylinder.



**Figure-3.** Analytical model of the gas-water mixture combustion in the engine cylinder:  $T_c$  - the cylinder wall temperature;  $T$  - the fuel mixture temperature;  $\eta$  - the reaction product concentration; BMT and HMT - top and lower dead points respectively;  $r$  - a spatial value.

The model shows that the procedure temperature and the combustion product concentration change with respect to  $r$  point from BMT to HMT.

The gas mixture temperature  $T$  and the reaction product concentration  $\eta$  change with respect to BMT, the occurrence of spark to HMT is proportional to  $r$  radius. Taking into account the polar coordinate system, the simplest statement of a mathematical problem will include the thermal conductivity equation and the diffusion equation [4].

$$\kappa \left( \frac{\partial^2 T}{\partial r^2} + \frac{1}{r} \cdot \frac{\partial T}{\partial r} \right) - V \frac{\partial T}{\partial r} = \frac{\alpha}{c_v \rho} (T - T_c) - \frac{Q_0}{c_v \rho} k(1 - \eta) \exp \left( -\frac{E_a}{RT} \right);$$

$$D \left( \frac{\partial^2 \eta}{\partial r^2} + \frac{1}{r} \cdot \frac{\partial \eta}{\partial r} \right) = -k(1 - \eta) \exp \left( -\frac{E_a}{RT} \right), \quad (1)$$

where  $\kappa$  - an effective thermal diffusivity coefficient;  $\alpha$  - a heat exchange coefficient;  $\rho$  - the fuel mixture density;  $C_v$  - the specific thermal fuel mixture capacity at constant volume;  $Q_0$  - the thermal reaction effect;  $\eta$  - a reaction order;  $k$  - speed constant;  $E_a$  - the activation energy;  $R$  - a universal gas constant;  $V$  - the fuel mixture speed;  $D$  - a diffusion coefficient.

Proceeding from the statement that temperature in a cylinder is equal to the temperature of combustible gas, the following boundary conditions should be accepted:  $r=R$ ;  $T=90^\circ$ ;  $\eta=0.9$ , where  $T_0$  - the operating mixture temperature. The external wall temperature will be equal to the cooling liquid temperature [5, 13, 14, 15].

To investigate the combustion procedure parameters depending on the gas-water mixture parameters and the cylinder sizes, it is necessary to move on to a stationary task. It should be noted that the fuel mixture movement speed parameter  $V$  is not exponential as it is equal to zero. Thus, the equation (1) is as follows:

$$k \left( \frac{d^2 T}{dr^2} + \frac{1}{r} \cdot \frac{dT}{dr} \right) = \frac{\alpha}{C_v \rho} (T - T_c) - \frac{Q_0}{c_v \rho} k(1 - \eta) \exp \left( -\frac{E_a}{RT} \right);$$

$$D \left( \frac{d^2 \eta}{dr^2} + \frac{1}{r} \cdot \frac{d\eta}{dr} \right) = -k(1 - \eta) \exp \left( -\frac{E_a}{RT} \right). \quad (2)$$

Boundary conditions in a stationary task are the same. The parameters  $k$ ,  $\alpha$ ,  $C_v$ ,  $\rho$  change with water.

#### 4. COMPUTER MODELING RESULTS

Gas combustion procedure modeling in ICE cylinders by a numerical considers using a package of applied Mathcad-14 programs by the Odesolve [2] function. Figure-4 presents the code of the system of differential equations (2).

It should be noted that despite set boundary conditions the combustion modes can proceed with various intensity and be caused by numerical changes of the physical and chemical parameters [5, 9, 10, 12]. The gas-water mixture combustion in the engine cylinder and influence of fuel properties on the ICE operating procedure speed and time are considered as an illustrative example.

Figure-5 graphically presents the dependences of the temperature variation on a spatial value for the stationary mode of the fuel gas mixture combustion without water.

$$\begin{aligned} m1 &:= 1.811 & m2 &:= 0.196 & m3 &:= -64.6 & c &:= 1112 & cv &:= 4.2 & q &:= 0.196 & r &:= 0.614 \\ m4 &:= 1 & a &:= 2.14 & E &:= -10 & P &:= 8.333 \\ f &:= m1 \cdot c & A &:= \frac{a}{(cv \cdot r)} & \mu &:= \frac{E}{P} & V &:= 10 & \chi &:= 1000 & Rk &:= 0.25 \end{aligned}$$

T1 := 0.2

Endpoint of solution interval

Given

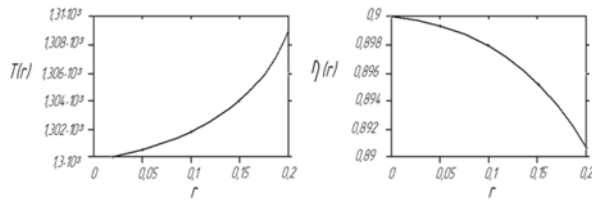
$$m1 \left( \frac{d^2}{du^2} x1(u) \right) = c \cdot x2(u) \cdot e^{-\frac{\mu}{x1(u)}} + m3 - \frac{m1}{x1(u)} \left( \frac{d}{du} x1(u) \right) + x1(u) \cdot A - f \cdot e^{-\frac{\mu}{x1(u)}}$$

$$m2 \left( \frac{d^2}{du^2} x2(u) \right) = \left[ x2(u) \cdot m4 \cdot e^{-\frac{\mu}{x1(u)}} - \frac{q}{x2(u)} \left( \frac{d}{du} x2(u) \right) - m4 \cdot e^{-\frac{\mu}{x1(u)}} \right]$$

$$x1(0) = 1300 \quad x1'(0) = 0 \quad x2(0) = 0.9 \quad x2'(0) = 0$$

$$\begin{pmatrix} p1 \\ p2 \end{pmatrix} := \text{Odesolve} \left[ \begin{pmatrix} x1 \\ x2 \end{pmatrix}, u, T1, 1 \times 10^3 \right] \quad z1 := 0, \frac{T1}{1 \times 10^3} \dots T1$$

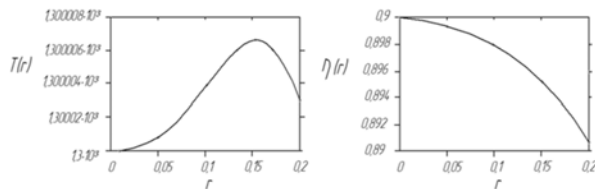
**Figure-4.** Code of the system of differential equations of the gas-water mixture combustion in the engine cylinder.



**Figure-5.** Schedules of the dependence of the variation of temperature  $T$  and concentration  $\eta$  on a spatial value  $r$  for the stationary mode of the fuel gas mixture combustion without water.

The schedule shows that the larger a spatial value, the higher the temperature.

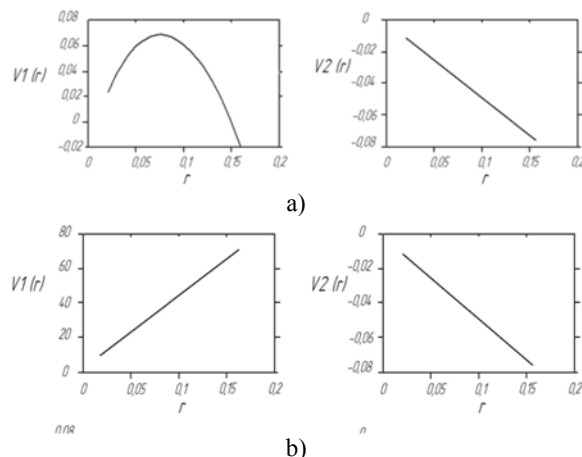
Figure-6 presents the variation of temperature with water vapor of 22%.



**Figure-6.** Schedules of the dependence of the variation of temperature  $T$  and concentration  $\eta$  on a spatial value  $r$  for the stationary mode of the mixture combustion with water vapor of 22%.

The schedule shows that the maximum value  $T$  is set at  $r=0.16$ , then there is the fast decrease in temperature of the combustion procedure. The higher concentration of water vapor, the lower the operation mixture temperature to values which are lower than combustion temperatures. The further decrease in temperature of a cycle can lead to the ICE combustion procedure termination.

Figure-7 shows speeds of the temperature variation  $V_1$  and the concentration  $V_2$  with respect to value of a coordinate  $r$ .



**Figure-7.** Speeds of the temperature variation  $V_1$  and the concentration  $V_2$  with respect to value of a coordinate  $r$ :

- speeds of the temperature variation and the combustion product concentration depending on a spatial value without water;
- speeds of the temperature variation and the combustion product concentration depending on a spatial value with water vapor of 22%.

On the basis of these obtained schedules it is possible to draw a conclusion that the changing parameters of a working medium directly influence not only the running cycle course intensity but also the combustion thermal effect. It should be also noted that the increased water vapor concentration in gas fuel causes the critical temperature variation in the cylinder that directly influences the ICE operation dynamics and the charge capacity of details of a sleeve group [1, 18, 20-22]. The most optimal concentration of water vapor in the gas mixture for initial and boundary conditions is 22% that lowers the ICE thermal operating mode. Also it should be noted that the temperature variation of cylinder walls or the fuel mixture combustion temperature leads to a changing value of the optimal concentration of water vapor in the gas mixture.

## 5. STRUCTURE OF THE DISTRIBUTED GAS INJECTION SYSTEM WITH WATER SUPPLY IN CYLINDERS

When developing the distributed injection system one of the requirements was its unification for use on serial ICE with their minimal engineering changes.

Figure-8 shows the air manifold structure with a water rail of VAZ-2110. An additional water rail and water nozzles on the angle of 45 degrees referred to a fuel rail are set in down part of a manifold.



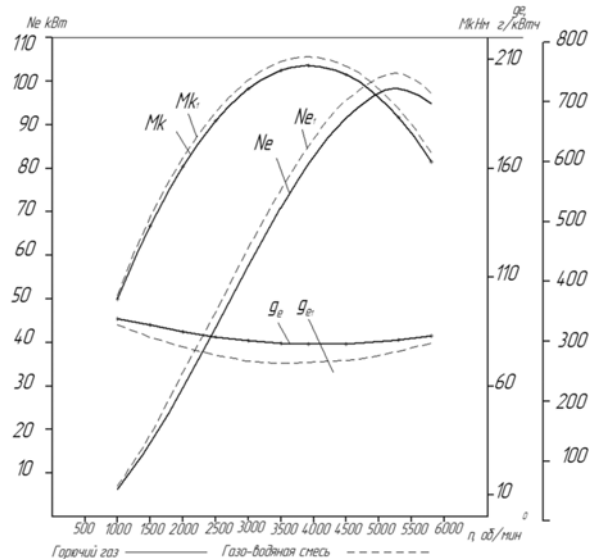
**Figure-8.** Air manifold with a water rail of VAZ-2110.

An electronic control module is used to control operation modes of the water nozzles. The operation of two electronic modules is synchronized by a crankshaft position sensor. As the quantity of water fed to the engine is 20-22% of the total quantity of injection fuel, the switch on time of a water nozzle should be less than the switch on time of a fuel nozzle.



To provide better air-gas carburation, at first a water nozzle is connected in each cycle of the cylinder operation and then after a while a fuel nozzle is connected.

Figure-9 presents schedules of the full-load curve when the ICE is operated in identical modes using gas fuel and the gas-water mixture.



**Figure-9.** Schedule of the full-load curve when the ICE is operated in identical modes using gas fuel and the gas-water mixture:  $Mk$  - a turning moment;  $Ge$  - fuel consumption;  $Ne$  - effective power of the ICE.

The schedule of the full-load curve of the gas-fueled ICE operation illustrates the increased effective power by 10% and the decreased fuel consumption by 15%. Thus, insufficient power of an operating cycle can be balanced by water added to fuel gas.

## 6. CONCLUSIONS

- The paper offers the distributed gas injection system with water supply in cylinders that improves fuel and economic figures of the ICE and reduces hazardous substances in exhaust gases.
- The developed mathematical model describes the gas-water mixture combustion procedure in a cylinder and models standard processes of the ICE operating cycles.
- Water injection in the combustion chamber improves fuel and economic figures of the ICE and reduces hazardous substances in exhaust gases.
- There is a choice of optimal parameters of the distributed gas injection system with water supply in cylinders taking into account the fuel consumption minimization and the increase in effective power of the ICE.

- The considered technical solution increases the detonation characteristic and optimizes the combustion efficiency.

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