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INJECTION OF LIQUID LPG THERMODYNAMICS

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Abstract: *This paper explains the events that accompany the injection of liquid LPG into the intake air in the intake manifold of an engine. A simple calculation shows that the injection of liquid LPG is associated with extremely low temperatures injected LPG and icing on the outflow nozzle. The results of experimental research on vehicle spark-ignition engine with the formation of the mixture by injecting liquid LPG into the engine intake manifold demonstrate that the anti-icing on the discharge nozzle requires optimization for reliable construction embodiment of the end of the injector. In conclusion, the article summarizes the findings from previous research injection of liquid LPG into the engine intake manifold.*

Keywords: Injection, liquid LPG, SI engine, thermodynamics, optimization.

1. Introduction

Fuel systems of automotive gasoline LPG engines usually works with the formation of a mixture of vaporized LPG blowing into the intake tract of the engine, and in this embodiment, the spark-ignition engine operating on LPG lower output by about (5-8)% versus engine operation on petrol. The cause of decrease of the engine power is to reduce the amount of intake fresh air due to the volume of gaseous fuel in the intake mixture. Prospective solution mixture formation by injecting liquid LPG into the intake air, which reduces the temperature of the intake mixture increases the volumetric efficiency of the motor and ensures during operation with LPG the same or even better performance than when running on petrol. Effect very rapid evaporation of the injected liquid LPG however arises in the intake tract of the engine icing (wet steam LPG has a discharge nozzle injector temperature below freezing, about -30 to -40 °C) which was breaking off and clogging intake air into the engine cylinders which causes occasional misfire. Trouble-free operation of the gasoline engine with injection liquid LPG must therefore be designed in such a solution provided the injection of liquid LPG to the engine intake manifold (generally the engine) to prevent icing of the outlet nozzles or injectors in the intake manifold.

2. Injection of liquid LPG into the engine intake manifold

A configuration diagram of the injection of liquid LPG shows a sketch of FIG. 1. Injector liquid LPG is formed by a solenoid valve (EV), from which the LPG in batches (synchronized with inlet of each cylinder of the engine) is introduced into the end portion of the injector (EPI) in the intake manifold to the individual cylinders (concept MPI). After the effluent from the LPG EV occurs due to a significant drop in pressure of LPG in the EPI to the very rapid evaporation of a portion of LPG: the heat required for evaporation is removed from the thermal energy supplied to the LPG EPI and a small proportion of the evaporation of LPG the heat transmission from the environment into the EPI. Into the intake air is injected wet steam LPG, which is due to intensive evaporation of LPG in the EPI very low temperature. Simplified computational modeling processes EPI were screened connection geometry flow channel state variables LPG EPI and during the injection of liquid LPG to the engine intake manifold. Solution procedure changes the status of LPG in the EPI briefly described in the following paragraphs.

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Delivery of liquid LPG is injected during dose supplied by a solenoid valve EV of elementary amounts $\Delta m_{LPG/liq}$ in EPI. The whole volume of the channels V_{BON} before the discharge orifice portion of LPG in the channels EPI evaporated portion remains in the liquid state and in the state arises EPI wet steam LPG. The density of wet steam can be expressed as the sum of the density of saturated vapor (gas) LPG and density of droplets dispersed in the volume V_{BON} channels EPI:

$$\rho_{LPG/V_{BON}} = \rho_{LPG/gas/V_{BON}} + \rho_{LPG/liq/V_{BON}} \quad (1)$$

The share of vaporized LPG in the channels of EPI determines the heat balance in the state of LPG EPI. The density of the gaseous phase in the volume of LPG V_{BON} depends on pressure and temperature LPG EPI (volume V_{BON}):

$$\rho_{LPG/gas/V_{BON}} = \frac{p_{LPG/V_{BON}}}{r_{LPG} \cdot T_{LPG/V_{BON}}} . \quad (2)$$

The density of the liquid phase in EPI represent LPG droplets dispersed throughout the volume V_{BON}. To express the proportion of vaporized LPG was introduced in EPI equation for the density of wet steam, LPG:

$$x = k_{evapor} \cdot \left(1 - \frac{\rho_{LPG/V_{BON}}}{\rho_{LPG/liquid}}\right) \quad (3),$$

$$\rho_{LPG/liquid} \cong 550 kg/m^3 \quad (4).$$

The size of the correction factor evaporation k_{evapor} is determined by calibrating the model calculation using measured during wet steam pressure of LPG in the EPI. (Cengel et al., 2008, Šesták et al., 2004)

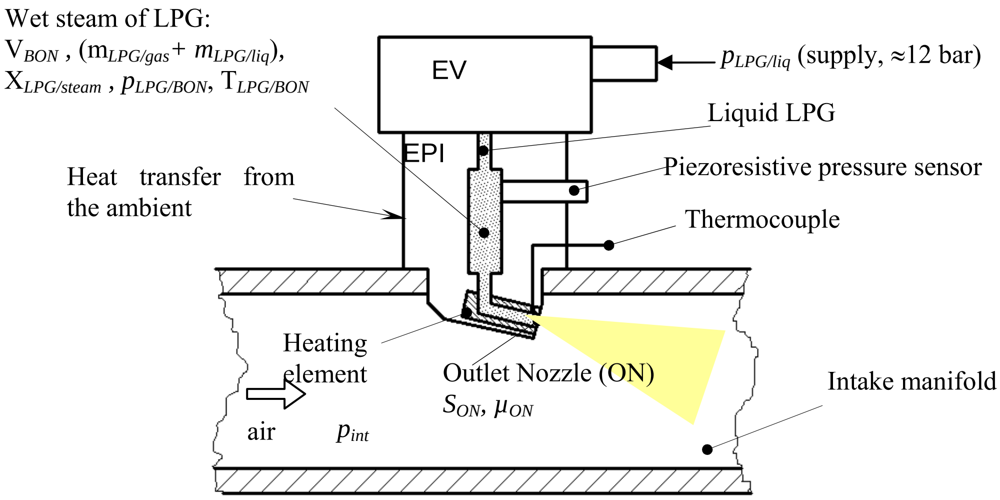


Fig. 1: The scheme of the injector for the liquid LPG injection. Heating element (HI) in the bottom of the EPI provides only heating the outlet nozzle (measures against freezing of the nozzle), heat transmission from HI to EPI EPI structure is minimized.

Heat balance for wet steam LPG EPI includes items (Beroun et al., 2013):

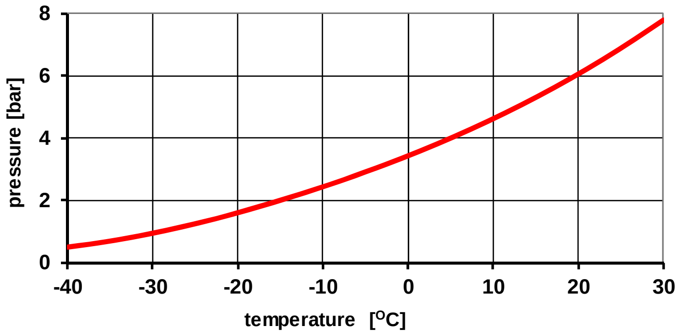
-Heat in the LPG (LPG_{liq} + LPG_{gas}) at the beginning of each calculation step $\Delta\tau$ (0.2 ms) in EPI.

-Heat the feed liquid LPG to the amount of EPI $\Delta m_{LPG/liq}$ at the beginning of each calculation step.

- The heat that the comparison stage permeate from around the body EPI to LPG.

-The heat required for evaporation of the LPG in the comparison step for estimating the density of wet steam. Correction coefficient estimate of wet steam saturation was measured by means of pressure in the EPI conducted a computational model calibration.

-From the heat balance for LPG in the EPI down temperature wet steam, LPG EPI and then conversion between temperature and saturation vapor pressure of LPG LPG pressure is determined in the EPI. The relationship between temperature and saturation vapor pressure of LPG for the intended ratio of propane and butane in LPG in size 50/50 shown in the graph in Figure 2.



Obr.2: The vapor pressures of the ratio of propane and butane in the LPG size 50/50 depending on the temperature. The illustrated dependence (in reverse relation) clearly documents the problem which is associated with the injection of liquid LPG into the suction line: after the discharge of the liquid LPG from EV to EPI pressure decreases from $p_{LPG/liq} \cong 12$ bar to $p_{LPG/V_{BON}} \cong 1 bar$ and begins intensive evaporation temperature drops LPG until $t_{LPG/V_{BON}} \approx -30^0 C$.

- The effluent of wet vapor of LPG into the intake air is designed as a flow of gas (with respect to the critical stages of expansion during discharge). Properties of gas is only saturated steam, which at the outlet entrains droplets LPG (wet steam outlet). In calculating the amount of elemental vaunted liquid phase (droplets) involves using a proportion of vaporized LPG (x values for wet steam saturation) in the EPI.

-The calculation procedure is repeated until the entire batch feeding LPG EPI and terminates discharge the entire dose of wet steam outlet nozzle into the intake air.

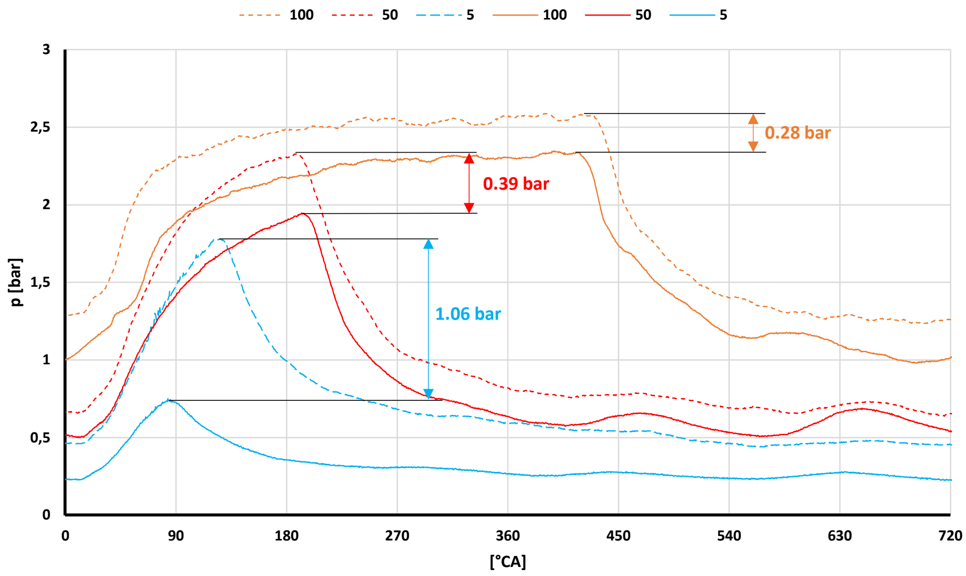
Comparison of the results of model calculations of pressure in EPI discharge of wet vapor of LPG into the intake air with the results of the measured waveforms of pressure of LPG in EPI showed that the algorithm calculation model gives a very good agreement with the measurement when using the correction (calibration) coefficients for the density of wet steam in size $k_{evapor} = 0.8$. Model calculations are primarily educational in nature, but the findings were used for design solutions EPI version with heating outlet nozzle.

3. Experiment

Measurement was carried out on the Skoda engine, whose parameters are shown in Table 1. The engine was controlled by an electronic control unit with version control software SIMOS 11. Measurement were made for two configuration of EPI (with and without heating) – both configurations had the same parametres of internal dimension. Selected results of experimental verification measurements are illustrated and described in FIG. 3.

Tab. 1: The engine parameters specified for laboratory measurements.

Type	SI, 12 valves, DOHC
Bore X Stroke	76.5 x 86.9 mm
Number of cylinders	3
Swept volume of engine	1198 cm3
Maximum power	51 kW
Maximum torque	112 Nm
Compression ratio	10.5 ± 0.3 :1
Cooling	water



Obr.3: The picture shows the course of pressure in the end part of the injector at a speed of 3700 1 / min for three different loading modes (100 - fully open throttle, 50 - medium load, 5 - low load) depending on the rotation of the crankshaft. The dashed line shows the progress of the pressure in the end part heated, the solid line shows the progress of the pressure in the end portion without heating. At the end portion is heated with heat balance a shift to higher temperatures (see. Fig. 2) due to the heat input into the end portion of the injector.

4. Conclusions

Research injection of liquid LPG into the intake manifold of the engine revealed that the decisive factor for the smooth operation of the engine on LPG is suitable structural solution for the end of the injector, placed in the engine intake manifold. Dimensions and insertion end portion of the injector into the intake manifold must minimize the reduction of the flow cross section in the suction pipe.

To avoid the formation of ice on the front surface of the discharge nozzle is an effective measure heating of the discharge nozzle with minimizing the effect of heating wet steam LPG before the outlet nozzle.

The effluent from the wet steam outlet nozzle must be directed to the central parts of the flow cross section in the intake manifold (on impact of wet steam LPG to the inner wall of the suction pipe there is also the risk of frost). In terms of the total discharge time of wet steam LPG from EPI is suitable EV with a larger flow cross section and to shorten the opening time EV significantly this will increase the pressure of wet steam LPG EPI and increase in speed of discharge of the ON and range compact beam to the suction channels in cylinder head (this will reduce the flow of wet steam contact with the inner wall of the plastic suction pipe and the formation of frost on the wall).

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