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Short Communication

Impact of Downsizing Technology on Operating Indicators for Combustion Engine Fed with Gaseous Fuel with Low Methane Content

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Abstract

Mine gases, in which the power factor is given by methane, have different chemical compositions and physical properties. These gases can be fuels for internal combustion engines. The diversity of gas parameters combined with downsizing, which is a trend in the development of internal combustion engines, is the foundation of this project, for which the research problem has been defined as an assessment of the impact of low-methane fuel on engine operating indicators. It has been shown to be possible to use a methane-downsized engine instead of gasoline by the application of high-energy fuel with methane content higher than 60%. The results have been obtained by modeling engine cycles, hence the next step in research will be testing on real objects.

Keywords: internal combustion engine, methane, downsizing

Introduction

Reciprocating internal combustion engines, in spite of new technology such as fuel cells, are still the most popular sources of power for a wide range of machinery and vehicles.

One area of application is their use in mines or fields of biomass, where the fuel is methane.

Methane deposits in Poland, as well as around the world, are diverse in terms of chemical composition, which may indicate a lack of direct use and the need to adjust the engine design to the type of fuel or a change in control of its work. For example, for abandoned mines methane (AMM), the content of methane is 60 to 80% and nitrogen content ranges 5 to 32%, so for coal bed methane (CBM) the content of methane can reach 90-98% with a low amount of nitrogen (20%) [1].

The source of origin also affects the physical and chemical properties that determine the characteristics of energy by various calorific values of 20 to 50 MJ/m^3 [2, 3].

In addition, the gas extracted from the mine must be treated in the methane installation, which makes that about 20 to 40% of the residual gases recovered. According to the Ministry of Economy [1, 4-6] 640 million m^3 of methane is emitted directly into the atmosphere through the ventilation system of the mine. In this way, in addition, methane enhances the greenhouse effect. According to [1], methane in the atmosphere raises warm climate 21 times more than carbon dioxide. It is, therefore, necessary to address the problem of methane energy utilization, especially because of the amount it will increase due to the mining of coal with lower and lower decks, accompanied by methane. In 2012, we extracted 50% more methane than in 2001 [6, 7].

The most common form of use of mine methane gas is to use it to power internal combustion engines, which are an

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important element of co-generation or tri-generation units [4-6, 8, 9].

The size and weight of these units encourages us to take action to apply downsizing technology, the idea of which is to reduce the engine sweep volume while keeping the power and reducing fuel consumption.

The downsizing treatment is accompanied by changes in the combustion process and the different mechanical and thermal loads that have to be identified.

If, therefore, the engine downsizing connects to fuel with different composition and properties, and especially with the low content of methane, there is a research problem outlined in this paper. When modeling the thermodynamic parameters and operating indicators have been described for states before and after downsizing, it shows the possibility of its application, and it fuels the mixture getting different calorific values as well as different methane content.

Combustion Engine Downsizing

Downsizing in relation to the internal combustion engine is a reduction in swept volume while keeping or increasing engine power as well as reducing fuel consumption.

Thermodynamics of the engine cycle giving thermal and mechanical loads of engine components are closely related to the cylinder diameter and the piston stroke [11-14] – indicators determining the downsizing factor W_d [15].

$$W_d = 1 - AB^2$$

...where:

A – ratio of piston strokes after:before downsizing

B – ratio of cylinder diameters after:before downsizing

Downsizing can be implemented in three variants: the reduced stroke ($W_d = 1 - A$), the reduced diameter ($W_d = 1 - B^2$), and mixed ($W_d = 1 - AB^2$) – Fig. 1.

The Test Results

The study was divided into two stages. The aim of the first was to demonstrate the applicability of mixed downsizing (Fig. 1) with factor by 0.3. During the same phase the engine was fed with methane instead of gasoline. The second phase of the study consisted in the assessment of select thermodynamic parameters and operating indicators when running on different mixtures of methane and air.

In both stages, the analysis was carried out for two different engine configurations (that is only geometric changes), and in the second phase – for swept-volume reduction with the use of support systems, such as: boost, variable valve timing, and a variable compression ratio, which was helpful in providing base engine power, i.e. before the introduction of downsizing [12, 13, 19, 20].

Results are included in the form of a relative, referring to the so-called statistical base engine, which was for the first stage engine before downsizing run on gasoline, and in the second stage after downsizing powered 100% methane fuel with calorific value of 47 MJ/kg.

Modelling the engine cycle obtained some thermodynamic parameters and operating indicators changed as follows:

η_v – filling ratio (volumetric efficiency) by 0% for geometrical downsizing only to +36% when downsizing was supported by turbo and variable valve timing and compression ratio

T_{max} – maximum temperature of thermodynamic cycle by 0% for geometrical downsizing only to +0.4% when downsizing was supported by turbo and variable valve timing and compression ratio

p_{max} – maximum pressure circulation by +3.0% for geometrical downsizing only to +4.7% when downsizing was supported by turbo and variable valve timing and compression ratio

g_e – specific fuel consumption by -2.0% for geometrical downsizing only to +-7.0% when downsizing was supported by turbo and variable valve timing and compression ratio

P_e – power (from fuel) by -28% for geometrical downsizing only to +3.0% when downsizing was supported by turbo and variable valve timing and compression ratio.

The next phase of research has shown affection of feeding engine with various methane-air mixtures on engine parameters.

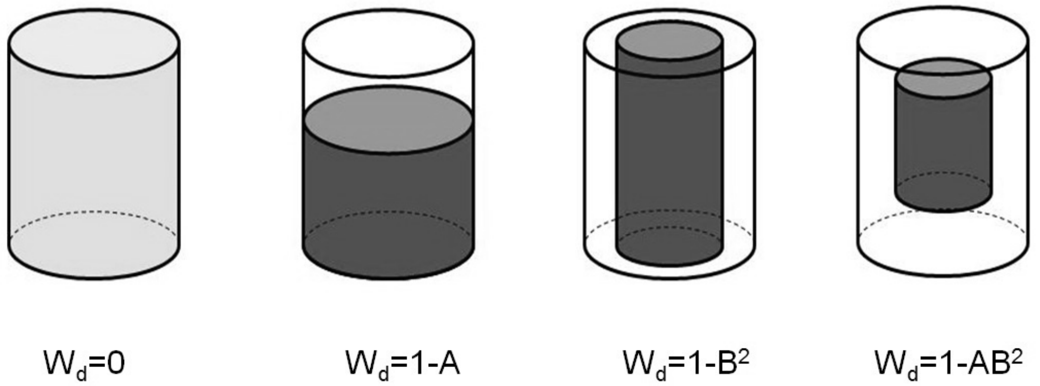

Fig. 1. Variants of downsizing and corresponding factors.

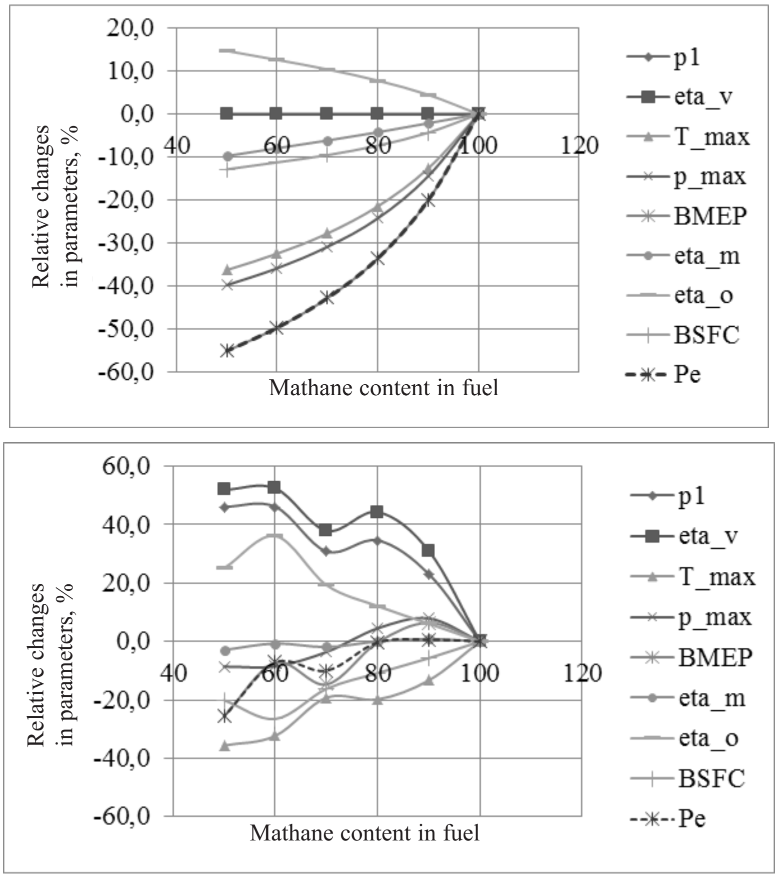

Fig. 2. Relative changes of select engine operating indicators:
a) For engine fuelled with methane of 47MJ/kg after geometrical downsizing only
b) For engine fuelled with methane of 47MJ/kg after downsizing supported by engine systems (turbo, variable valve timing, and compression ratio)
p_1 – The pressure at the end of the intake stroke, eta_v – filling ratio (volumetric efficiency), T_{max} – maximum temperature of thermodynamic cycle, p_{max} – maximum pressure circulation, BMEP – brake mean effective pressure, eta_m – mechanical efficiency, eta_o – overall efficiency, g_e – specific fuel consumption, P_e – useful engine power (from fuel)

Conclusions

The analysis of the data shows that it is possible to downsize a gasoline engine to a gas engine powered with methane, and it is important to support changes in geometry by turbocharging and variable-valve timing systems and variable compression. This ensures that base engine power, while simultaneously reducing specific fuel consumption, will result in lower emissions of carbon dioxide into the atmosphere.

It is possible to use downsizing technology even at lean mixture (from $\lambda = 1.5$ to $\lambda = 2.2$), as determined by the losses in the range of 0 to 10% and are fully acceptable.

Running the engine in the vicinity of the stoichiometric mixture will mean the ability to opt out of technical support, which can result in a consequent increase in fuel consumption and decrease overall efficiency of the engine.

The use of fuel with a lower calorific value has a negative impact on the indicators of the engine. The existence of this fact at the same time decreases the methane content in the fuel and intensifies the effect so that the use of downsizing technology is neither recommended nor requires consideration of a different design of engine support systems.

References

1. BADYDA K. Perspectives of use of mine gas for energy development in Poland. Energetyka. pp.416-423, czerwiec **2008** [In Polish].
2. SKOREK J., KALINA J. Gas cogeneration systems. WNT Publishing House, Warszawa **2005** [In Polish].
3. DUDEK J. Data of quality of distributed gas. The heat of combustion for RCS. GEN, Gaz Energia. March **2012** [In Polish].
4. GANTAR K., KUŚ G. Cogeneration generators fuelled with gas from demethanetion process – work in electric power generators at coal mines of JSW S.A., Proceedings of Prob. Masz. Elektr. **85**, 141, **2010** [In Polish].
5. GOSIEWSKI K., PAWLACZYK A., JASCHIK M. Utilization of methane from ventilation air on coal mines in the thermal reversible reactor. Inż. i Apar. Chem. **3**, 37, **2010** [In Polish].
6. http://www.nettg.pl
7. JANICKA A., JANICKI M. The potential of biomass in Poland – opportunities for use of it. Piece Przem. & Kotły **1/2**, 47, **2012** [In Polish].
8. BACZEWSKI K., KAŁDOŃSKI T. Fuels for spark ignition engines, WKŁ Publishing House, Warszawa **2005** [In Polish].

9. GANTAR K. Power systems that use methane from demethanetion of coal mines of JSW S.A. as part of the local energy market. Polit. Ener. 10,515, **2007** [In Polish].
10. SZWAJA S., TUTAK W., GRAB-ROGALIŃSKI K., JAMROZIK A., KOCISZEWSKI A. Selected combustion parameters of biogas at elevated pressure-temperature conditions. Comb. Eng. **1**, (148), 40, **2012**.
11. HEYWOOD J.B. Internal Combustion Engine Fundamentals, McGraw-Hill Inter. Ed. Singapore **1989**.
12. KORDYLEWSKI W. Spalanie i paliwa. Wyd. Polit. Wroc. Wrocław **2005** [In Polish].
13. KOWALEWICZ A. Fundamentals of combustion processes, WNT Publishing House, Warszawa **2000** [In Polish].
14. LUFT S. Fundamentals of design of combustion engines, WKŁ Publishing House, Warszawa **2011** [In Polish].
15. SROKA Z.J. Some aspects of thermal load and operating indexes after downsizing for internal combustion engine. J. Therm. Anal. Calorim. **110**, 51, **2012**.
16. GRAJNERT J., KWAŚNIOWSKI S., SROKA Z.J. Identification of heat transfer dynamic model for diesel engines, Motauto 2000, Proceedings **1**, Sofia **2000**.
17. SROKA Z.J. BIESIADA H., DENGLER F., KOLANEK C., LANGEMACK H., PACZKOWSKI J., SITNIK L. Computer-aided tests of internal combustion engines. Pro-Motor 1. Wyd. Polit.Wroc. **1996** [In Polish].
18. LOCKER M., WINTER F., AGERWAL K.A. Handbook of Combustion, Wiley, Indian. **2010**.
19. AMBROZIK A. Analysis of thermodynamic cycles of four-stroke internal combustion engines. Wyd. Pol. Świętokrzyskiej, Kielce **2010** [In Polish].
20. KUŁAŻYŃSKI M., SROKA Z.J. Developing Engine Technology. PintPap Łódź-Wrocław, **2011**.