



SOME POSSIBILITIES OF DUAL FUELLING SUPPLY DIESEL ENGINES

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Abstract

In the paper are presented conditions for gaseous fuelling of different engine types: stationary engines and traction engines to trucks and passenger cars. On the base of performed investigations, one made comparison of operational costs of dual fuel gaseous engines and an engines with spark ignition system. In the analysis one took into consideration operation of an engine on natural gas, the most expensive gas, and on the mine gas, so called cheap gas. In case of stationary engines, the analysis showed considerable benefits of the dual fuel system comparing with spark ignition system. One confirmed considerable savings in purchasing costs of the fuels, regardless of size of initial dose and price of the gas. Earnings in purchase of the fuels increase together with growth of price of the gas and reduction of initial dose. In traction engines one should use the CNG or LNG gas. During transitional period of introduction of the gas one should implement systems with full interchangeability of fuelling with gaseous fuel and liquid fuel, both in compression ignition and spark ignition engines. Used in trucks, the dual fuel system gives substantial savings in operational costs and improves conditions of engine operation comparing to systems with spark ignition. In turn, in case of passenger car engines, due to size of the engines and different operational conditions, systems with spark ignition and so called flexi-fuel systems should be used. Due to it, gaseous fuelling in passenger cars should be first implemented in the engines with spark ignition system.

Keywords: *natural gas, dual fuel engine, pilot dose, gas share, operating costs*

1. Introduction

During the nearest future it will be seen a rapid growth of application of gaseous fuels to fuelling of the engines. It results from general tendency of search for a fuels being alternative to petroleum fuels, and diversification of sources of energy. Gaseous fuels, due to their properties, belong to important among alternative engine fuels, and due to their resources, gaseous fuels may largely replace traditional liquid fuels in future.

To the most important gaseous fuels belong [1, 2, 3, 7, 9]:

- natural gas in form of compressed CNG gas and liquefied LNG gas,
- bio-gases such as gas from sewage-treatment plants, burrow gas and gas from bio-gas plants,
- mine gas,
- waste gases from manufacturing processes,
- hydrogen,
- liquefied propane-butane, popularly known as the LPG.

Due to market supply and price, the first four from the above mentioned gases shall have fundamental importance in the nearest future [1, 2, 4, 9]. Three from them belong to the waste gases, and their rational use is connected with environment protection. The hydrogen is considered as future fuel, but nowadays is very expensive, while implemented methods of production and

storage are inefficient [12]. Overall manufacturing efficiency of the hydrogen, *well to wheel*, amounts to about 15%, what makes this fuel also unprofitable from environment protection point of view. In turn, popular in our country LPG gas, due to its small market supply (about 2% of processed crude oil) can not be considered in global scale as a strategic fuel [11].

Method of use of the gases depends mainly on a type of the gas and the engine. Waste gases, due to low energetic density, should be destined to fuelling of stationary generator engines, operated in co-generator systems [1, 5, 7, 9, 13]. Such engines are the most often installed near sources of the gas and make use of the gases having pressure close to the atmospheric one, what reduces costs of transportation and storage of the gas. At extremely low energetic values, the waste gases can be enriched with the network natural gas, or in case of lack of such gas, the engines can be run on pure natural gas [9].

Traction engines should be powered by the CNG or LNG gas due to permissible masses of fuel tanks [1, 3, 4, 9, 13]. In the European Union countries, fuelling with the natural compressed CNG gas is preferred, while its market share in 2020 should reach level of about 8% of the whole of consumed engine fuels [7, 9]. Nowadays, development of such fuelling type is limited by mass of the gas cylinders (Fig. 1) and number of filling stations (Fig. 2).

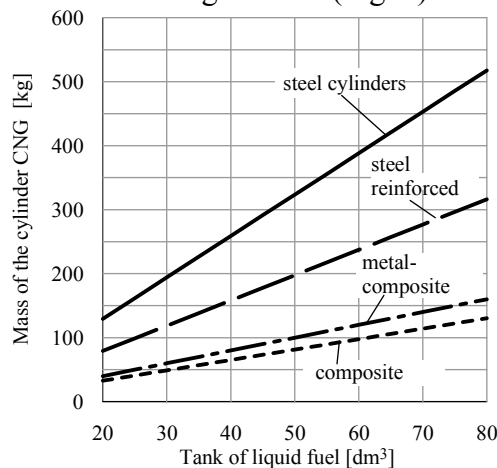


Fig. 1. Estimated mass of CNG gas cylinder, depending on capacity of liquid fuel tank [9]

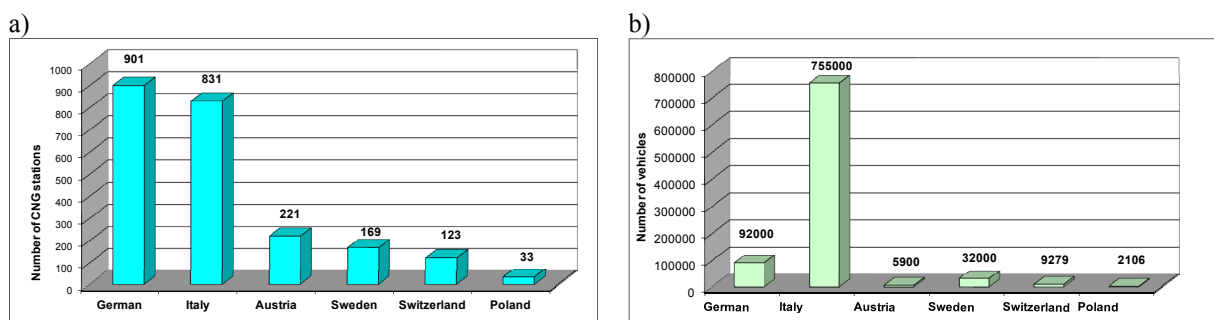


Fig. 2. Number of CNG gas filling stations and number of vehicles run on CNG gas in selected European countries [source: Gas Vehicle Report, May 2011]

The engines running on the gas can operate according to two combustion systems:

- spark ignition system (majority of applications),
- dual fuel system (limited number of applications).

In the past, selection of the system was determined mainly by significant difference in price of the fuels, natural gas and waste gases with low price of unit energy and Diesel oil with high unit prices. At considerable fractions of Diesel oil, production cost of unit energy in dual fuel engines was higher than production costs of energy in spark ignition engines. In result, gaseous engines with spark ignition are the most of practical implementations [2, 7, 9].

Anyhow, a system of gaseous fuelling with spark ignition features many disadvantages, comparing to dual fuel supply, especially with respect to compression ignition engines adapted to gaseous fuelling. To the most important belong:

- necessity of reduction of compression ratio to value 9.0-9.5, what results in reduction of overall efficiency of the engine,
- difficulties in ignition of lean gaseous mixtures, what results in fuelling of the engines with stoichiometric mixture with $\lambda=1.0$ or leaned to $\lambda=1.6$ (required special ignition systems),
- special requirements for ignition systems (increased energy of spark) and spark plugs,
- reduced durability of spark plugs,
- worsening of engine start-up capability and increased non-uniformity of engine operation at low loads.

Small gaseous engines, used as a power units to passenger and pick-up cars are fuelled with stoichiometric mixtures with $\lambda=1.0$. Very often these are *flexi-fuel* engines, possible to run alternately on the gas or the gasoline. Engines used in trucks and big stationary engines are, as a rule, turbocharged or fuelled with the gas only. They operate mainly at lean gas-air mixtures with the excess air number $\lambda=1.6$, what reduces susceptibility to knocking combustion, and owing to lower combustion rate, reduces emission of the NO_x . Reliable ignition of leaned mixture is attained due to increased energy of the spark plug, or through incorporation of spark plug's electrode to a special pre-chamber (Fig. 3). During compression stroke, the gaseous mixture gets at the pre-chamber, and is ignited from the spark. Increase of pressure in the chamber results in intense injection of burning mixture to the main chamber and propagation of the combustion into big volume of the chamber. The spark plug having described design is shown in the Fig. 3.

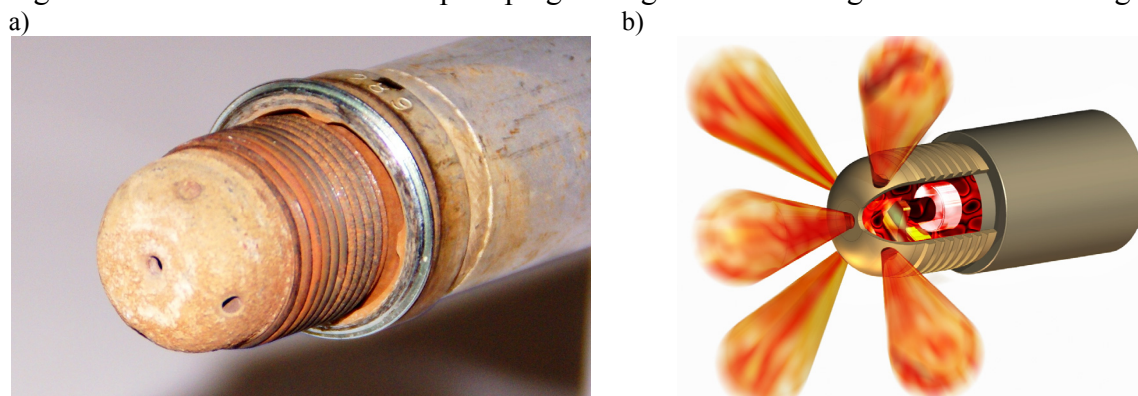


Fig. 3. Spark plugs from gaseous engines operated at lean mixtures (photo of the author):
a) view of the spark plug, b) cross-section and outflow of burning gases

Dual fuel engines are constructed, as a rule, on the base of compression ignition engines powered traditionally by Diesel oil. They enable to maintain majority of positive properties of their progenitors, and additionally they can play important transportation role during period of insufficient number of gas filling stations. To the most important benefits of such engines belong:

- high efficiency at full load, considerably higher than in case of gaseous spark ignition engines, and often higher than compression ignition engines fuelled traditionally,
- maintaining operational parameters of base engines (maximal output power, torque),
- combustion of gaseous mixtures in broad range of change of the excess air number, not possible to be obtained in spark ignition engines,
- decreased emission of nitrogen oxides, solid particles and carbon dioxide, comparing to compression ignition engines fuelled traditionally,
- possibility of compensation of composition change of the gas through change of initial dose,

- possibility of alternate operation in dual fuel system or on Diesel oil only, what is of an essential importance in case of some applications (emergency installations, public transportation) or lacking of the gas, or breakdown of installation of the gas,
- engine start-up on Diesel oil, what assures the same start-up capabilities like in case of traditional fuelling,
- smooth engine operation at low loads and in transient states,
- decreased noise of engine operation.

Costs of engine operation, having decisive impact on selection of the dual fuel system, are under considerable impact of extent of operational interchangeability of liquid fuel by gaseous fuel. Due to big differences in price of the fuels (twice cheaper price of unit energy of the gas) in case of such engines one strives after minimization of the initial dose in possibly widest range of changes of engine load. It is determined by design of the dual fuel engine in stationary applications and restricts operational range of dual fuel traction engine.

The work presented in this paper deals with these issues on example of some engine types and their applications.

2. Dual fuel stationary engines

The lowest number of problems connected with engine adjustment is present in case of dual fuel stationary engines operated at constant rotational speeds and loads close to the maximal load [2, 7, 9]. Steady conditions of engine operation enable optimization of size of the initial dose and create possibilities to maintain correct composition of combusted mixture, owing to it, emission of toxic components of exhaust gases is very low [1, 7, 10].

The most often, small initial doses needed to stable ignition of gaseous mixture only, are used in stationary engines. The following sizes of the initial doses are used:

- $3\div 5\% Q_{zn}$ (of nominal dose of the engine fuelled traditionally) in case of a smaller engines,
- $1\div 1.5\% Q_{zn}$ in case of big power units.

However, use of small initial doses requires changed design of the engine, adapting it to operation in dual fuel system. The changes depend on whether the engine requires alternating operation in dual fuel system and in traditional fuel supply, or with gaseous fuelling only.

Obtainment of initial dose within limits of 5% of nominal dose requires use of a special pump and injectors adapted to injection of small initial doses. In such pumps a smaller diameters and bigger travels of the piston are used. Moreover, one should pay attention on scavenging of the suction chamber, because in case of injection of small doses, quantity of the fuel carried off through overfall decreases, what results in tendency to foaming. An example of the duplex installation is shown in the Fig. 4.

The system of duplex fuel installation is possible to application in bigger engines with lower rotational speed only. Possibility of seizure of idle injectors due to longer time of switching-off from operation of one from the systems can be considered as the main disadvantage of such system. It results in difficulties in transfer from one fuelling system to the second.

Avoiding this disadvantage is possible in a big generator engines, where three injectors in *common rail* system are used per a single cylinder. In case of an engine operated in dual fuel system one uses a single injector, switched over successively from time to time to another one, what prevents seizure of the injectors. In case of engine operation on Diesel oil only, one uses three injectors operating simultaneously, which can be also switched over successively when the engine operates at low loads.

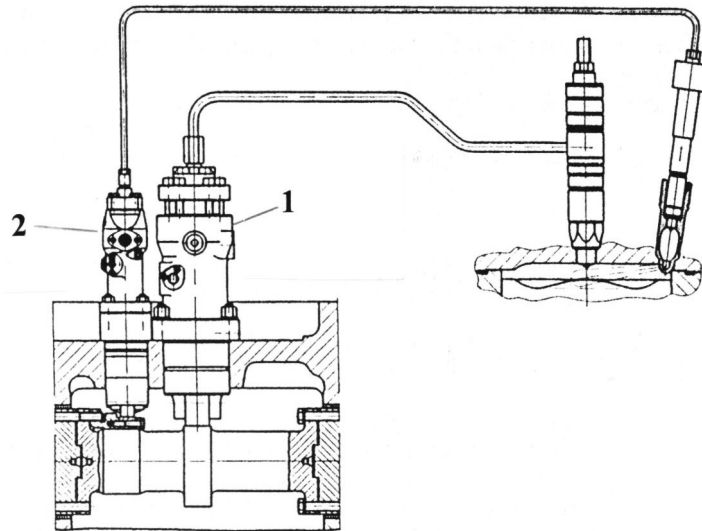


Fig. 4. Fuel supply system with Diesel oil of the 32/40 engine made by MAN B&W [5]:
 1 – main pump (engine operation at Diesel oil only),
 2 – pump to injection of initial dose (operation in dual fuel system)

In case of *common rail* systems it is possible to use a duplex injector of the main fuel and the initial dose. Mode of engine operation and size of the dose are controlled electronically by the ECU.

In the Fig. 5 is shown a duplex injector from the 50DF engine made by Wärtsila Company [14]. The injector is equipped with two needles, the bigger one to operation on Diesel oil only, and the smaller one to injection of initial dose. Smaller needle is controlled electronically while the bigger one is controlled hydro-mechanically. In dual fuel operation, advance angle and time of the injection are adjusted individually for each cylinder.

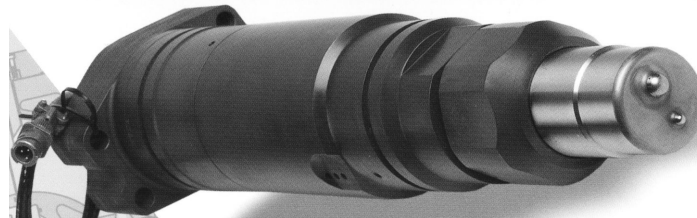


Fig. 5. Duplex injector used in the 50DF Wärtsila engines [14]

Use of extremely small initial doses $1.0 \div 1.5\% Q_{jzn}$ requires special design of combustion chamber, enabling increased energetic and spatial influence of the ignition dose. Injection of initial dose occurs to pre-chamber, where gaseous mixture is present before the end of compression stroke (Fig. 6). After ignition of the gaseous mixture, increase of pressure occurs in the pre-chamber, what results in injection of burning liquid and gaseous fuel to the main chamber. Suitable selection of geometry of holes in the pre-chamber enables maximal increase of spread of burning stream of mixture of the fuels, what favors rapid injection of the gas in the main chamber.

The dual fuel engines in nominal conditions develop efficiencies higher with $5 \div 6\%$ comparing to their equivalents with spark ignition system. It is possible, therefore, to perform comparison of their operational costs for extreme conditions of fuel supply:

- supply with the network natural gas – the most expensive gas in the market,
- the mine gas with average contents of methane 55% - as a cheap waste gas.

Prices of the gases and liquid fuel (fuel oil) were taken on the base of the prices paid by an enterprise, which operates dual fuel gaseous engines. Results of the comparison are presented in the Fig. 7.

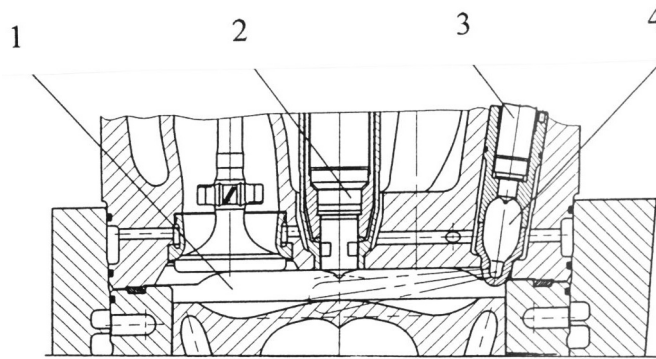


Fig. 6. Combustion chamber of dual fuel, 32/40 DG engine made by MAN B&W [5]:
 1 – main chamber, 2 – main injector, 3 – injector of initial dose,
 4 – pre-chamber

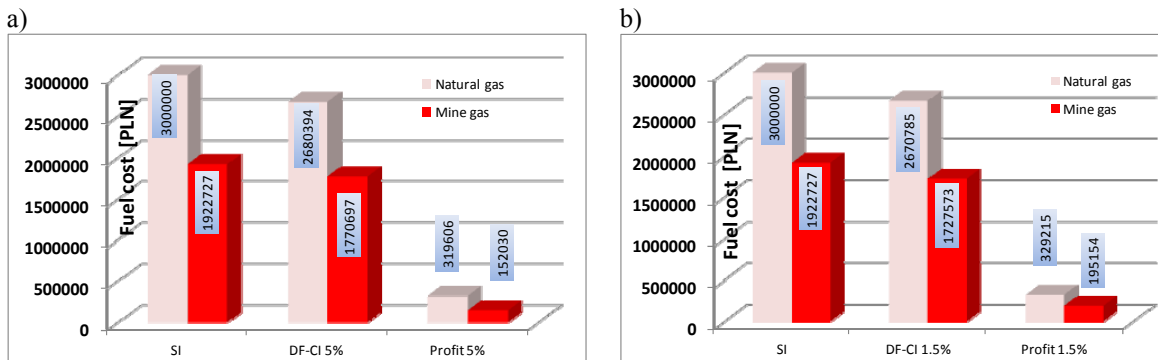


Fig. 7. Comparison of yearly fuel costs to the engines with 1 MW output power, with spark ignition and dual fuel engines run on natural gas and mine gas: a) initial dose of dual fuel engine, 5% of nominal dose, b) initial dose of dual fuel engine, 1.5% of nominal dose

From comparison shown in the Fig. 7 is seen that dual fuel supply is more advantageous in case of more expensive and also the cheapest gases, both in case of 5% dose and 1.5% of nominal dose. Yearly profit in case of the natural gas fuel supply amounts respectively to about 320 000 PLN with 5% dose and 330 000 PLN with 1.5% dose, what gives relative savings, comparing to fuelling costs of a spark ignition engine, of - 10.7% and 12.2%. Profits in case of fuelling with the mine gas amount to about 152 000 PLN with 5% dose and 195 000 PLN with 1.5% dose, what gives 7.9% and 10.1%. From presented comparison is seen, that a bigger profits can be generated when one uses the network natural gas, relatively expensive due to partial networking and transfer costs included in unit price of the gas. Use of dual fuel engines in a 6 MW power plant, when the engines are fuelled with the natural gas can generate profits of about 2 million PLN, what considerably influences on amortization time of purchase costs of the engines. Profits due to fuelling with the mine gas in a similar power plant (6 MW is an average output power of the power plant in the Jastrzębska Spółka Węglowa) are a little bit lower and amount to 0.9÷1.2 million PLN.

To additional beneficial factors belong: long lasting period of failure-free operation of injection systems and smaller tendency to knocking operation of the engine, and in case of generator engines - considerably lower frequency of engine switching-off due to loss of frequency synchronization with external network.

3. Dual fuel traction engines

Traction engines should be absolutely fuelled with the natural gas compressed to 20÷25 MPa pressure and equipped with steel gas cylinder reinforced with carbon fiber, or entirely

made from composite material. It enables to maintain required mileages between successive refueling with the gas on the level a little bit lower comparing to the engines fuelled traditionally.

Nowadays as a power units to trucks and buses are used compression ignition engines. Adaptation to gaseous fuelling requires rework of these engines to spark ignition system (reduction of compression ratio, stoichiometric combustible mixtures), what is connected with decreased efficiency in complete range of change of engine load (Fig. 8). Decrease of the efficiency can range from a few to several percent, depending on engine size and load. It is worth to underline, that the biggest differences in the efficiency occur in area of partial engine loads, and hence, in area of the most frequent operation of the engine.

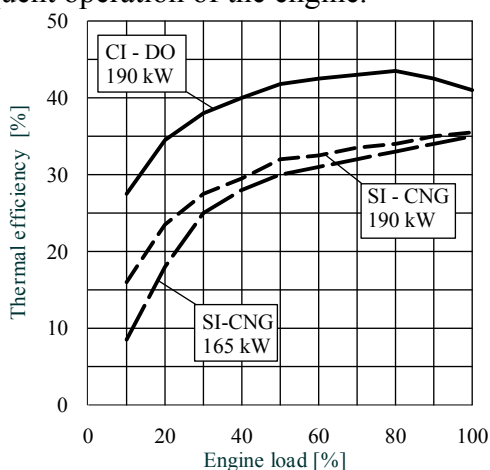


Fig. 8. Comparison of thermal efficiency of SI gaseous engines and CI engines fuelled traditionally [8]

Use of the dual fuel system assures maintaining the efficiency at maximal engine load at the same level as in case of traditional fuelling. As confirmed by investigations performed by the author on various engines, selection of a suitable initial dose enables even increased overall efficiency with 2÷4%, calculated in absolute units. This should contribute to reduction of consumption of energy and the fuels in the engines mounted in trucks operated on long routes, and the same, to reduction of operational costs.

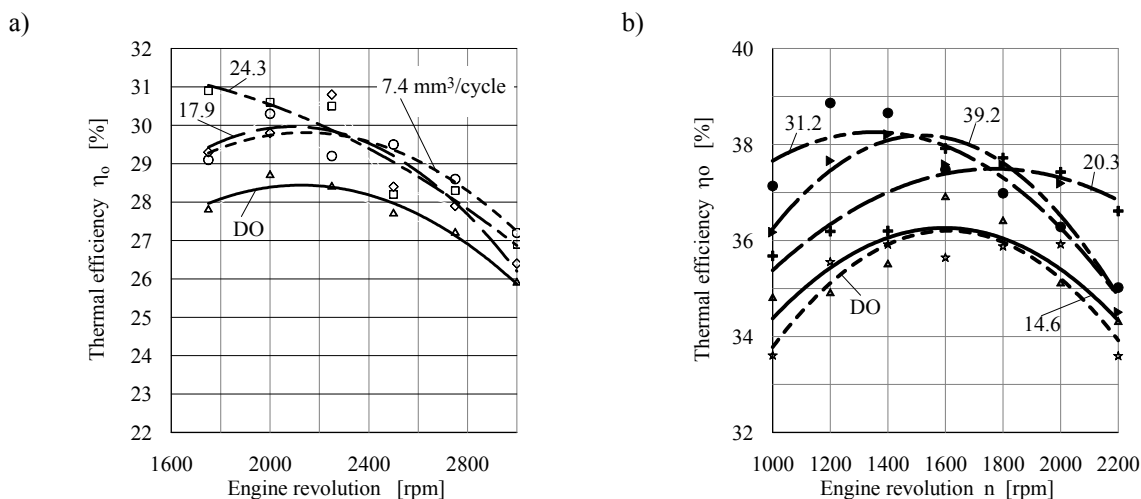


Fig. 9. Influence of rotational speed on overall efficiency of dual fuel engine at maximal load and different initial doses: a) 1CA90 engine [7], b) SB3.1 engine [9]

Investigations of the SB3.1 engine with cylinder bore 127 mm, piston stroke 146 mm and capacity of the cylinder 1.84 dm³, equipped with common rail system and injection of the gas to area near the inlet valve, have shown that with small initial doses, in area of partial loads, the

engine can develop efficiencies close to the efficiency of the engine fuelled traditionally (Fig. 10). Average dose $14.6 \text{ mm}^3/\text{cycle}$ used in course of the investigations was increased with respect to minimal dose possible to be achieved in common rail system, needed to assure long lasting operation of the injector without risk of overheating.

Additionally, use of increased initial dose leads to reduction of hazard of knocking combustion, what in supercharged engines can be utilized to increase maximal output power of the engine. It should be underlined, however, that increase of the initial dose leads to reduction of overall efficiency of the engine at partial loads, comparing to the engine run on Diesel oil only.

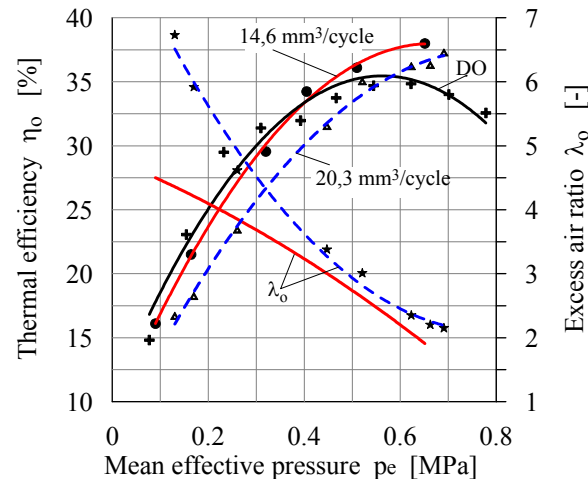


Fig. 10. Dependency of the overall efficiency on the load of the SB3.1 engine fuelled traditionally and run in dual fuel system: λ_0 – excess air ratio of gaseous mixture, various initial doses, rotational speed 1400 rpm

Due to insufficient network of CNG filling stations, in case of dual fuels engines one should assure full interchangeability of fuelling with the gas and Diesel oil only. Due to size of the engines, such condition requires maintaining original injection apparatus, used in case of traditional fuelling. This restricts, both in the systems with injection units and in common rail systems, possibility of unlimited reduction of the initial dose. It results from worsening of uniformity of dosing, or decay of injection (from one cycle to another) when very small doses are used. It should be underlined, that the initial doses are most often close to, or smaller than the doses injected at idling speed of the engine, when uniformity of the dosing at traditional fuelling is not so important.

In course of adaptation of the engines to dual fuel supply when serial injection apparatus is utilized, the following sizes of the initial dose can be used:

- $15 \div 25\% Q_{zn}$ – for serial piston pumps,
- $10 \div 15\% Q_{zn}$ – for serial common rail systems.

Size of the initial dose is most often referenced to size of Diesel oil injected in the engine at nominal loads and traditional fuelling.

In traction engines operated in conditions of changing load, interchangeability of the liquid fuel with gaseous fuel belongs to important issues. The interchangeability can be evaluated by fraction of gaseous fuel energy U_g in complete dose of energy supplied to the engine.

Changes of fraction of the gas U_g in function of engine load at constant rotational speed, for different initial doses, are presented in the Fig. 11. They show that in case of stationary engines use of the initial dose having energetic size of about 5% enables more than 90% interchangeability of the liquid fuel in complete range of change of engine loads. It requires, however, usage of separate injectors for the initial dose and the dose at traditional fuelling.

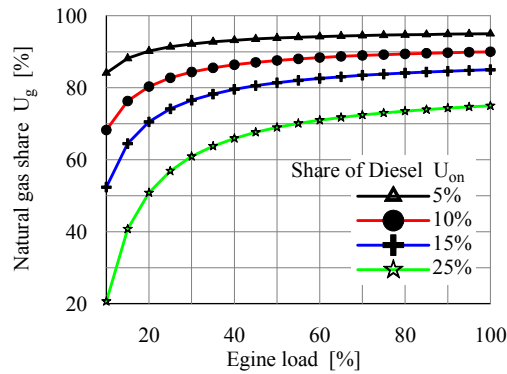


Fig. 11. Effect of dual fuel engine load on energetic fraction of the gas for different initial doses: constant rotational speed; assumed linear change of overall efficiency of the engine from 0.362 for $p_{e\max}$ to 0.125 for $p_e=0.1p_{e\max}$

At the doses with energetic fraction of about 10%, possible to be achieved in *common rail* systems when the injector was carefully selected, it is possible to obtain substitution of the gaseous fuel above 80% for engine loads higher than 20% of nominal load.

It is also worth to pay attention, that during adaptations of an older engines, with classic injection apparatus, when doses with energetic value of about 25% are used, it is possible to obtain substitution of the liquid fuel greater than 60% for engine loads higher than 30% of nominal load. This should be a signal that even in older traction engines dual fuel supply can bring about tangible economic benefits.

Selection of the initial dose is very important in the dual fuel traction engines. When serial injection apparatus shall be kept, used initial doses are bigger, as a rule, than the ones needed to robust ignition of the gas. From the other side, they should assure sufficient cooling of the injectors at maximal engine loads. Due to this, selection of the initial dose should be accomplished on the base of engine testing, while reduction of the dose should be limited by requirement of suitable durability of the engine.

In the Fig. 12a are presented fractions of the gaseous fuel achieved in the SB3.1 engine at maximal engine load and various initial doses. The SB3.1 engine is a single cylinder engine constructed on the basis of the SW 680 engine (swept capacity 18.1 dm³), with size corresponding to the engines used in truck transport. At maximal engine load, energetic fraction of the gas is nearly independent from rotational speed. It results from usage of electronic systems to injection of the gas and initial dose, where doses of the both fuels depend only on opening time of the injectors. Effect of operational parameters of the engine, inclusive of temperature of injectors in common rail system, on quantity of injected fuel is small.

At minimal dose 14.6 mm³/cycle it is possible to achieve more than 90% substitution of the liquid fuel in complete range of change of rotational speeds. Increase of the initial dose to 39.3 mm³/cycle results in reduction of fraction of the gas to value of about 60%. Moreover it results in growth of engine load, below which the engine should be fed with Diesel oil only. It is worth to notice, that big initial dose reduces safety of engine operation in range of knocking combustion, while 60% substitution of the liquid fuel can considerably reduce operational costs.

In area of partial engine loads, fraction of the gas in total dose of energy supplied to the engine decreases together with reduction of the load (Fig. 12b). Simultaneously, in area of partial engine loads is seen a distinct tendency to increase of fraction of the gas U_g as rotational speed increases.

In the research SB3.1 engine at initial dose of about 20 mm³/cycle, energetic fraction of the gas changed in range of 45÷82% in complete investigated area of engine operation, i.e. at changes of engine load in range 0.1÷0.7 MPa and rotational speed 1200÷2000 rpm.

a)

b)

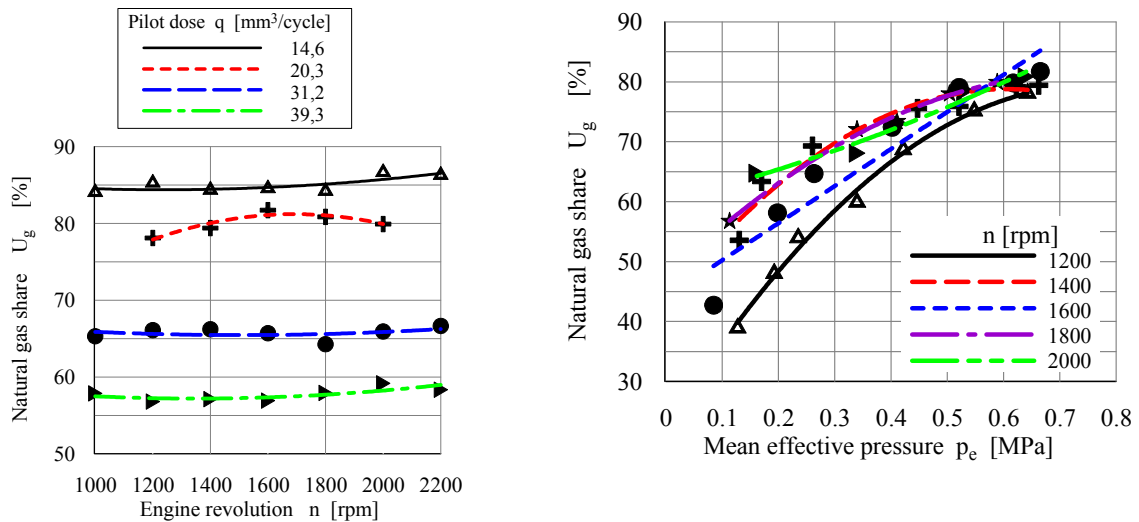


Fig.12. Comparison of energetic fraction of the gas in the SB3.1 engine run in dual fuel system:
 a) engine load close to the maximal one, various initial doses, b) changing engine load, different rotational speeds, constant initial dose 19.8 mm³/cycle

In real conditions of engine operation, substitution of the liquid fuel by the gas depends on conditions of engine operation, is higher in out-of-urban driving and decreases in case of urban driving. Additionally, it depends on weigh of transported load and conditions on a road. Due to it, it is difficult to specify accurate operational substitution of liquid fuel, and the same, real profits from adaptation of the engine to dual fuel supply.

In the Fig. 13 are presented estimated yearly profits for a dual fuel medium size engine with 300 kW output power, used as a power unit to a truck-tractor in international transport. The data concerning consumption of Diesel oil were obtained from an enterprise operating over a dozen truck-tractors of a similar size. Price of Diesel oil was assumed as 5.50 PLN/dm³ and CNG 2.55 PLN/nm³, mandatory in filling stations in April 2013.

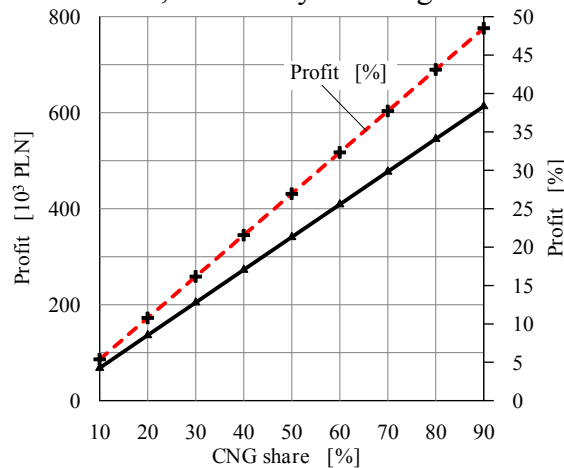


Fig. 13. Effect of fraction of the gas on profit in yearly purchasing costs of the fuel to dual fuel medium size engine used in trucks

From analysis depicted in the Fig. 13 is seen, that 50% substitution of the liquid fuel by the CNG can bring about yearly profits of about 350 000 PLN, what in case of over a dozen operated vehicles, generates significant profits for the enterprise. It seems that due to specifics of vehicle's operation in the analyzed enterprise, real substitution can be even bigger, and generated profits could be higher.

Quite different is the situation in case of the engines used in passenger cars. These engines are mainly operated at partial loads, in urban traffic with limited speed, with big portion of idling operation, as underloaded cars. Due to this, operational substitution of the liquid fuel by the gas in such engines can be considerably smaller than the substitution in the trucks. Due to significantly lower prices of the gas comparing to Diesel oil (more than twice), operational cost of gaseous engine with spark ignition will be lower than operational cost of dual fuel engine. However, rework of compression ignition engine to spark ignition and fuelling with the gas requires numerous design changes, and because of size of the engine could be unprofitable. Moreover, engine after such rework could be run on the CNG only, or after big design changes can be also run on gasoline. Presented considerations lead to conclusion that during transitional period, gaseous fuelling of passenger cars should be introduced to spark ignition engines in so called *flexi-fuel* system, enabling alternate fuelling with gasoline or natural gas.

In compression ignition engines, dual fuel system can be used to reduction of smokiness of exhaust gases, what considerably lengthens time to regeneration of DPF filters and increases their life. Fraction of gaseous fuel in case of such strategy of fuel supply can be smaller (about 30%), and CNG or LPG can be used as the fuel. In spite of relatively low octane number of the LPG, due to big doses of Diesel oil, knocking combustion doesn't occur. Use of the LPG, having price similar to the CNG, reduces costs of engine adaptation to dual fuel supply.

In case of traction engines, particularly adverse conditions of combustion are present in area of low engine loads [10]. In some implementations, necessity of maintaining the same output power like in case of run on Diesel oil only, belongs to important issues. Due to it, dual fuel supply can be limited to range of engine loads of 20÷90% of the nominal load. The controller automatically switches mode of engine operation according to the following scheme:

- load 0÷20 N_{zn} run on Diesel oil only (increase of overall efficiency of the engine and reduction of CO and THC emissions),
- load 20÷90 (95) N_{zn} dual fuel supply with minimal initial dose,
- 90 (95)÷100% N_{zn} run on Diesel oil only (engine output power like in traditional fuelling).

More detailed information on control strategy of the dual fuel engines can be found in the study [9].

4. Conclusions

On the base of performed analyses and investigations it is possible to draw the following conclusions with general character:

- Dual fuel system enables maintaining the most of positive features of compressed ignition engine fuelled traditionally, like high efficiency, low sensitivity to changes in quality of the fuel, smooth operation in conditions of changing load.
- The most advantageous conditions of dual fuel supply are present in stationary engines operated under constant loads and rotational speeds. In such engines one should use a special apparatus to injection of the initial dose, if the engine can be fuelled with the gas only, or doubled system (special to the initial dose and serial to feed with Diesel oil only) in a cases where full alternation is required. It enables decreasing of the initial dose to a value smaller than 5% of nominal dose and increasing of operational fraction of the gaseous fuel.
- Usage of dual fuel supply in stationary engines enables obtainment of a considerable savings in cost of the fuel, comparing with spark ignition engine, regardless of the price of the gas and used size of the initial dose. Value of the profit is bigger in case of more expensive gases, like the natural gas.
- In traction engines one should use compressed natural gas (CNG), what results from requirements of a suitable mileage between successive refueling. During transitional period, in compression ignition engines one should use the dual fuel supply systems with full alternation

of the fuelling, while in case of spark ignition engines one should use the *flexi-fuel* systems, enabling combustion of pure gas or pure gasoline.

- In the engines assembled in trucks one should use dual fuel systems, what promotes rational use of energy. Moreover, such systems enable considerable cost reduction of the fuel. Value of the profits depends on operational fraction of gaseous fuel, and the same on operational condition of vehicles.
- In the engines assembled in passenger cars, due to considerable differences in price of the gaseous fuel and the liquid fuels, dual fuel system can prove unprofitable from economic point of view, comparing to spark ignition. Moreover, extent of changes in compression ignition engine needed to adaptation to gaseous fuelling and spark ignition is too big. Due to this, gaseous fuelling in passenger cars should concern spark ignition engines operated in the *flexi-fuel* system.

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