Changes of Low Load Engine Parameters by Temperature of Mixture

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SHRNUTÍ

V rámci R&D aktivit na čtyřválcovém zážehovém motoru v nízkém zatížení byl také proveden výzkum vlivu teploty nasávané směsi na parametry motoru. Obsahem tohoto článku bude popis změn parametrů motoru v režimu nízkého zatížení vlivem zvyšování teploty nasávané směsi. Z naměřených dat jednoznačně vyplývá, že zvýšení teploty směsi motoru zvyšuje rychlost spalování směsi a má pozitivní účinek na parametry motoru, zejména spotřebu. Dobré výsledky poukazují na smysluplnost těchto experimentů a dávají podnět pro pokračování výzkumu v této oblasti i v budoucnu.

KLÍČOVÁ SLOVA

teplota směsi, nízké zatížení motoru, indikace tlaku ve válci

ABSTRACT

Within the framework of research and development (R&D) activities on four-cylinder internal combustion (IC) engine in a low load state, a research for influence of mixture temperature on engine parameters has been performed. Content of this article will be describe of changes of low load engine parameters by increasing of mixture temperature. On the base of measured data, the increasing of mixture temperature causes increasing of mixture combustion rate and it has a positive effect on the low load engine parameters, especially on fuel consumption. Achieved results in this topic give impulse for continue of this research.

KEYWORDS

Temperature of mixture, low load engine state, in-cylinder pressure indicating

1. INTRODUCTION

In order to obtain maximal performance of engine, it is necessary to get maximal mass of working substance into combustion chambers (cylinders). There are several way to do it, for example to use a cooling of mixture, to use a turbocharging together with intercooling, to use a tuned intake and/or exhaust manifold and so on.

Another situation is in case of engine operating at low load. The power output is not preferred in this state. Another parameters are preferred – e.g. fuel consumption and exhaust emissions. It is well-known that for example emission of CO_2 is possible to decrease by decreasing of fuel consumption.

Future possibilities for decreasing of fuel consumption and exhaust gas emission are e.g. in another types of IC engines, described in e.g. [1].

Decrease of fuel consumption of cars operating within large cities (usually at very low load) may help to decrease the smog loading of the environment. On the base of mentioned reasons, research for influence of mixture temperature on engine parameters has been performed and the measured courses will be described later.

2. ARRANGEMENT OF THE TEST BED

Test bed layout is shown in Figure 1. The examined engine is four-stroke, naturally-aspirated (ϕ75.5 x 72 mm), natural gas-fueled and equipped with a closed-loop λ-control system and tree-way catalyst placed in exhaust manifold.

Test bed is equipped with DAQ system and in-cylinder pressure acquisition. The author's laboratory is equipped with so-called on-line in-cylinder pressure indicating system. Test bed crew can observe peak and minimum values of in-cylinder pressure and IMEP on the screen during measurement on the test bed.

In-cylinder pressure recording is considered a standard part of experimental activity, which is exploited continuously during the whole process of experimental research in engine laboratory. For this purpose the examined engine is equipped permanently with a cooled pressure transducer and an angle encoder (Incremental Rotary Encoder or IRC), which is permanently connected through a spring disc-type coupling at the front end of the crankshaft.

Special software was developed for recording in-cylinder pressure pattern during test bed operation [2] as well as for the evaluation of such records [3]. All the developed software were made using TestPoint professional development system [4].

Torque of examined engine is measured using tensiometric transducer (T10F), placed in shaft between the engine and dynamometer. The transducer is placed in the shaft according to the demands of manufacturer [5]. This transducer allows measure the revolution of engine as well.

A purposely designed heater was placed into intake manifold for increasing of aspirated air temperature upstream of mixer. More about the heater and regulation process of mixture temperature downstream of the throttle will be described later.

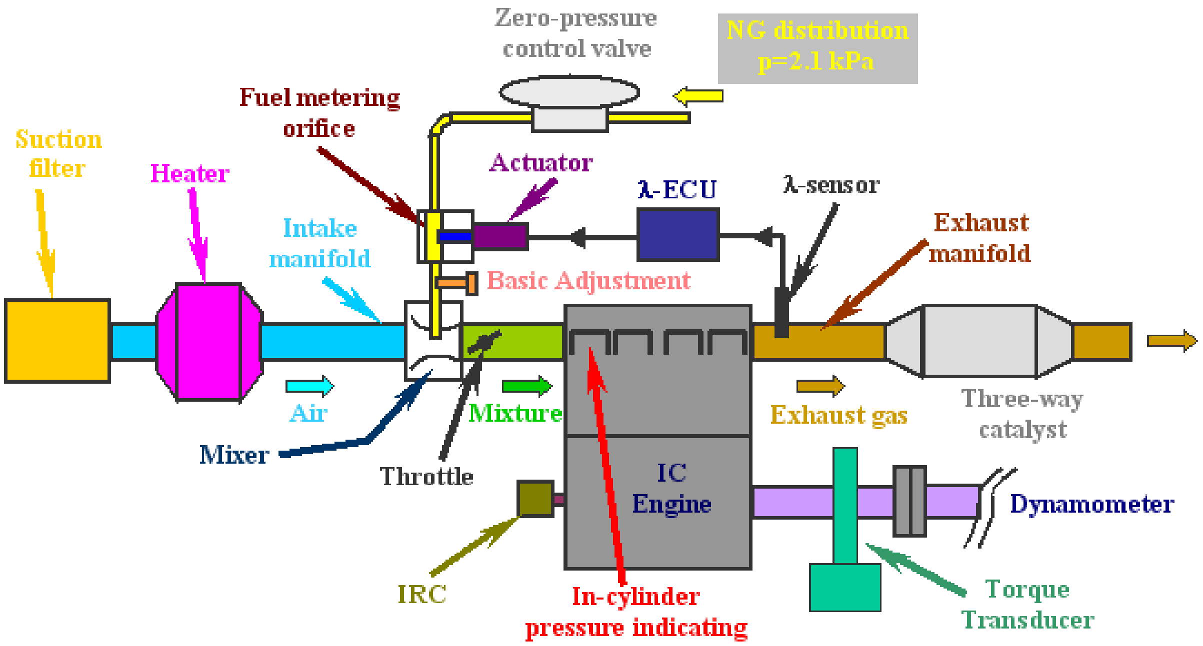

Figure 1: Scheme of the test bed layout with tested engine.
Obrázek 1: Schéma uspořádání zkušebního stanoviště.

3. HEATER DESIGN AND CONTROL OF TEMPERATURE

As mentioned, for increasing of temperature of mixture a heater placed into intake manifold upstream of mixture has been used. The heater contains three electric heating windings spirals. Power supply of each spiral is 230 V AC, input power of each spiral is about 1.5 kW. Author of the article [6] is designer of the heater.

Two thermometers were used for control of heater power. Heater power was controlled using relays that switched on and switched off the power supply of each spiral of heater. Two thermometers controlled these relays.

The first thermometer was connected with thermocouple placed into output of heater. This first thermometer controlled the maximal temperature in output of heater (so-called limiting thermometer). The second thermometer was connected with thermocouple placed in required place (or near this place) in intake manifold. The first thermocouple is superior to the second thermometer.

Required place for control of mixture temperature was downstream of throttle. However in this place was not enough space for mounting of thermocouple of the second thermometer. That is why the thermocouple of the second thermometer was placed upstream of throttle, not downstream.

Thermocouples of both thermometers must have special design not conventional one. The thermocouples feature quick response and they are heat-isolated from the wall of the manifold, in which are mounted. Design of these thermocouples was developed in author’s laboratory.

Temperature of mixture was measured using conventional thermocouple downstream of throttle. Design of body of this thermocouple allows measurement of static pressure downstream of throttle by appropriate output for pressure transducer.

Additional requirement on the temperature-control process was to keep the average value of mixture temperature downstream of throttle within a range of 1 °C. This requirement was accomplished. Using this described method there is the possibility to control the temperature of mixture or air in arbitrary place in intake manifold (where it is possible to place the thermocouple).

4. CHOICE OF MEASUREMENT METHOD

Low load engine was simulated by chosen load represented by: BMEP = 200 kPa = const. Speed regimes of examined engine were chosen: 1300; 1500; 1700 and 2000 RPM. Temperatures of mixture downstream of throttle were chosen: First measurement without heating (BO), in each from further three measurements the mixture temperature should be about 50 °C higher than that in previous measurement. The highest mixture temperature in described low load engine state without heating was measured about 37 °C. So in this way the mixture temperature in further three measurements was chosen: 90; 140 and 190 °C. It must be pointed out that the mixture temperature downstream of throttle was not controlled in case without heating. This mixture temperature was given by the ambient conditions during measurement in engine laboratory.

The low load engine state should be kept constant (BMEP = 200 kPa). However this load of engine is very complicated to keep constant using the instruments on the test bed. Therefore the method described follow was suggested:

All of the measured points (without heating including) will be measured twice. First the parameters of engine in load of BMEP > 200 kPa (usually about 250 kPa) will be measured. Second the parameters of engine in load of BMEP < 200 kPa (usually about 150 kPa) will be measured. Values of observed parameters of engine in load of BMEP = 200 kPa will be calculated using linear interpolation. The isolines of constant value of BMEP = 200 kPa are depicted in marked Figures.

5. MEASURED COURSES AT VARIOUS TEMPERATURES OF MIXTURE

In Figure 2a the measured courses of mixture temperature downstream of throttle (tK3) are shown. For better comparison the courses of mixture temperature measured without possibility to control the temperature (this measurement was performed about half year ago) are depicted in Figure 2a with thin lines. The courses of controlled mixture temperature (actual measurement) are depicted in Figure 2a with bold lines. Directly measured values are shown in this figure.

In Figure 2b the courses of underpressure downstream of throttle (pK3) are depicted. Values of underpressure are decreased with increasing of mixture temperature. Decreasing of density volume of heated mixture causes this effect. Courses of opening of throttle (%thr) are depicted in Figure 2c. Opening of throttle is increased with increasing of mixture temperature. However, at the mixture temperature about 90 °C almost the same throttle position was observed than that without heating (BO). Only at the mixture temperature above 140 °C it is necessary to increase the opening of the throttle to keep demanded engine power.

Courses of exhaust gas temperature (upstream of catalyst – tT1) are shown in Figure 3a. Exhaust gas temperature is decreased with increasing of mixture temperature. For examination of this measured phenomenon data from in-cylinder pressure indicating were used. Calculated values of in-cylinder temperature (Tcyl) during high-pressure part of four-stroke cycle at 1300 RPM and BMEP < 200 kPa and at all of adjusted temperatures of mixture are depicted in Figure 3b. Exhaust gas temperature in the end of expansion is decreased with increasing of mixture temperature, see detail in Figure 3c. The measured courses in Figure 3a were verified by this way.

Courses of mass of charge in cylinder (Mcyl) are shown in Figure 4a. Mass of charge is decreased with the increasing of mixture temperature as it was expected. Brake specific fuel consumption (bsfc) is decreased with increasing of mixture temperature, which is shown in Figure 4b. In this Figure it is visible, that specific consumption is decreased in all the measured points except one (1300 RPM).

For examination of situation in this point, the measured data from in-cylinder pressure indication were used again. In Figure 5a are shown calculated courses of normalized heat-release (5.1) at 2000 RPM and BMEP < 200 kPa.

$$\boldsymbol{Qnm} = \frac{\boldsymbol{Q_\alpha}}{\boldsymbol{Q_c}} \quad [-] \tag{5.1}$$

where:
Q_α is released heat at given crankshaft angle,
Q_c is total delivered heat

In Figure 5b calculated courses are shown of rate-of-heat-release. It is visible in Figure 5b that rate-of-heat-release is increased with increasing of mixture temperature in engine state 2000 RPM and BMEP < 200 kPa.

In Figure 5c are shown isolines of crank angles at which the heat-release reaches 10, 50 and 80% of total delivered heat at BMEP = 200 kPa for all the measured points of RPM. As shown in Figure 5c, duration of heat-release is shortened not only by mixture temperature increasing but by increasing of RPM as well. This is caused by higher turbulence of working fluid in combustion chamber in higher RPM, which supports combustion of mixture. Only small turbulent flow of mixture is in engine state of 1300 RPM, which causes the slow rate-of-heat-release. This is probably the reason, the specific consumption is a bit higher in engine state of 1300 RPM, 90 °C than in state without heating, see Figure 4b. But in state at temperature of mixture about 140 °C and more, 1300 RPM, the bscf is decreased as well. In order to achieve the effect of increasing the specific consumption it is necessary to increase more the temperature of mixture in this engine state (in this point).

Exhaust gas temperature downstream of catalyst (tTCO) is increased with increasing of mixture temperature, see Figure 4c. It is caused probably by increasing of content of NOx (represented by NO) in exhaust gas upstream of catalyst as it is shown in Figure 6. It is to assume that exhaust gas after-treatment is able to cope with increased NOx content in raw exhaust gas) Increasing of the content of the other particular pollutant by increasing of mixture temperature was not observed.

Courses of in-cylinder pressure during low-pressure period of four-stroke cycle at 1500 RPM and BMEP < 200 kPa at all of measured temperatures of mixture are depicted in Figure 7. Work necessary for working fluid exchange in combustion chamber is decreased with increasing of mixture temperature only very little, as visible in this Figure.

6. CONCLUSION

From showed measured courses it is clearly visible, that rate-of-heat-release is increased with increasing of mixture temperature. Decrease of negative area is negligible, however it is possible to improve engine efficiency at low load thank to higher burning velocity of pre-heated mixture. Performed measurement confirmed the theoretical assumptions, that by increasing of mixture temperature in low load engine state there is the possibility to spare the fuel.

For practical using there is a problem about solution for quick heating of mixture with suitable energy demand.

7. ACKNOWLEDGEMENT

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LIST OF NOTATIONS AND ABBREVIATIONS

BMEP	Break Mean Effective Pressure [Pa];	**pCyl**	In-cylinder indicated pressure [Pa, bar];
BO	Without heating;	**pK3**	Underpressure downstream of throttle [Pa];
bsfc	Break Specific Fuel Consumption [g.kW^{-1}h^{-1}];	**Q_{α}**	Released heat at given interval [J];
CA	Crankshaft Angle [°], Czech ⇒ OKH;	**Q_c**	Total leaded heat [J];
CO_2	Molar fractions of CO_2 in dry exhaust gas [%vol.];	**Qnm**	Standardized heat-release [-];
DAQ	Data AcQuisition system;	**RPM**	Revolutions Per Minute [min^{-1}];
IC	Internal combustion;	**Tcyl**	Temperature of working fluid [K];
IMEP	Indicated Mean Effective Pressure [Pa, bar];	**TDC**	Top Dead Center;
IRC	Incremental rotary encoder;	**tK3**	Mixture temperature downstream of throttle [°C]
Mcyl	Mass of charge [kg.s^{-1}];	**tT1**	Exhaust gas temperature [°C]
NOx	Molar fractions of NO in dry exhaust gas [ppm];	**tTCO**	Exhaust gas temperature downstream of catalyst [°C]

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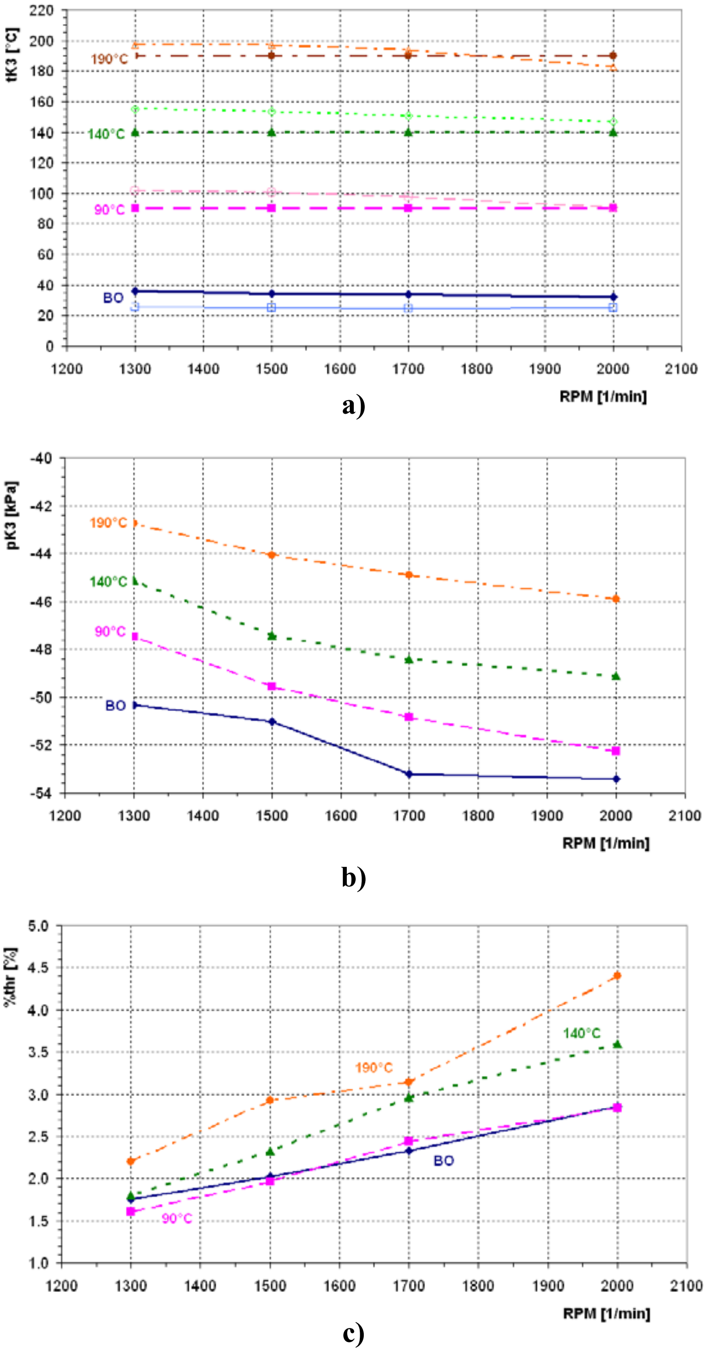

Figure 2: Measured courses of: a) tK3; b) isolines of pK3; c) isolines of %thr.
Obrázek 2: Naměřené průběhy: a) tK3; b) izočáry pK3; c) izočáry %thr.

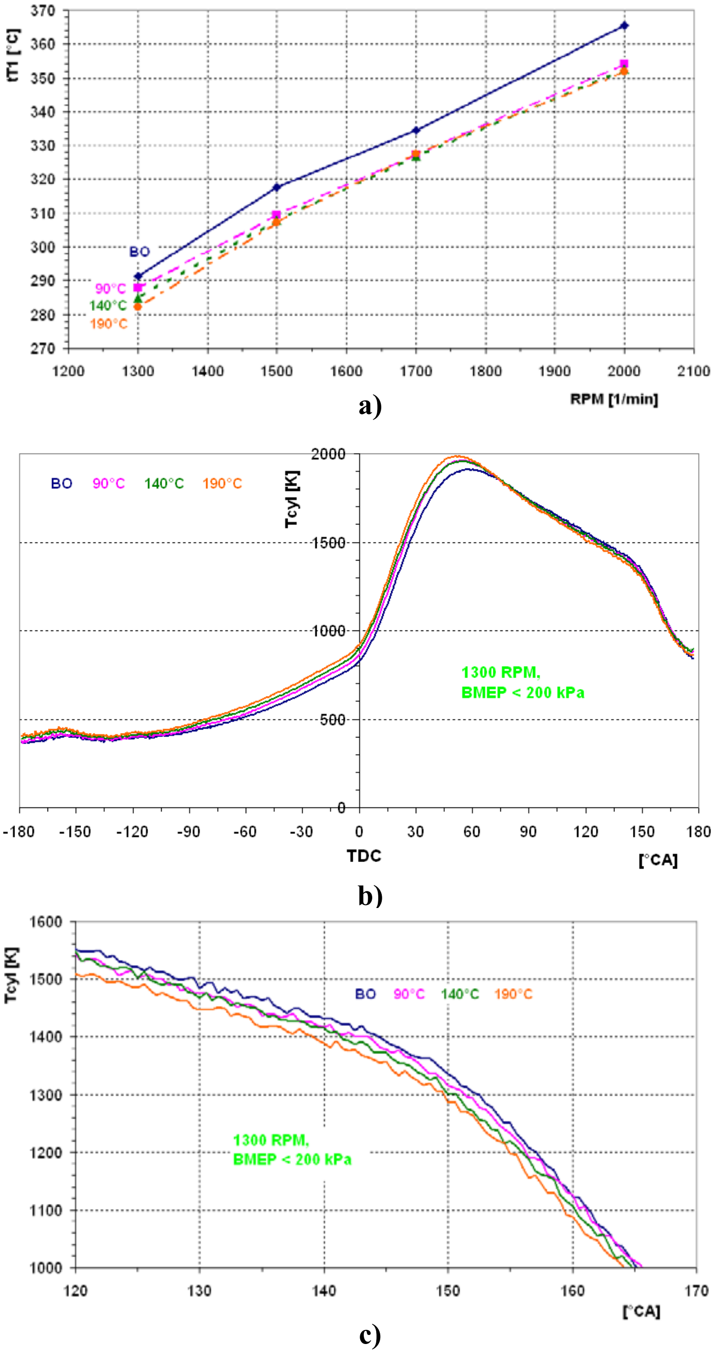

Figure 3: Measured courses of: a) isolines of tT1; b) Tcyl; c) Tcyl in the end of expansion.
Obrázek 3: Naměřené průběhy: a) izočáry tT1; b) Tcyl; c) Tcyl na konci expanze.

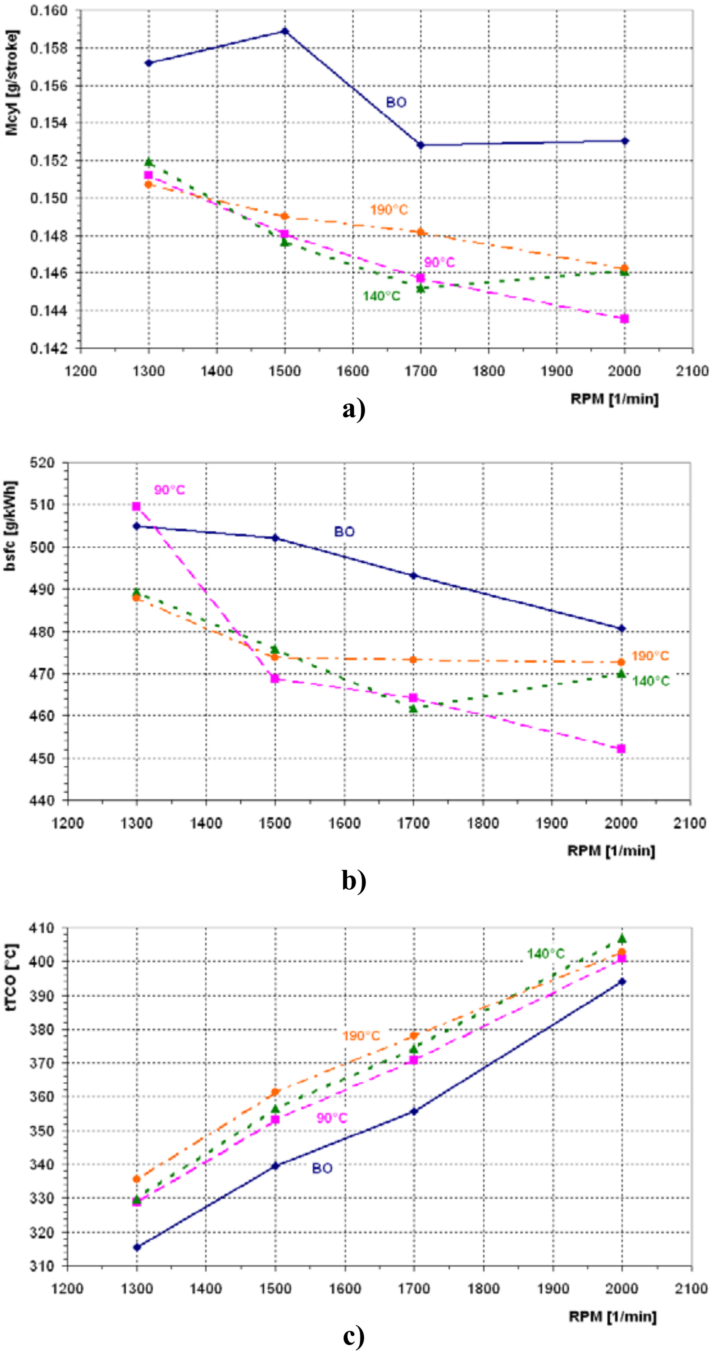

Figure 4: Measured courses (isolines) of: a) Mcyl; b) bsfc; c) tTCO.
Obrázek 4: Naměřené průběhy (izočáry): a) Mcyl; b) bsfc; c) tTCO.

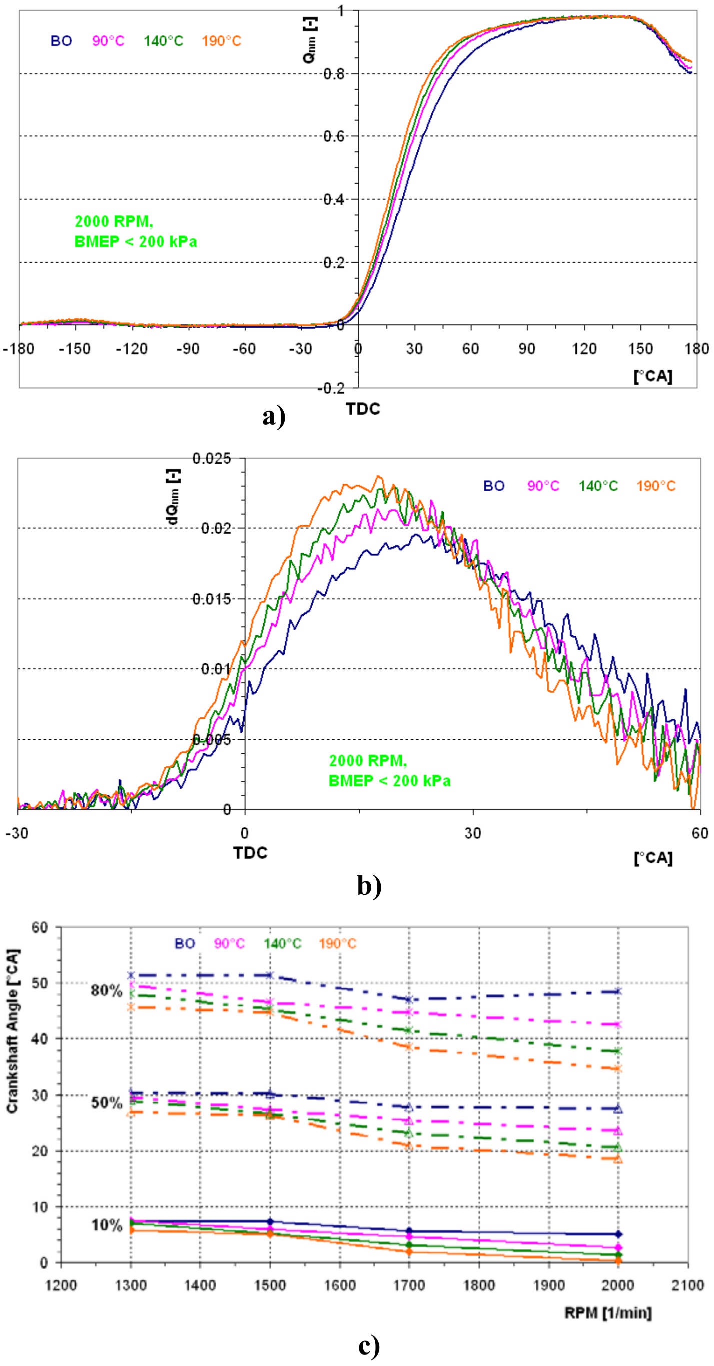

Figure 5: Calculated courses of: a) Qnm; b) dQnm in chosen interval of CA; c) Duration of heat-release for 10, 50 and 80% of Q_c.
Obrázek 5: Vypočítané průběhy: a) Qnm; b) dQnm ve zvoleném intervalu OKH; c) Doba vývinu tepla pro 10, 50 a 80% z Q_c.

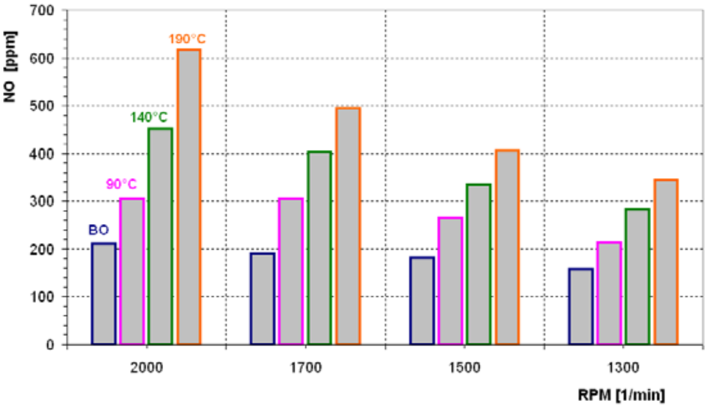

Figure 6: Measured courses (isolines) of NO upstream of catalyst
Obrázek 6: Naměřené průběhy (izočáry) NO před katalyzátorem.

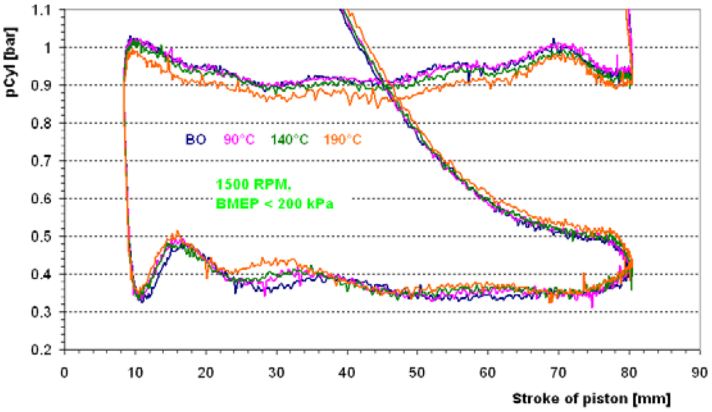

Figure 7: In-cylinder pressure courses during working fluid exchange.
Obrázek 7: Průběhy tlaku ve válci během výměny pracovní náplně.