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Comparison of Combustion Characteristics of S.I. Engine Fuelled with Butane and Gasoline on Lean Operating Limit

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According to worldwide trend, many research centres focus on fuelling of SI engine with homogeneous and heterogeneous lean mixtures. In the Department of Internal Combustion Engines in Radom Technical University some investigation on fuelling of SI engine with lean air — fuel mixtures was carried out. For these experiments butane was used, because it has relatively wide flammability limits and it seems to be a good fuel for experiments on fuelling the engine with the lean mixture. The objectives of this paper are:

— Analysis of the influence of air-fuel ratio (A/F) on combustion characteristic parameters, engine performances anf thermal efficiency,
— Comparison of fuelling with butane with convetional carburettor fuelling in the aspect of above mentioned data,
— Optimisation of combustion of butane-air mixture on account of spark timing.

The results of the investigation show that there is possible to fuel the engine with lean butane — air mixture in efficient way. Its performance and efficiency are at the same level as for gasoline carburettor engine. There are also some potential possibilities of increasing advantages, which are hidden in modification of fuel system. The improvement of it, especially application of injection of the liquid gas could strongly improve above presented results, which will be used as a base for the next examination of modified engine.

Introduction

Application of gaseous fuels to conventional spark ignition engine depends not only on simple change of fuel which is supplied to the engine. At the very least it requires modification of engine fuel system as well as optimization of engine operating parameters for new type of fuelling. First of all, both the new fuel system and engine control should take into account the properties of new fuel. Generally the examination of the engine should take into account the following problems:

- type/mode of engine fuelling: place and time of introducing the fuel to the engine,
- range of necessary modifications,
- optimization of engine operating parameters,
- optimization of air — fuel (A/F) ratio,
- type of load control (quantitative or qualitative).

For these and any other special questions the answers could be provided by analysis of combustion process of new fuel in modified engine, as well as by measurements of engine performance and emission.

According to the world-wide trend, many research centres focus on fuelling SI engine with homogeneous and heterogeneous lean mixtures. In Radom Technical University some investigations on fuelling of S.I. engine with lean air–fuel mixtures were carried out [1, 2, 3]. Several different modes of fuelling were applied, including gaseous fuelling. This paper presents some results of investigations of application of butane for fuelling of S.I. engine with lean mixtures. The experiments are a part of wider program of searching of effective method of fuelling of S.I. engine with lean air–fuel mixture.

2. Butane as a fuel for S.I. engine

The properties of butane allow to apply this gas as a fuel to S.I. engine. Its high octane number and the same A/F ratio for steichiometric mixture as for gasoline–air mixture, as well as relatively high heating value could give good results of application for S.I. engine. The comparison between butane and gasoline is shown in the tab. 1 [4].

Table 1

Fuel	Formula	Molecular weight	Heating value [MJ/kg]	Density [kg/m³]	Octane number RON	A/F (Steichiometric)	Mixture flammability limits[1]
Butane	C_4H_{10}	58	45.27	2.73	98	15.2	$0.34 < \lambda < 1.74$
Gasoline	$C_{8,26}H_{15,5}$	113–126	42–44	0.72–0.78	97–98	14.9	$0.2 < \lambda < 1.16$

The special advantage of butane as a fuel are wide limits of mixture flammability. It is especially important for experiments which were planned to perform of this work.

3. Objectives of the work

The experiments are going to provide a lot of data which will be useful for modification of conventional engine for fuelling with lean air–butane mixture. The objectives of this paper are:

- Analysis of the influence of air–fuel ratio (A/F) on combustion characteristic parameters, engine performances and thermal efficiency,
- Comparison of fuelling with butane with conventional carburettor fuelling with gasoline in the aspect of above mentioned data,
- Optimization of combustion of butane–air mixture on account of spark timing.

[1] For normal conditions

4. Description of experiment

Experiments were carried out at the test stand shown in Fig. 1.

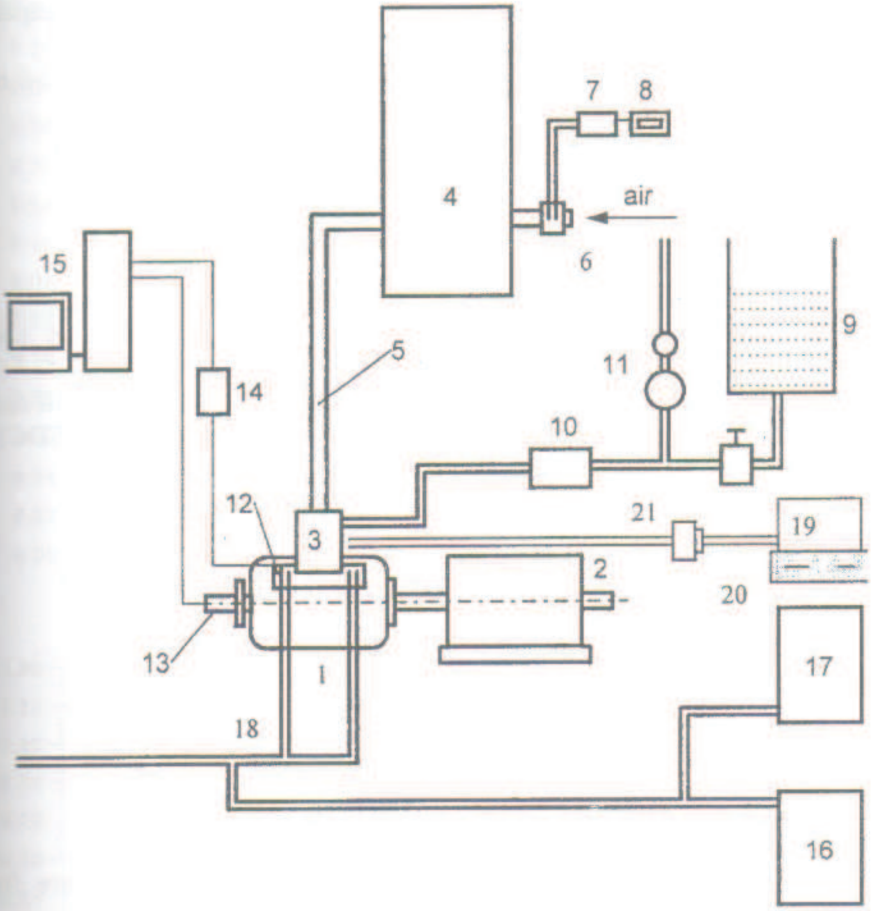


Fig. 1. Test stand. 1 — engine, 2 — dynamometer, 3 — mixer, 4 — surge tank, 5 — air pipe, 6 — laminar flowmeter, 7 — voltage converter, 8 — indicator of flow-rate, 9 — fuel tank, 10 — fuel accumulator, 11 — volumeter, 12 — pressure sensor, 13 — speed sensor INTROL, 14 — amplifier, 15 — data acquisition system with A/D converter and control system, 16 — NO_x analyser Beckman Model 951, 17 — AVL Model 465. Analyser, 18 — exhaust manifold, 19 — butane tank, 20 — balance, 21 — gas vaporiser

As an experimental engine the engine of Fiat CINQUECENTO 704 was used. The engine was equipped with the air-butane mixer and the gas installation. The inlet port of the one cylinder of the engine was choked, so the only one cylinder of the engine worked. Engine was connected to the eddy-current dynamometer Vibrometer SWB15. The air was supplied to the engine through the flowmeter, surge-tank, pipe and a carburettor. Liquid fuel was supplied to the carburettor from the tank. Fuel flow rate was measured with the use of the volumeter. The most important measurements from the point of view of the work objectives were the measurements of pressure in the cylinder. Pressure was measured with the AVL 8QP500 sensor with the use of a measuring and data acquisition system (worked out in the Department of I.C. Engines and Automobiles). Engine speed was measured with the sensor-encoder of the C.A. connected to this system. Data from measurement and data acquisition system based on the card of Kithley Co. were used for computation of:

— the indicated mean effective pressure, of each cycle (imep) and mean of 200 cycles,

— the coefficient of variation of indicated mean effective pressure [5]:

$$COV_{imep}=\frac{\sigma_{imep}}{imep}$$

where σ is the standard deviation of imep in each individual cycle.

— engine thermal efficiency and for analysis of P_{max} inside cylinder and the moment of its appearance.

Experiments were carried out for constant engine speed — 3000 rpm. In order to compare results, the same ignition timings ($\varphi_i=25$, 30, 36 degree before TDC) were applied for both fuelling modes (gasoline and butane).

Measured quantitiese were as follows:

— pressure in engine cylinder,

— torque,

— fuel consumption,

— coefficient of air excess λ,

— NO_x and HC emission.

Coefficient of air excess λ was measured directly with AVL 465 analyser.

5. Results and discussion

Main results of the experiments are as follows:

— engine operation is possible up to $\lambda=1.65$, but the leanest mixture for the acceptable level of COV_{imep} ($COV_{imep}=10\%$) is similar for both fuels:
- $\lambda=1.5$ — for gasoline,
- $\lambda=1.45$ — for gas fuel, Fig. 2,

— thermal efficiency is similar for both fuels in the range of $\lambda=0.9-1.35$ and reaches maximum value $\eta_{th}\sim0.32$, Fig. 3,

— the difference of values of thermal efficiency for different ignition timing starts from $\lambda=1.35$ for gasoline and sooner ($\lambda=1.25$) for butane, Fig. 3,

— with leaning the mixture, the decrease of thermal efficiency for gas fuel is slower than for gasoline, Fig. 3,

— much more lower maximum pressure is obtained for butane in comparison with gasoline in the whole range of A/F, Fig. 4,

— with leaning the mixture, maximum pressure shifts towards higher λ, Fig. 4,

— though higher imep were observed for gasoline, (imep$=0.7-0.9$ MPa), decrease of imep with mixture leaning is quicker than for gas fuelling, Fig. 5,

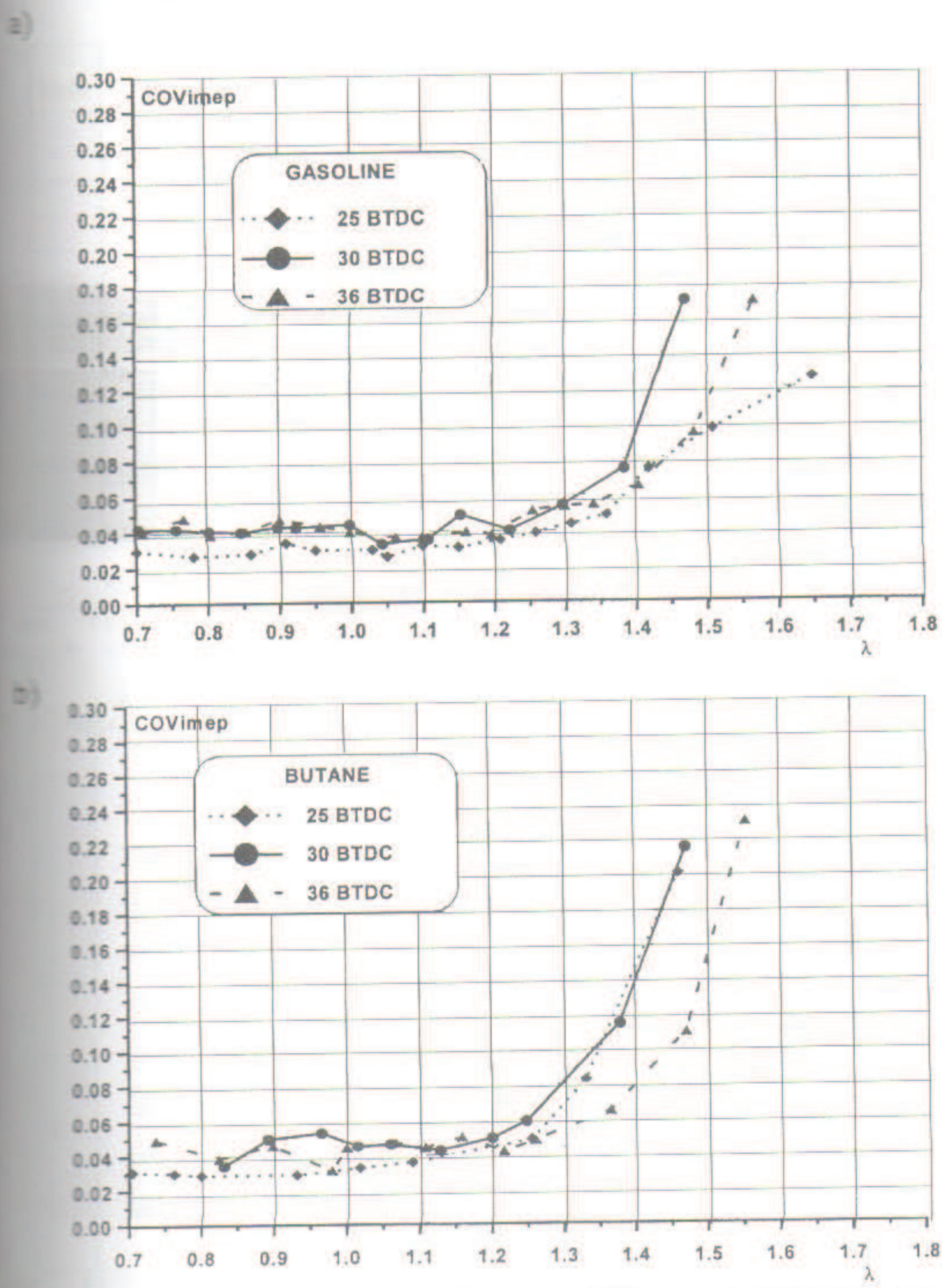


Fig. 2. Coefficient of variation of indicated mean effective pressure COV_{imep} vs. coefficient of air excess λ for fuelling with; a) gasoline, b) butane. COV_{imep} is calculated for three ignition timings (25, 30, 36 deg BTDC)

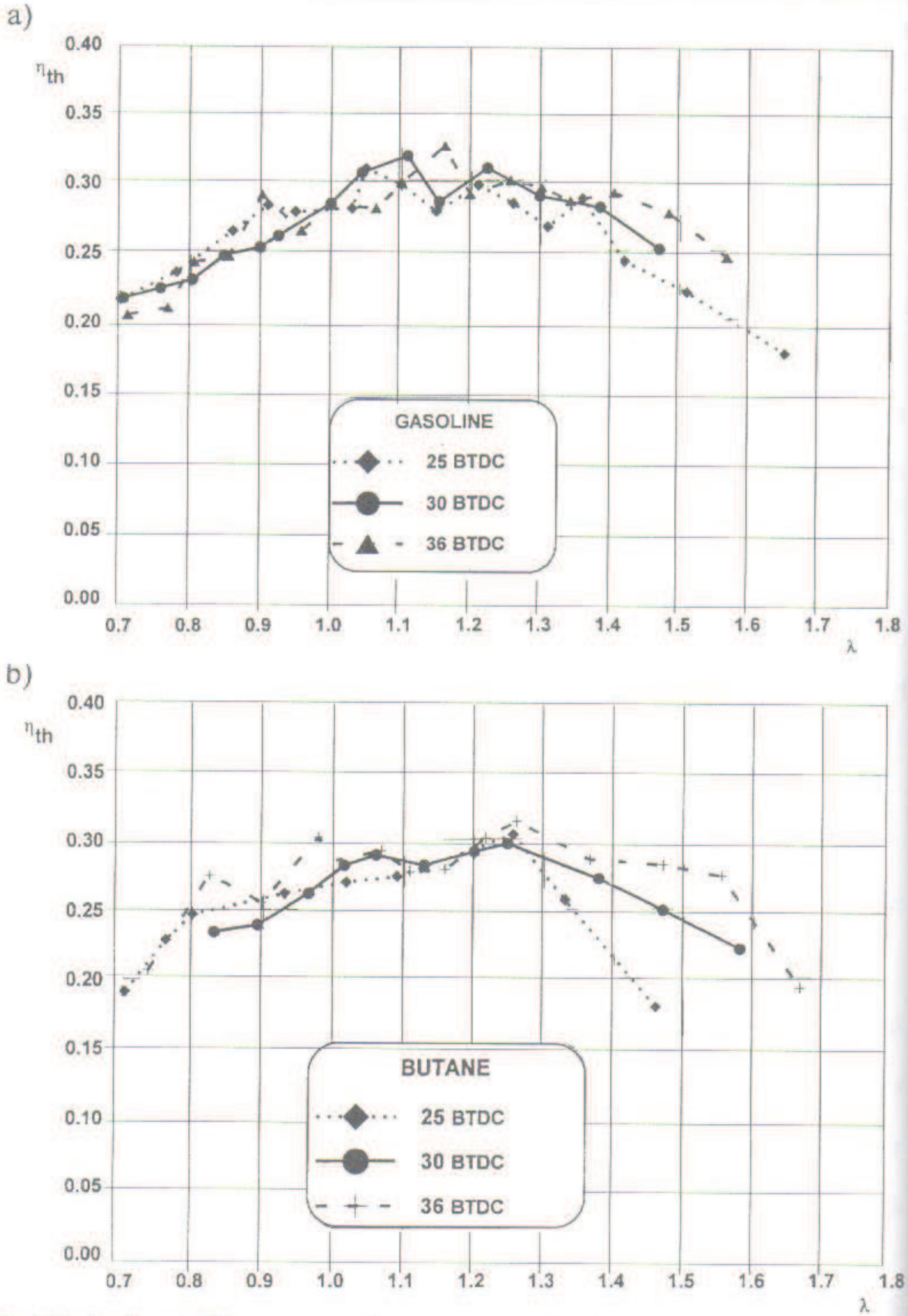
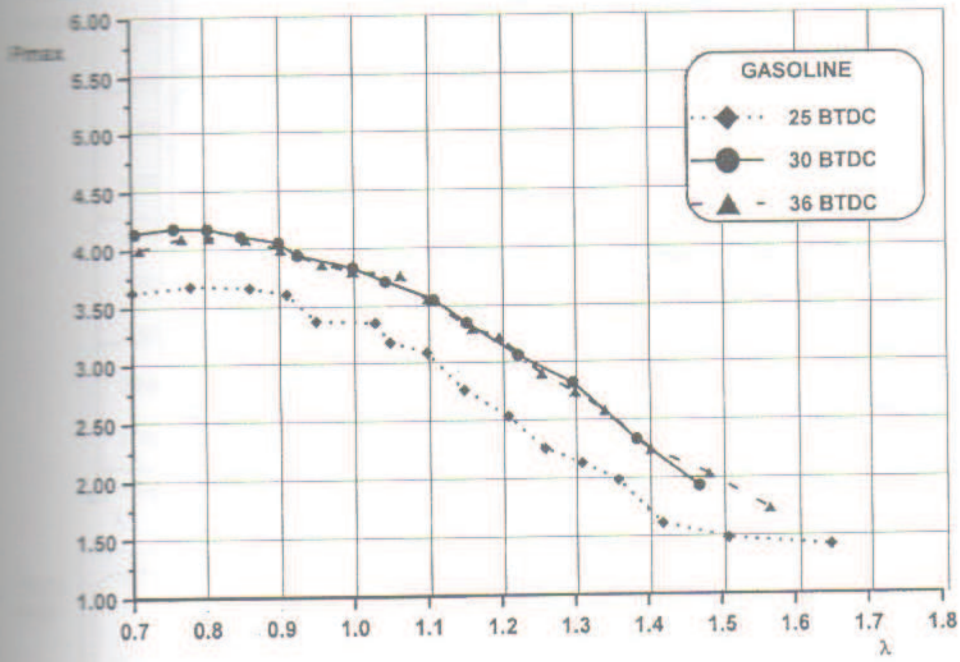


Fig. 3. Engine thermal efficiency η_{th} vs. coefficient of air excess λ for three ignition timings (25, 30, 36 deg BTDC); a) engine fuelled with gasoline, b) engine fuelled with butane

a)



b)

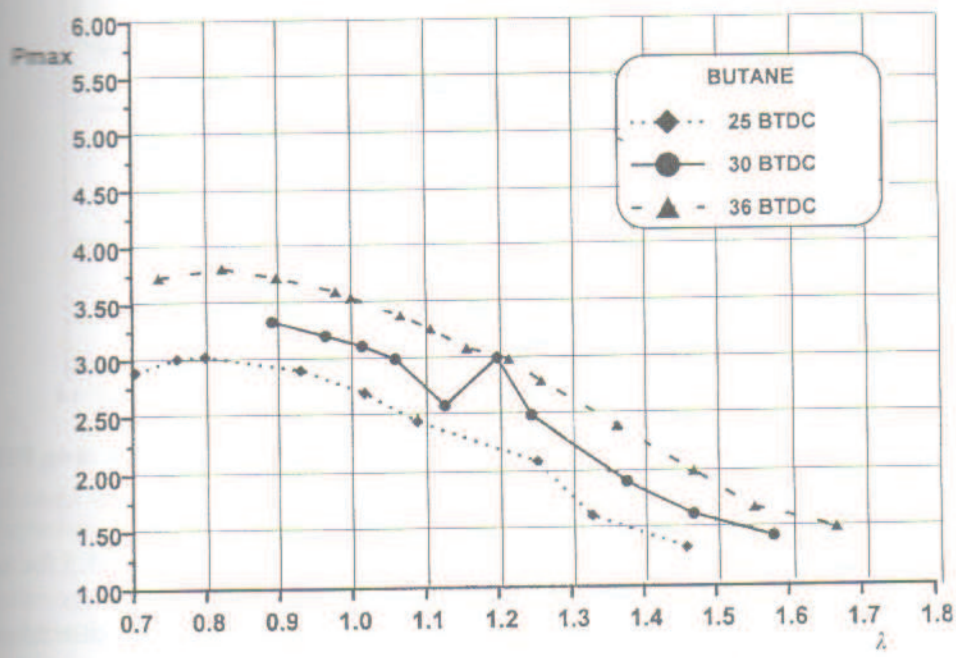


Fig. 4. Cylinder maximum pressure vs. coefficient of air excess λ for three ignition timings (25, 30, 36 deg BTDC); a) engine fuelled with gasoline, b) engine fuelled with butane

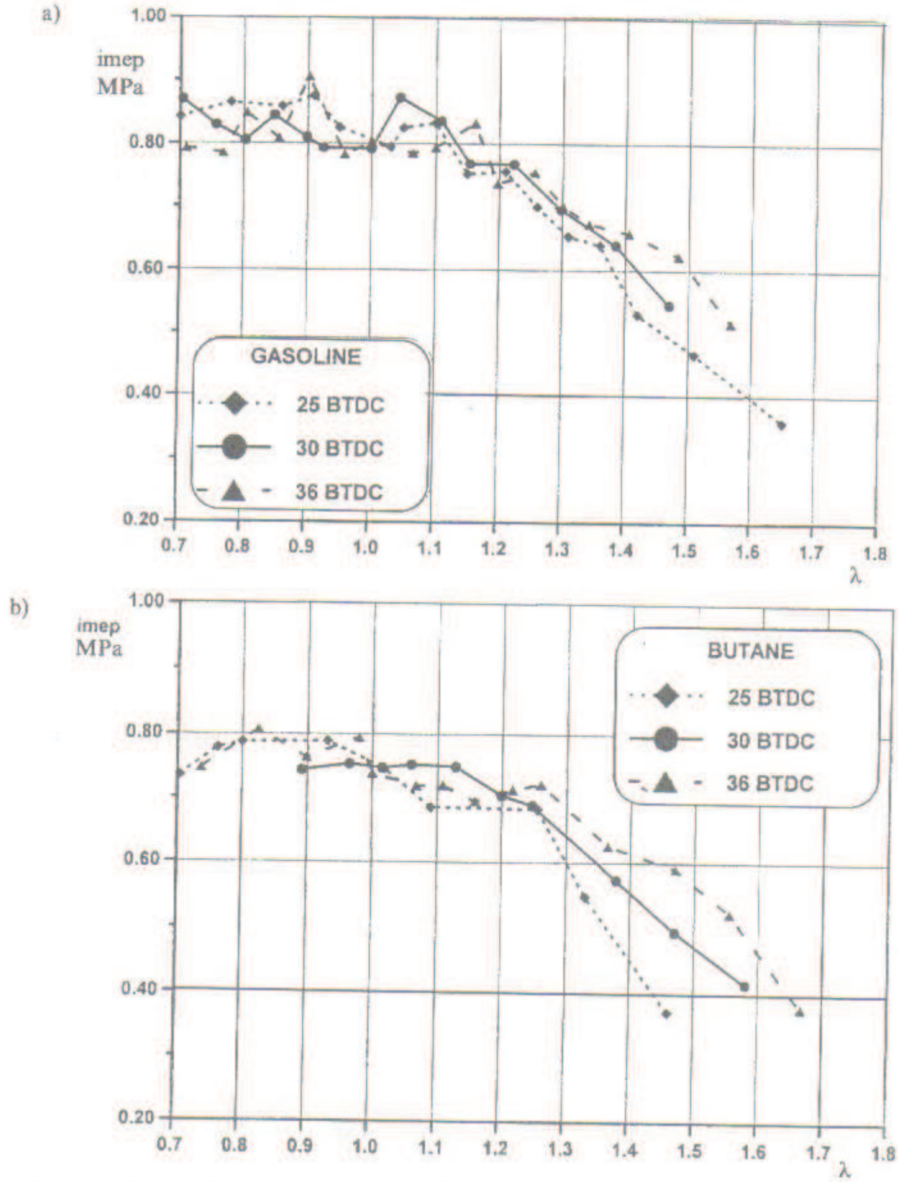


Fig. 5. Mean effective pressure vs. coefficient of air excess λ for three ignition timings (25, 30, 36 deg BTDC): a) engine fuelled with gasoline, b) engine fuelled with butane

— the ratio of maximum pressure to imep has its minimum for $\lambda = 1.4 - 1.5$ for both fuels for ignition advance $\varphi_i = 36$ deg BTDC, Fig. 6,
— though maximum torque is obtained for gasoline, its decrease with mixture leaning is quicker than for gas fuel (Fig. 7),
— NO_x emission for butane fuel is more influenced by ignition timing than for gasoline. NO_x emission is approximately equal for fuelling with both fuels Fig. 8,

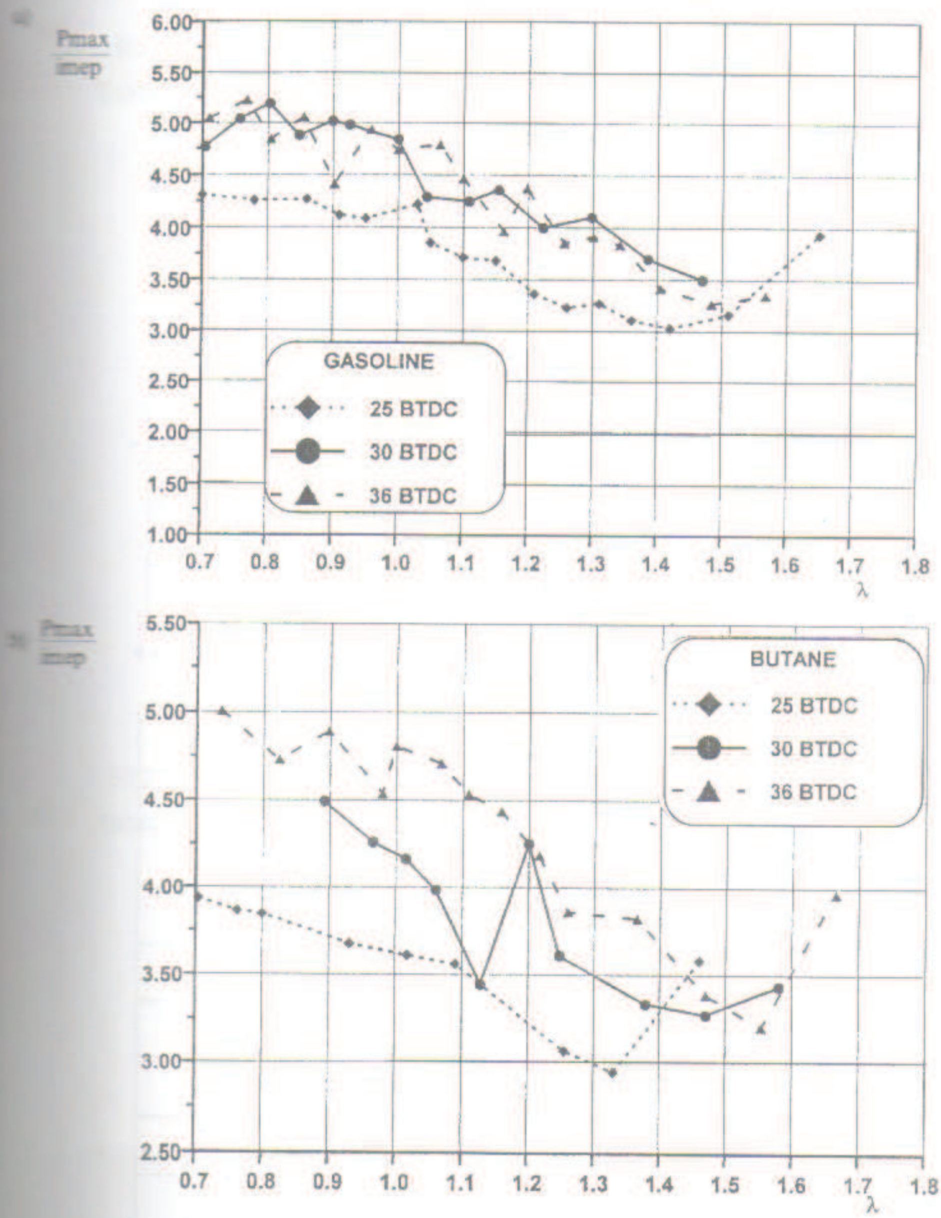


Fig. 8. Cylinder maximum pressure/indicated mean effective pressure vs. coefficient of air excess λ for three ignition timings (25, 30, 36 deg BTDC); a) engine fuelled with gasoline, b) engine fuelled with butane

— hydrocarbon emission for butane fuelling, the same as for gasoline fuelling depends more strongly on ignition time Fig. 9.
— for butane fuel the hydrocarbon emission start growing for leaner mixture than for gasoline,
— PDF of imep for both fuels are very similar, Fig. 10.

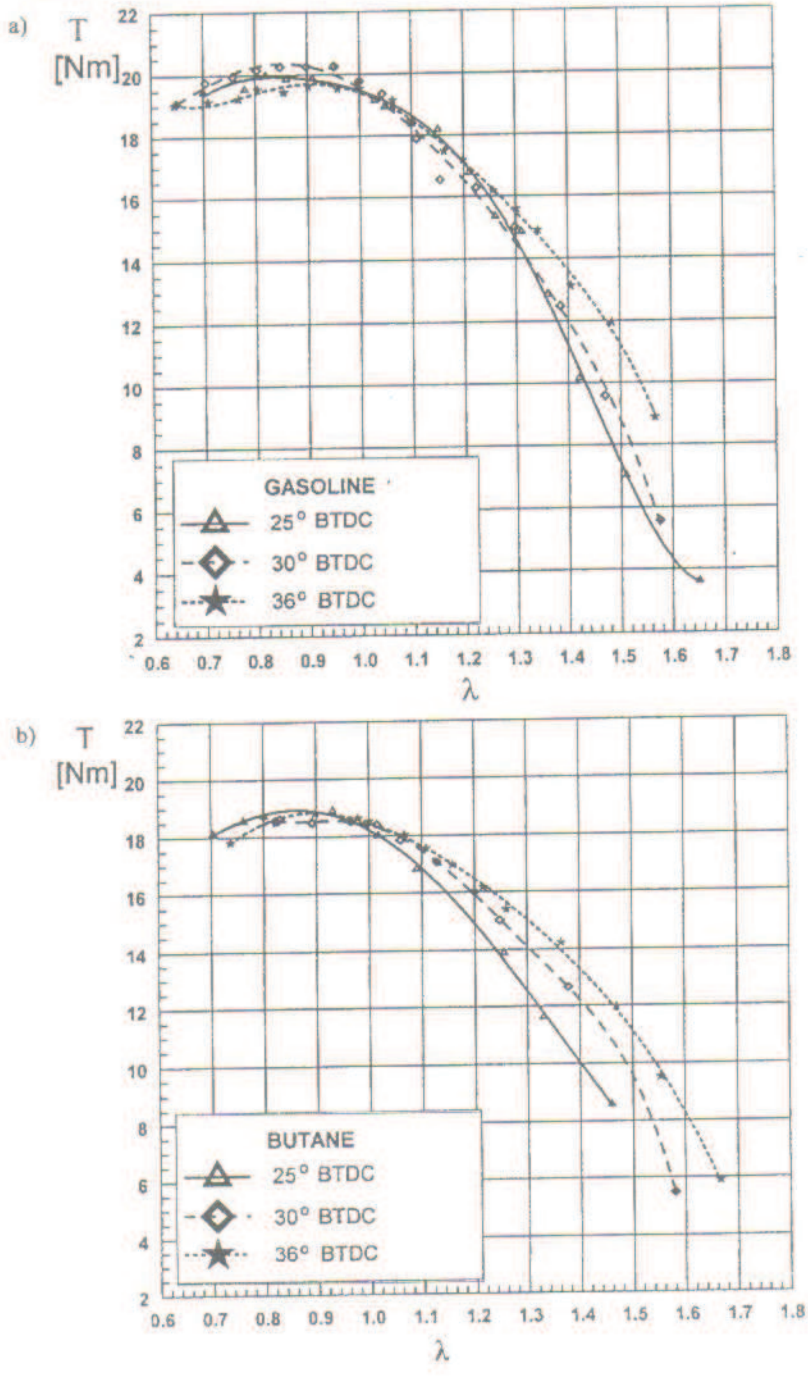


Fig. 7. Engine brake torque vs. coefficient of air excess λ for three ignition timings (25, 30, 36 deg BTDC)
a) engine fuelled with gasoline, b) engine fuelled with butane

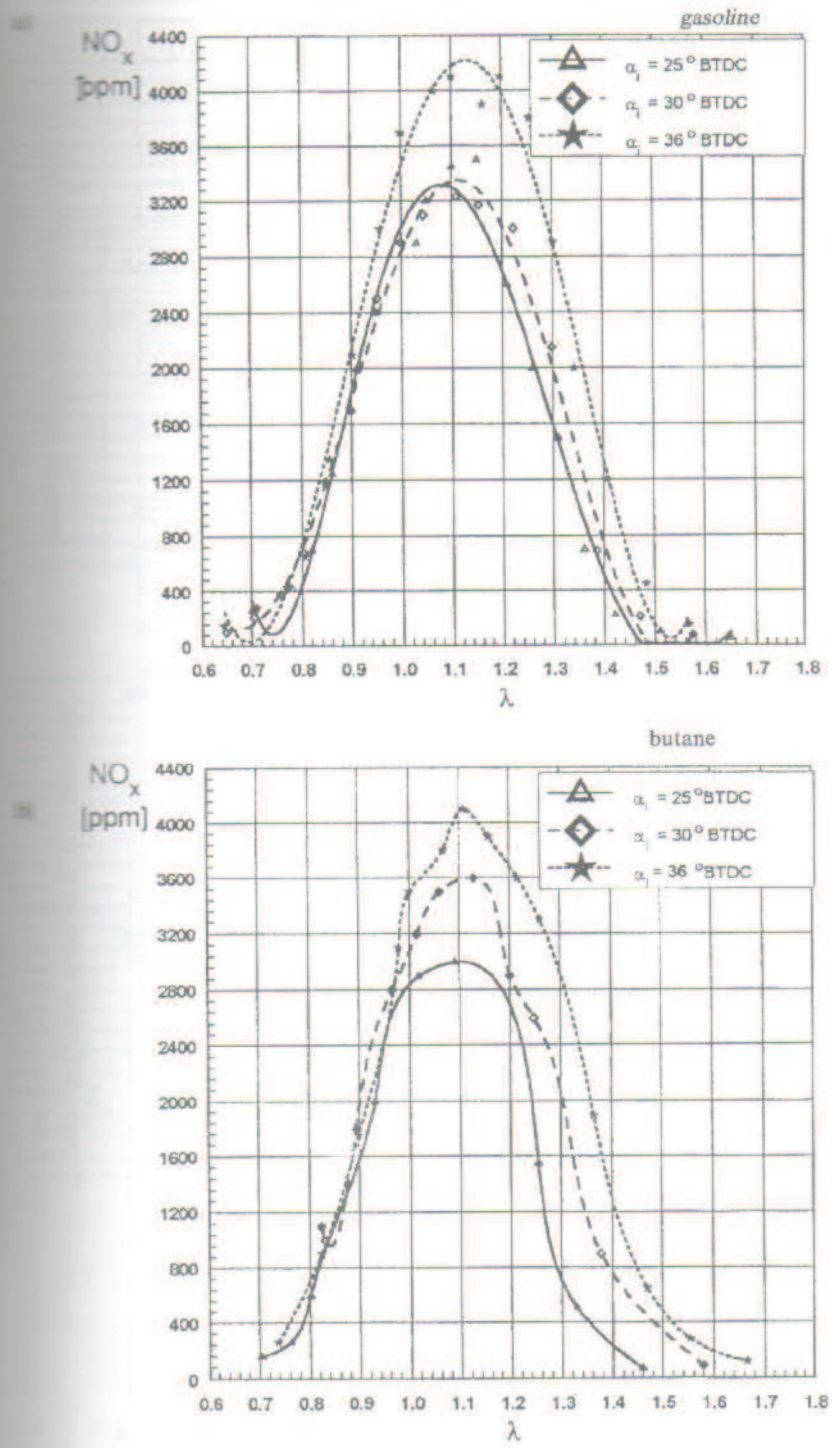


Fig. 8. NO_x emission vs. coefficient of air excess λ for three ignition timings (25, 30, 36 deg BTDC); a) engine fuelled with gasoline, b) engine fuelled with butane

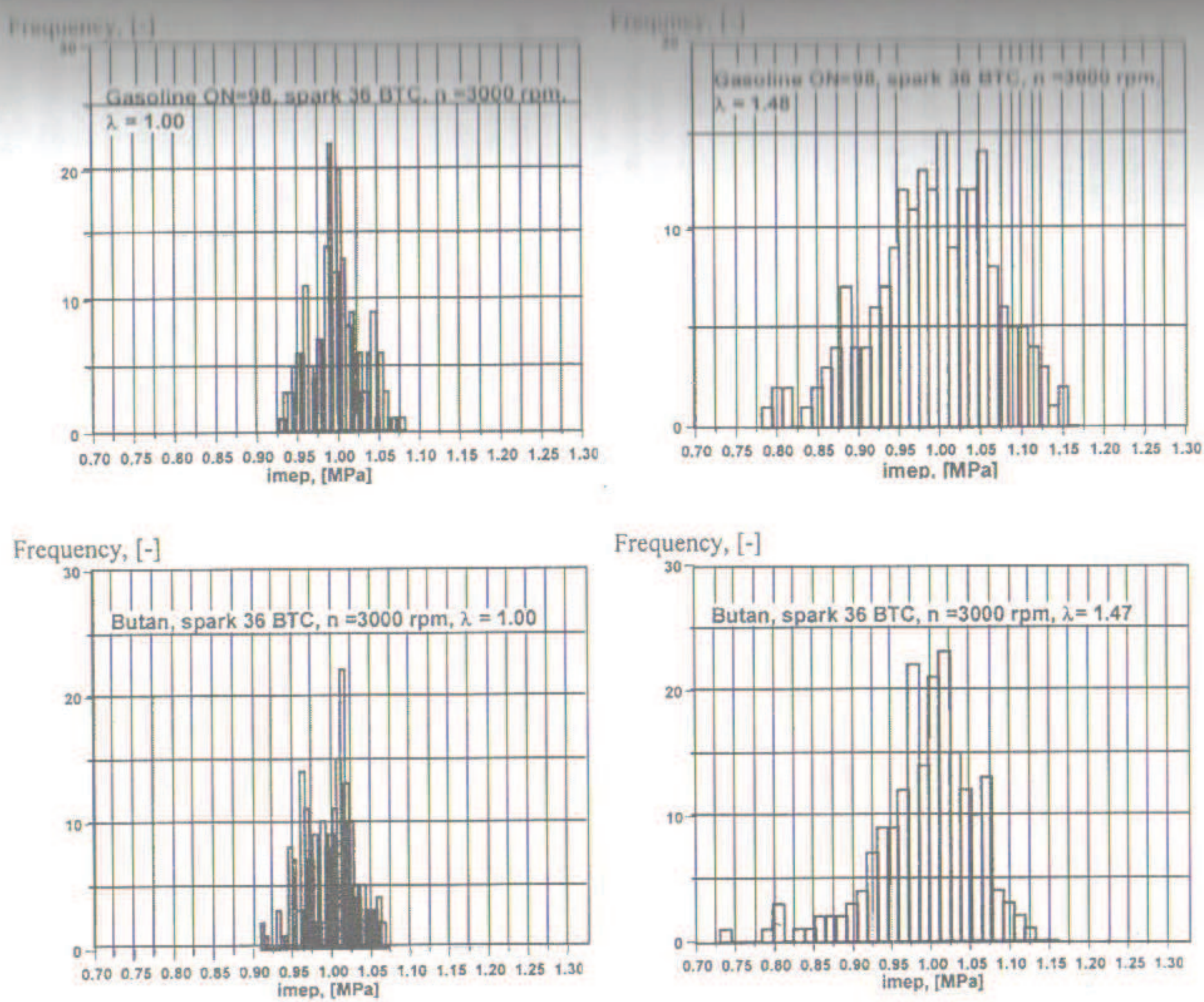


Fig. 10. Comparison of PDF of imep for fuelling with butane and gasoline

6. Conclusions

The results show that there is possible to fuel the engine with lean butane–air mixture in efficient way. Its performance and efficiency are at the same level as for gasoline carburettor engine. However, there is some advantages for butane fuelling: it is almost three times cheaper in Poland than gasoline, taking into account comparison of the energy of both fuels necessary for producing the same power in the same time (at the test stand).

Moreover, there are some potential possibilities which are hidden in modification of fuel system. The improvement of it, especially application of injection of the liquid gas could strongly improve above presented results, which will be used as a base for the next examination of modified engine.

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Porównanie charakterystycznych parametrów procesów spalania w silniku o ZI przy zasilaniu benzyną i butanem w zakresie ubogich mieszanek

Streszczenie

Zgodnie ze światowymi trendami wiele centrów badawczych skupia się na badaniach zasilania silników o ZI ubogimi mieszankami homogenicznymi i heterogenicznymi. W Zakładzie Silników i Pojazdów Politechniki Radomskiej wykonano badania zasilania silnika o ZI ubogimi mieszankami. Badania przeprowadzono na silniku do samochodu Cinquecento. Jako paliwa użyto butanu, który ma szerokie granice palności. Cele tych badań były następujące:

– analiza wpływu udziału powietrza do paliwa na charakterystyczne parametry procesu spalania, osiągi silnika i jego sprawność cieplną.
– porównanie zasilania butanem i benzyną za pomocą standardowego układu gaźnikowego.
– optymalizacja kąta zapłonu przy zasilaniu butanem.

Wyniki badań wykazały, że jest pełna zamienność paliw (benzyna na butan) w zakresie ubogich mieszanek. Osiągi silnika i parametry procesów spalania są bardzo zbliżone przy obu sposobach zasilania. Istnieją dalsze możliwości poprawienia osiągów silnika obniżenia jego emisji przez zastosowanie wtrysku gazu bezpośrednio do cylindra, co będzie przedmiotem dalszej pracy.