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# START OF LIQUID LPG SEQUENTIAL INJECTION INFLUENCE ON THE SELECTED USEFUL AND ECOLOGICAL PARAMETERS OF SI ENGINE

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**Summary**. In the paper some research results in relation to start of liquid LPG sequential injection influence on the useful parameters of spark ignition engine was presented. The main process that decides about an engine's working process is the fresh charge supply into cylinder and air-fuel mixture formation. In an engine fuelled with sequential injection of liquid LPG into the suction manifold arms, the process of air-fuel mixture formation among other things depends on the start of fuel injection, that directly influences useful and ecological parameters.

**Key words:** liquid LPG injection, sequential injection, air-fuel mixture creation

## INTRODUCTION

The newest feed systems with LPG injection into the suction manifold use petrol electronic control unit for injection gaseous fuel dose control. Command signal of petrol injectors is converted to command signal of gaseous fuel injector opening in this type of systems. LPG electronic control unit uses, among other things: gas pressure signals, accumulator voltage, gas temperature and they determine LPG injector opening signal. In systems of gaseous phase fuel injection, the time of LPG injection is longer than petrol injection time. For systems with liquid phase injection, the time of LPG injection is shorter than petrol injection time, instead. This results from energetic differences of petrol doses for time unit in relation to LPG fuelling with gaseous or liquid phase.

In multipoint petrol injection systems the injection into individual cylinders can be realized simultaneously or sequentially. For simultaneous injection the cylinders are grouped, and the injection is realized in the same time for this group of cylinders. For sequential injection the start of injection for each injector is individually controlled.

A fundamental problem for liquid propane-butane injection is fuel warm-up in the feed system [Dutczak 1999, 2003, Gola 2002, Jaworski 2005]. An increase of fuel temperature is connected with a decrease of fuel density. It requires an increase of fuel injection time. It is connected with fuel pressure change in the feed system, that produces injection time shortening. In an extreme case, the consequence of fuel's warm-up is vaporization into the fuel hoses and disturbance of engine run [Cipollone 2000, 2002].

Start of injection in an engine fuelled with fuel injection into the suction manifold influences the filling and air-fuel mixture creation processes. In petrol engines, for the sake of the long time of fuel evaporation, the injection is usually realized before opening of inlet valve. Injection on the open valve enables better mixture distribution in the cylinder and stratification with rich mixture zone near the spark plug area [Gisoo 2002, Seungmook 2002, Enju Lee 2003].

Essential parameters of fuel injection are pressure and temperature of fuel. The fuel pressure influences the fuel stream formation. Fuel and air temperatures influence the fuel vaporization process. It is hardly connected with time and start of injection [Jeremy 2004].

An example of new feed system with LPG liquid sequential injection is VIALLE fuelling system (Fig.1). This type of fuel system was used in the engine research [Jaworski 2005, 2006], and the received results are the subject of this paper.

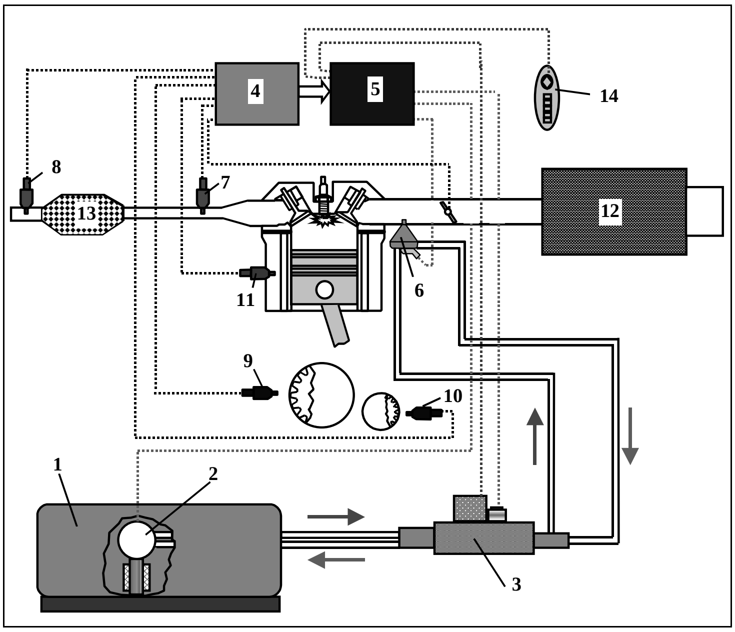


Fig. 1. Scheme of VIALLE fuelling system: 1 – LPG tank, 2 – LPG pump, 3 – fuel pressure regulator, 4 – petrol controller, 5 – LPG controller, 6 – LPG injector, 7 – first oxygen sensor, 8 – second oxygen sensor, 9 – engine speed sensor, 10 – camshaft position sensor, 11 – coolant temperature sensor, 12 – air filter, 13 – exhaust gas catalyst, 14 – fuel type switch

## DESCRIPTION OF STUDIES

The tested object was six-cylinders spark ignition engine MD-111ET with turbocharger Čz K36. This engine is the modification of compression-ignition engine MD-111E.1 of „PZL Mielec" Engines Company.

Configuration of the test stand (Fig. 2) include:

– hydraulic brake Schenck D-630E, enables smoothness change of engine load in the all range rotational speed and output power,

– automated mass fuel consumption system AVL with two Micro Motion sensors F025M and F010M,

– mass air flowmeter system AVL, enables to observe combustion air factor,

– combustion gas analyzing system PIERBURG type AMA 2000 for measurement of hydrocarbons and nitric oxides in the exhaust gas,

– combustion gas analyzer BOSCH type BEA-350 for measurement of carbon monoxide in the exhaust gas and for combustion air factor $\lambda$ analysis,

– computer system of high-variable signals acquisition, used for measurement of injector control signals, pressure into the suction manifold, engine valves lift, pressure course in the 1 and 6 cylinders and crankshaft position; it includes measuring card National Instruments AT-MIO-16E-1 and signal separator type NI-SCXI 1125.

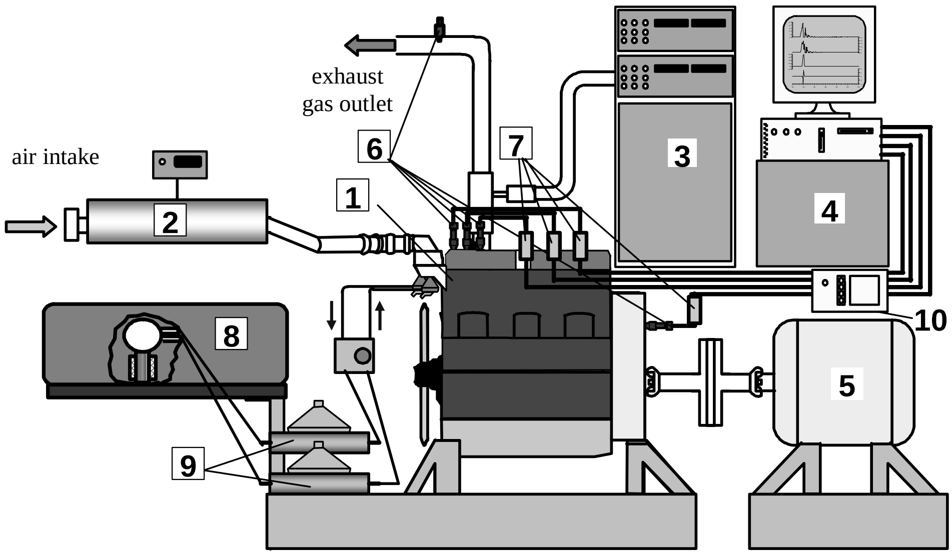


Fig. 2. Scheme of the test bed: 1 – engine, 2 – air flowmeter system, 3 – combustion gas analyzers, 4 – computer control with logging card, 5 – brake, 6 – sensors of high-variable signals, 7 – signal amplifiers, 8 – LPG tank, 9 – fuel consumption flowmeters, 10 – signal separator

The research was realized for fixed combustion air factor $\lambda \approx 1$ and for constant ignition advance angle $\alpha_{wz} = 16°$. In each testing point, after thermal stabilization of an engine there were measured working parameters of the engine and temperatures inside the suction manifold (in points according to Fig. 3). Research was realized for injection starts from measuring range represented in Fig. 4, for two signal disk injection sensor positions. In the first case, injection start was realized before and during the inlet valve opening phase. In the second signal disk sensor position, fuel injection was realized in all range of open inlet valve.

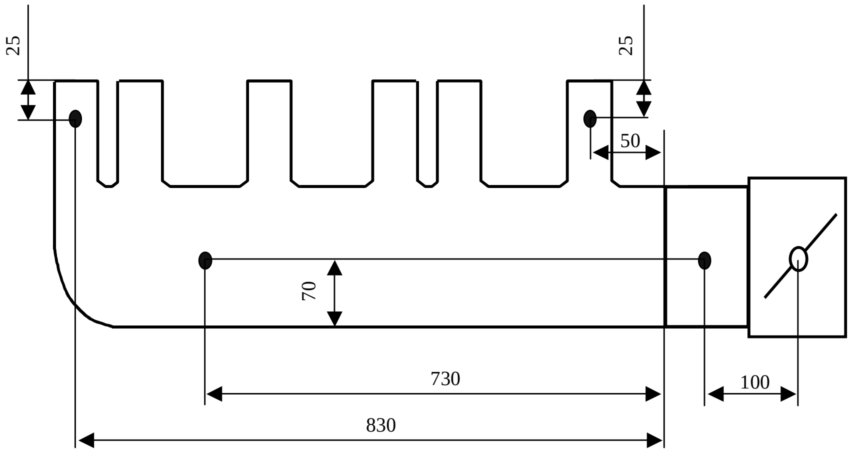


Fig. 3. Places of temperature measurement inside the suction manifold (point marking, sensors located in the symmetry axis of pipe)

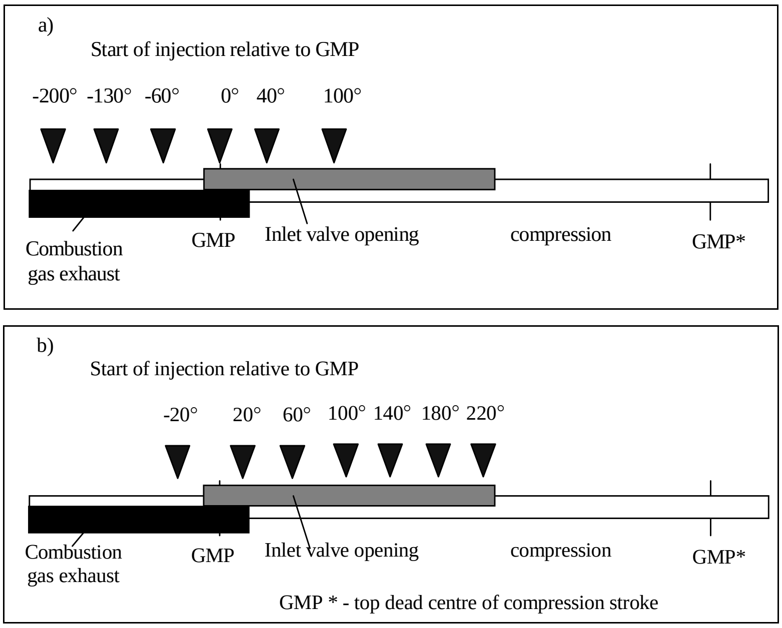


Fig. 4. Tested injection starts with signal disk sensor position: a) first, b) second

## RESEARCH RESULTS

Working medium temperature before inlet valve during liquid LPG injection while inlet valve is closed is lower than injection when inlet valve is open (Fig. 5÷10). It is especially apparent for temperature inside the suction manifold measured before inlet valve of cylinder 6. This can indicate, that some part of LPG fuel is supplied into the cylinder in drops form and vaporizing inside cylinder. For injection start at the crank angle range from 140° to 220° after top dead center in suction stroke, temperatures into the suction manifold before inlet valves are lower than for injection realized at the crank angle range from 0° to 100° after top dead center in suction stroke.

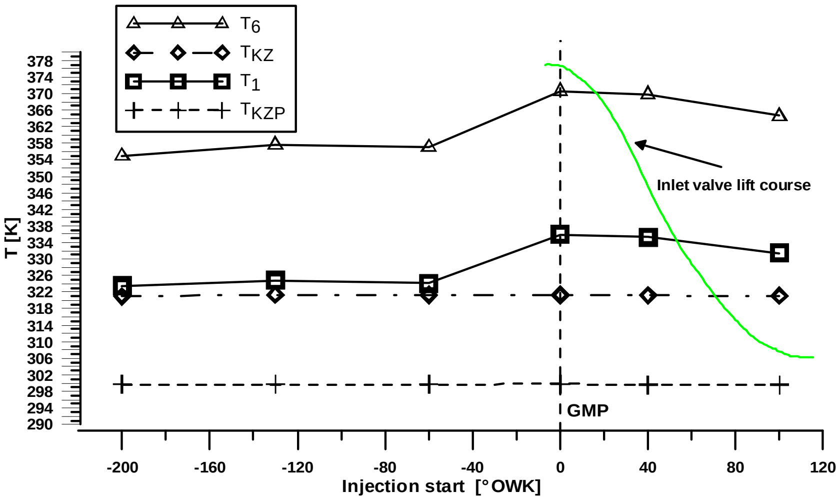


Fig. 5. Liquid LPG injection start influence the temperatures into the suction manifold (n = 1500 rpm, injection time 4,6 ms): $T_1$ – temperature before inlet valve of 1 cylinder, $T_6$ – temperature before inlet valve of 6 cylinder, $T_{KZ}$ – temperature into main suction manifold, $T_{KZP}$ – temperature behind throttling valve

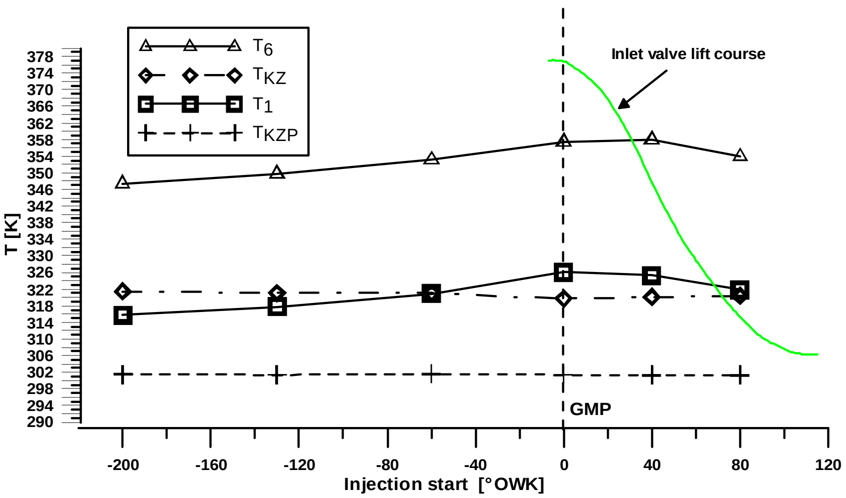


Fig. 6. Liquid LPG injection start influence on temperatures into the suction manifold (n = 1500 rpm, injection time 6,9 ms): $T_1$ – temperature before inlet valve of 1 cylinder, $T_6$ – temperature before inlet valve of 6 cylinder, $T_{KZ}$ – temperature into main suction manifold, $T_{KZP}$ – temperature behind throttling valve

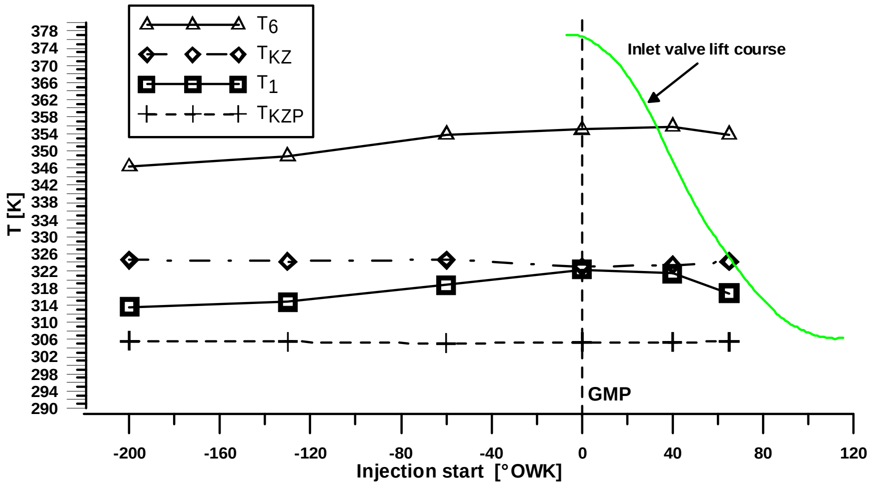


Fig. 7. Liquid LPG injection start influence on temperatures into the suction manifold (n = 1500 rpm, injection time 8,9 ms): $T_1$ – temperature before inlet valve of 1 cylinder, $T_6$ – temperature before inlet valve of 6 cylinder, $T_{KZ}$ – temperature into main suction manifold, $T_{KZP}$ – temperature behind throttling valve

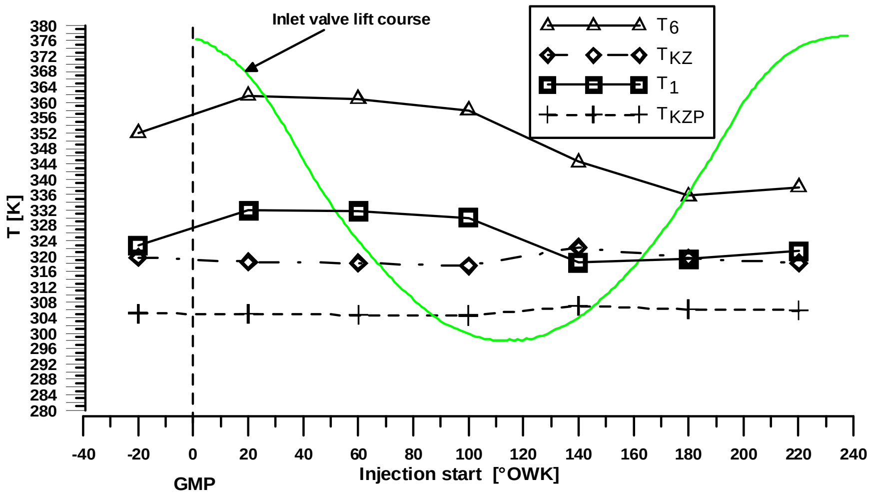


Fig. 8. Liquid LPG injection start influence on temperatures into the suction manifold (n = 900 rpm, injection time 5,5 ms): $T_1$ – temperature before inlet valve of 1 cylinder, $T_6$ – temperature before inlet valve of cylinder 6, $T_{KZ}$ – temperature into main suction manifold, $T_{KZP}$ – temperature behind throttling valve

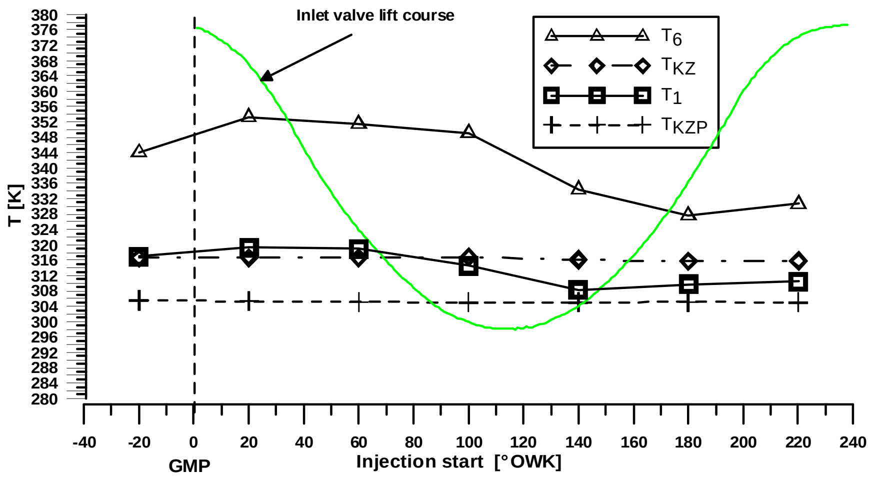


Fig. 9. Liquid LPG injection start influence on temperatures into the suction manifold (n = 900 rpm, injection time 6,6 ms): $T_1$ – temperature before inlet valve of 1 cylinder, $T_6$ – temperature before inlet valve of 6 cylinder, $T_{KZ}$ – temperature into main suction manifold, $T_{KZP}$ – temperature behind throttling valve

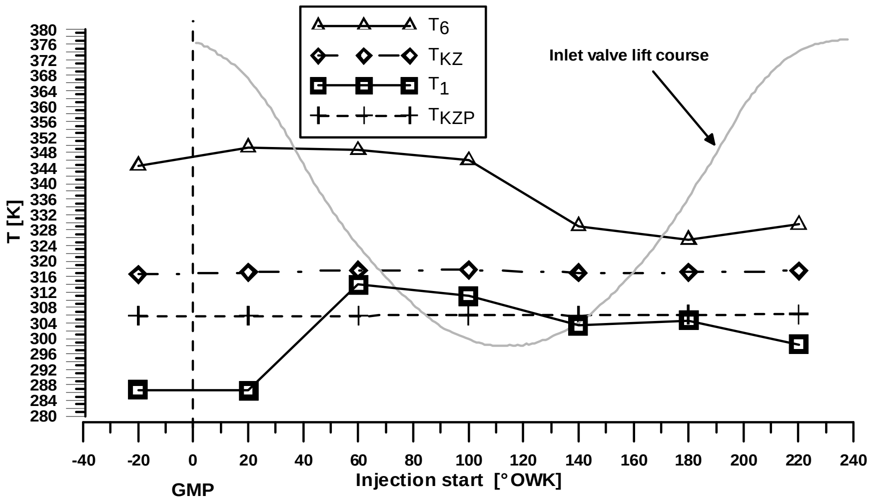


Fig. 10. Liquid LPG injection start influence on temperatures into the suction manifold (n = 900 rpm, injection time 8,4 ms): $T_1$ – temperature before inlet valve of 1 cylinder, $T_6$ – temperature before inlet valve of 6 cylinder, $T_{KZ}$ – temperature into main suction manifold, $T_{KZP}$ – temperature behind throttling valve

Changes of air-fuel mixture formation conditions for different injection starts makes different quality of this process. This effect changes useful parameters of an engine (Fig. 11 and 12), quantity of toxic compounds in exhaust gas (Fig. 13 and 14) as well specific emission [PN-EN ISO 8178, 1999–2004] of HC, CO and $NO_X$ (Fig. 15÷17).

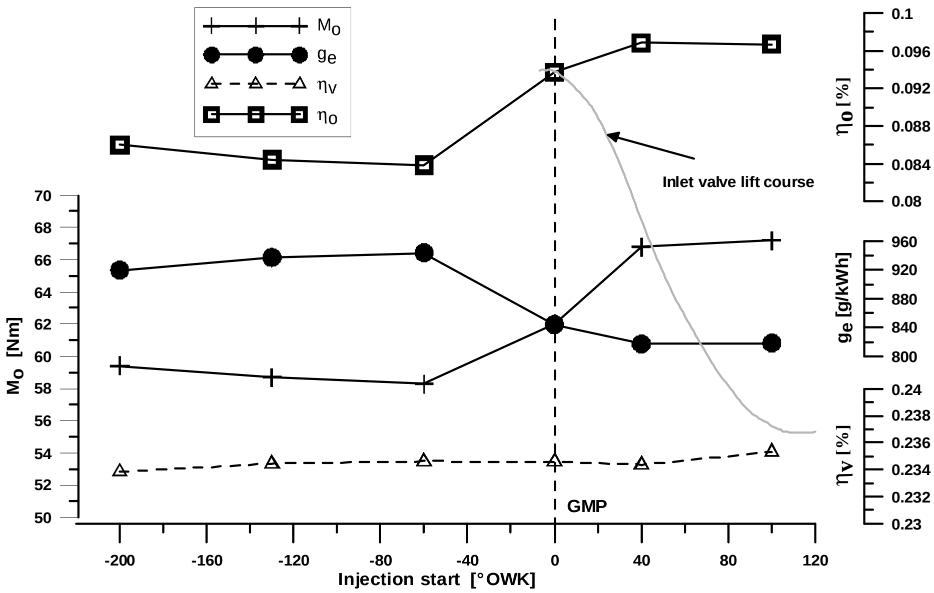


Fig. 11. Liquid LPG injection start influence on output torque $M_o$, filling efficiency $\eta_v$, total efficiency $\eta_o$ and energy consumption per unit $g_e$; (n = 1500 rpm, injection time 4,6 ms)

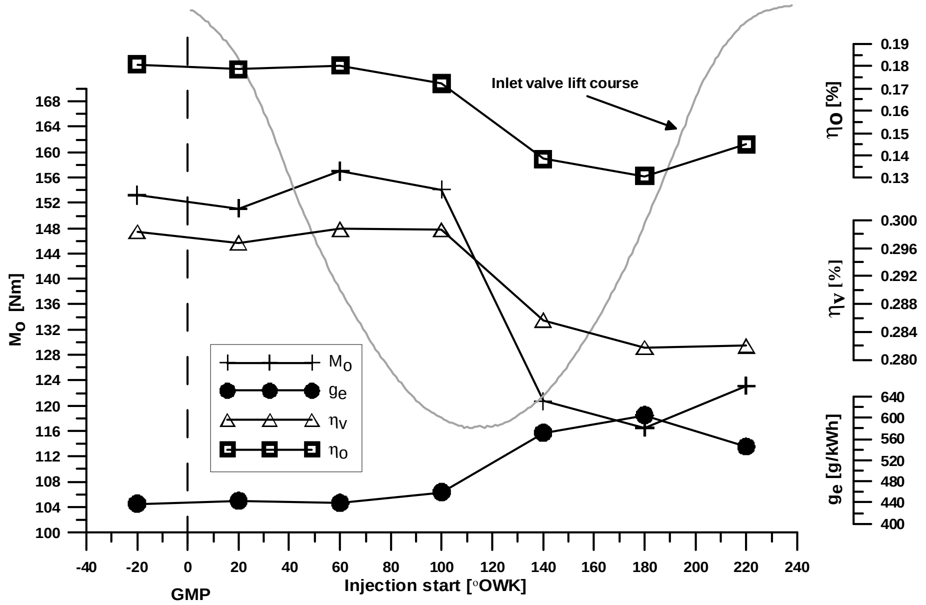


Fig. 12. Liquid LPG injection start influence on output torque $M_o$, filling efficiency $\eta_v$, total efficiency $\eta_o$ and energy consumption per unit $g_e$; (n = 900 rpm, injection time 5,5 ms)

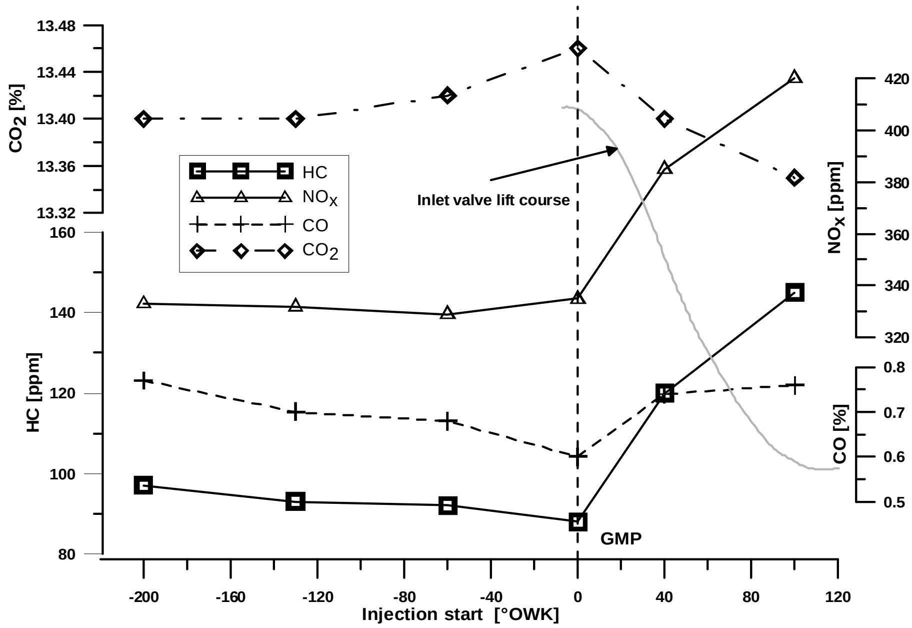


Fig. 13. Liquid LPG injection start influence on CO concentration, $CO_2$ concentration, HC concentration, $NO_x$ concentration of exhaust gas; (n = 1500 rpm, injection time 4,6 ms)

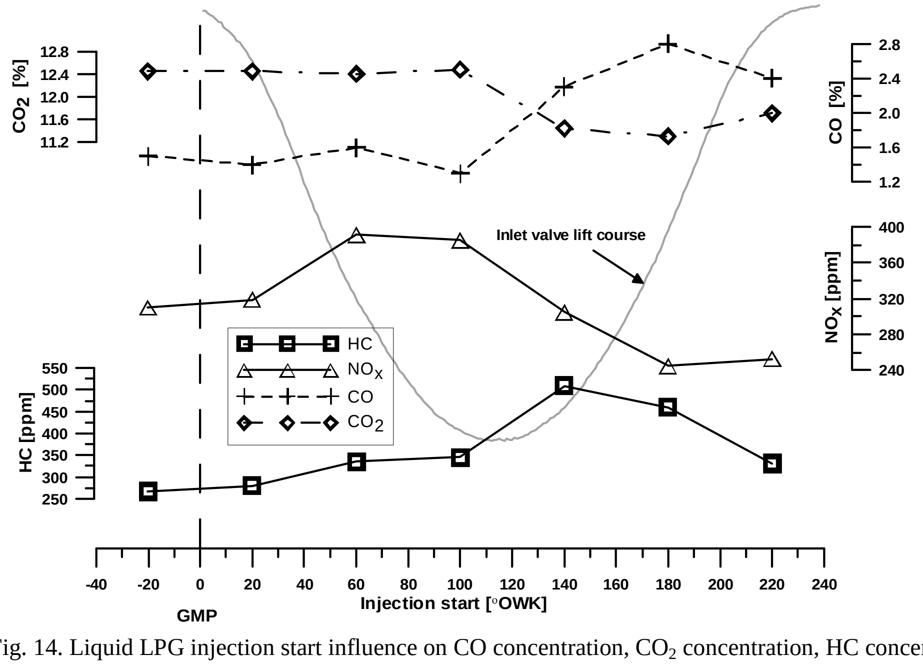


Fig. 14. Liquid LPG injection start influence on CO concentration, $CO_2$ concentration, HC concentration, $NO_x$ concentration of exhaust gas; (n = 900 rpm, injection time 5,5 ms)

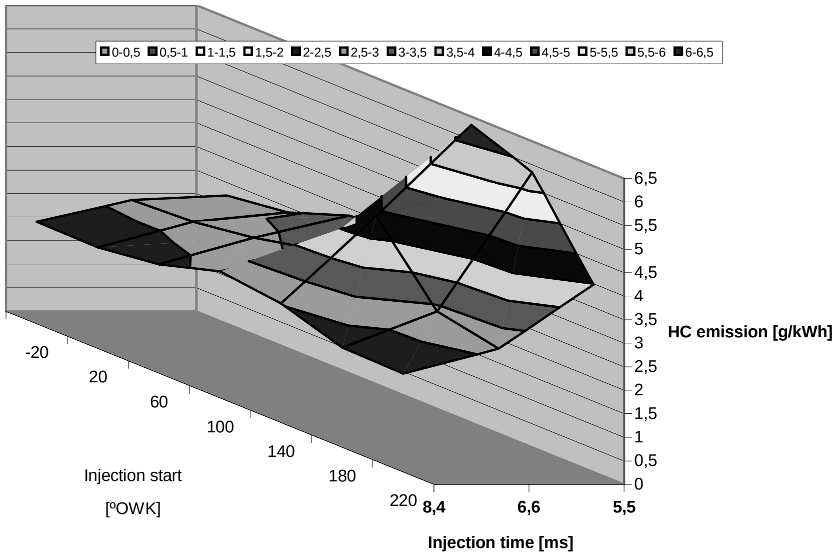


Fig. 15. Specific emission of HC for selected injection parameters (n = 900 rpm)

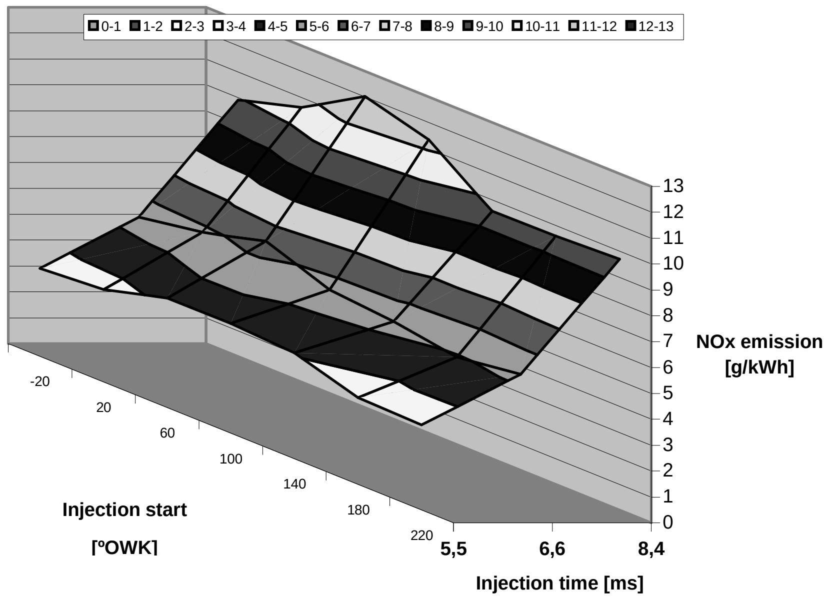


Fig. 16. Specific emission of $NO_x$ for selected injection parameters (n = 900 rpm)

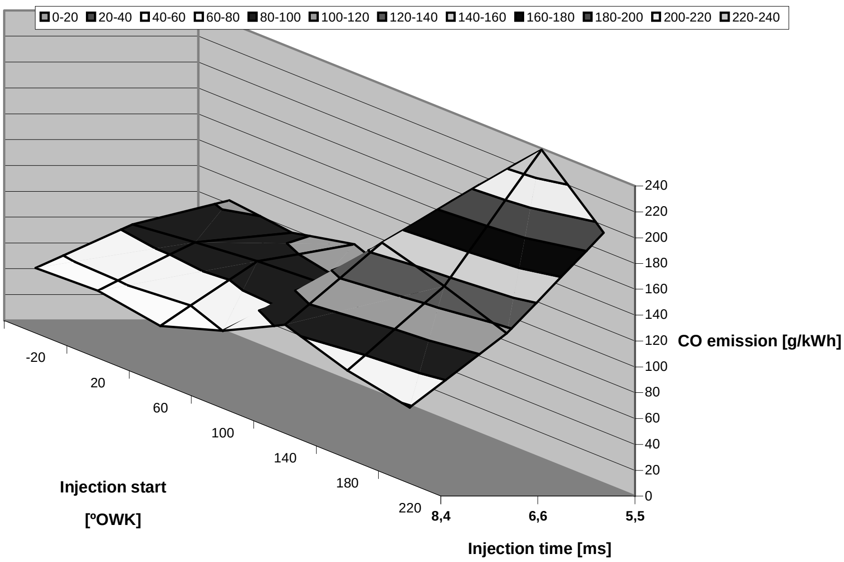


Fig.17. Specific emission of CO for selected injection parameters (n = 900 rpm)

## CONCLUSION

Change of injection parameters influences considerably the air-fuel mixture formation quality [Kowalewicz 1984]. This is connected with useful parameters of an engine. The principal parameter is injection start. Change of fuel injection start is connected with small change of cylinder filling efficiency ($\lambda \approx 0{,}98 \div 1{,}02$).

For LPG injection realized when the inlet valve is open, the measured temperatures inside the suction manifold arms increased. Injection when the inlet valve is closed, as well in the end period when it is open, makes temperatures lower. This shows that fuel vaporizes inside the suction manifold. In spite of a decrease of average temperature in the cylinder for injection LPG into the suction manifold with the stream oriented on the open injection valve, $NO_x$ emission increases. The reason for this and also for an increase of output torque can be the following phenomena:

– injection realized when inlet valve is open with concurrent air flow improves air-fuel mixture formation process, which in this case is more homogeneous,

– homogeneity of air-fuel mixture improves it ignition ability and increases combustion speed (it is the tendency for increasing speed of combustion for injection on the open inlet valve, that produces higher peaks of pressure and maximal temperatures of cycle),

– the quality of air-fuel mixture formation process is influenced by dynamical phenomena inside the suction manifold of engine,

– decreasing average medium temperature into the cylinder (especially in the decompression and exhaust phases) allows for an increase of thermal efficiency,

Taking into consideration output torque, higher values were received for injection start at the crank angle range from about 20° to about 100° after top dead center in suction stroke, when the inlet valve is open.

Research results show distinctly the dependence between injection parameters and toxicity of combustion gas. Essential parameters that effect on the combustion gas toxicity are start of injection and injection time (dose). For injection start at the crank angle range from 20÷100° after top dead center in suction stroke, we have the higher contents of $NO_x$ in the combustion gas, than for asynchronous injection or injection at the crank angle range from 140÷220° after top dead center in suction stroke.

Calculated specific emission of $NO_x$ attains higher values at the injection starts for lower useful parameters. Specific emissions of HC and CO get the highest values outside the range of injection start for which useful parameters were the best.

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