

The Concept of a Dual Fuel Highly Efficient Internal Combustion Engine

2010-01-1480

Published
05/05/2010Grzegorz Pawlak
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ABSTRACT

The paper presents some results of an examination of a dual fuel compression ignition engine fuelled with natural gas and diesel oil and a new concept of a dual fuel highly efficient internal combustion engine. For the examined dual fuel engine the homogeneous air-natural gas mixture was formed outside the engine cylinder and was ignited by a dose of diesel oil directly injected to the cylinder. The analysis of the combustion of a dual fuel mixture is based on cylinder pressure diagrams. The diagrams show some problems connected with self-ignition and control of the combustion of the mixture that should be solved to obtain a better engine performance and lower emissions. Particularly important is the control of the combustion process that causes many problems such as knock combustion or engine overheating. For the above-mentioned solution it is also difficult to reduce the engine emissions of hydrocarbons and nitrogen oxides. As a result of the analysis of the theoretical engine cycle and the dual fuel engine performance as well as some phenomena connected with dual fuelling of compression ignition engines a new idea of fuelling and combustion control was created. Generally, the idea combines Otto and Sabathè theoretical processes in one engine. The Otto process, which is more efficient, would be applied for lower engine load but the Sabathè process with changing share of heat supplied at constant volume is to be applied for higher engine loads. The concept of a dual fuel highly efficient internal combustion engine foresees the application of ethanol and diesel oil and two separate direct injection systems for these fuels as well as spark ignition system which would enable the ignition of stratified ethanol-air mixture. The engine can run in two modes - spark ignition mode (the engine fuelled with ethanol) for lower loads and compression ignition mode (the engine fuelled with ethanol and diesel oil) for higher and full loads. The ethanol-air mixture is lean for both modes. It could also contribute to higher engine efficiency as well as a relatively

high maximum cylinder pressure for all range of loads. The tests of the new concept that are to be carried out will focus on the optimization of the engine control parameters. The parameters of the injection of both fuels and amount of air (controlled by throttle) would be changed in a very high range that could give a higher efficiency and lower emissions. It is also possible to apply natural gas instead of ethanol for the new concept of fuelling of IC engine. The concept could be described as dual fuel mixed ignition (DFMI) engine.

INTRODUCTION

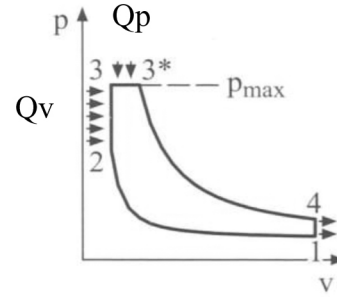
The idea of dual fuelling of compression ignition engines with diesel oil mixed with natural gas or ethanol to the engine cylinder is developing because it gives an opportunity of using alternative fuels. There are some practical applications of the idea. A good example is the Caterpillar DFNG 10 engine with a specially designed Westport injector that enables an injection of small diesel oil dose igniting natural gas that is injected just after the injection of diesel oil [1]. Last December Volvo Trucks announced that they were the first to run diesel engines on diesel oil and natural gas or biogas in compliance with the Euro 5 standards. They expect to be able to run on up to 80 percent of natural gas or biogas, but the tests to be carried out in 2010 will start with a mixture containing up to 70 percent of natural gas or biogas. The remainder will consist of bio-mix diesel, i.e. fossil diesel mixed with diesel produced from renewable raw materials [2]. The interest of big firms in the idea of dual fuelling indicates that it will be developed in the future. Still, there are many problems to be solved. The problems are generated by the complexity of the mixture formation as well as the self-ignition mechanism and combustion of dual fuel mixtures, which is not entirely controlled but creates the shape of a real engine cycle. One of the engine parameters strongly affected by these phenomena is the engine thermal efficiency. The problem was examined during the tests carried out at the Technical University of Radom of a compression ignition

engine adapted for dual fuelling with ethanol and diesel oil [3] as well as with natural gas and diesel oil in. The tests of dual fuel compression ignition engine gave a new idea of dual fuelling of the engine. The concept of dual fuel highly efficient internal combustion engine was described as dual fuel mixed ignition (DFMI) engine. The idea combines spark ignition and compression ignition engine in order to get a more efficient engine fuelled with two fuels.

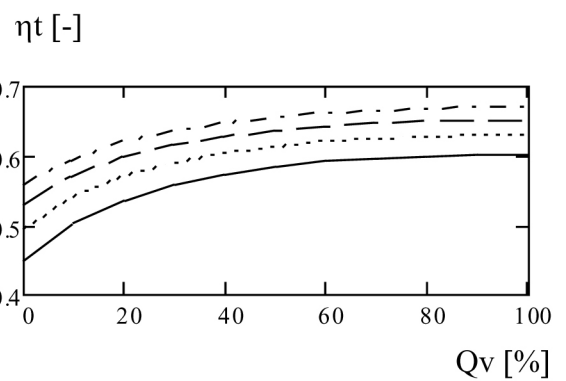
THE ANALYSIS OF THEORETICAL IC ENGINE CYCLE

The analysis of IC engine theoretical cycles provides information about the possibilities of boosting the engine efficiency. Fig. 1 shows some results of a calculation of engine theoretical efficiency of the Sabathè cycle calculated for four compression ratio values. It was assumed that for each calculating cycle the amount of heat supplied to the cycle Q ($Q=Q_v+Q_p$) was constant but the amount of heat Q_v supplied at constant volume process was different. The calculation which was done for the air shows possible benefits of supplying of 100% of heat Q at a constant volume process but also provides information about one of the problems which is a high maximum pressure for high compression ratio values and a big amount of heat supplied to the cycle.

a)



b)



c)

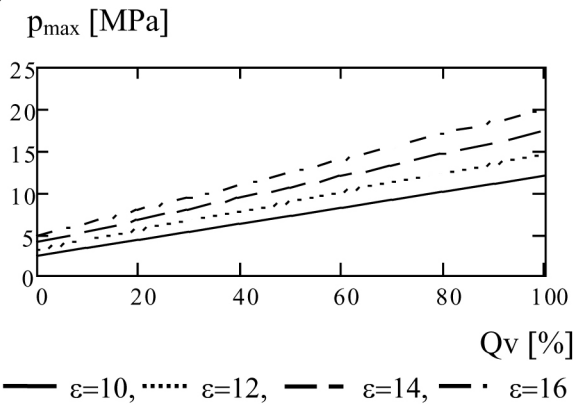


Fig. 1. The Sabathè cycle (a) with calculated theoretical efficiency η_t (b) and maximum cylinder pressure p_{max} (c) vs. share of heat supplied at constant volume process Q_v for different compression ratios ϵ and constant heat Q ($Q=Q_v+Q_p$) supplied to the cycle [4]

In order to receive the maximum possible theoretical efficiency of the cycle for different amount of heat (Q) supplied to it and to limit the maximum pressure (p_{max}) it is proposed to change the cycle depending on the amount of heat and the limit of the maximum cylinder pressure. The calculation of the theoretical cycles for a different amount of

heat supplied to the cycle with the limit of the maximum pressure is shown in Fig. 2.

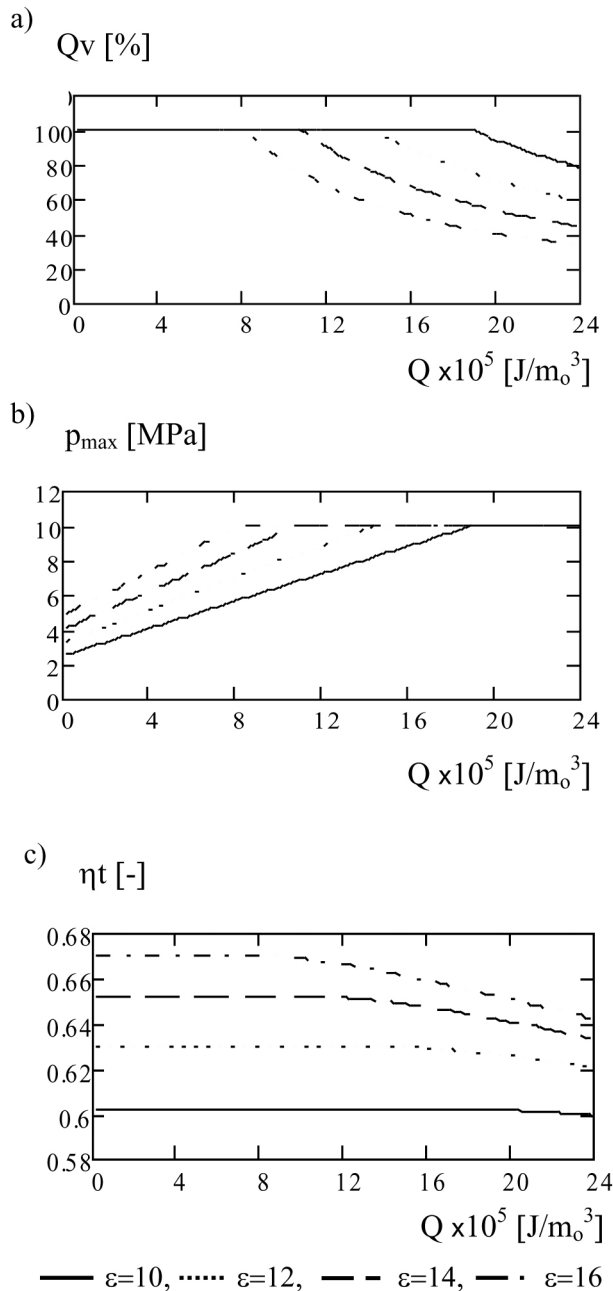


Fig. 2. The share of heat supplied at constant volume process Q_v (a), maximum cylinder pressure p_{max} with a limit ($p_{max}=10$ MPa) (b) and cycle theoretical efficiency η_t (c) vs. the amount of heat Q ($Q=Q_v+Q_p$) supplied to the cycle for different compression ratio ϵ

When the pressure of point 3 (Fig. 1a) topped out assumed maximum pressure the diagram was modified and the share of heat supplied at constant volume process Q_v was limited in order to limit the pressure p_3 to the value of the assumed maximum pressure. For the rising amount of heat supplied to

the cycle it was changed from the Otto cycle (good for a lower amount of heat) to Sabathé cycle with a lower share of heat supplied at constant volume process Q_v . Such a change of cycles enables obtaining a maximum possible theoretical efficiency for a different amount of heat supplied to the cycle and limiting of the maximum cylinder pressure. It is not easy to apply the theory in practice. Dual fuel compression ignition engine provides the possibility of checking some of its aspects.

DUAL FUEL COMPRESSION IGNITION ENGINE AND ITS EXAMINATION

The possibility of control of dual fuel mixture combustion and its influence on the real engine cycle and the engine overall efficiency was examined during the tests of dual fuelling of Andoria ADCR compression ignition engine. It is 2,6 liter, four cylinder engine. The compression ratio is 17,5. The engine is fitted with a turbocharger, intercooler and a common rail fuel system. The maximum torque in the standard version fuelled with diesel oil is 250 Nm (1800-2200 rpm). The engine was adapted for dual fuelling with diesel oil and natural gas (Fig. 3).

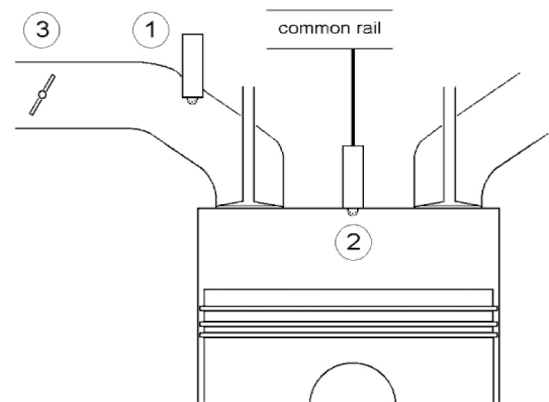


Fig. 3. The concept of dual fuelling of compression ignition engine with natural gas and diesel oil (1-CNG injector, 2-diesel oil injector, 3-throttle) [5]

The homogeneous natural gas - air mixture was formed outside the engine cylinder and was ignited by the dose of diesel oil directly injected to the cylinder by a common rail system. The adjustment of the turbo bypass was not changed. The amount of air was nearly constant for each engine speed. The examination of the engine was based on load characteristics performed for some engine speeds (1200, 1400, 1800, 2200, 2600, 3000, 3200 rpm). During the tests the cylinder pressure was measured with the use of a measurement system for high-speed engine parameters [6]. For each characteristic the engine load started from the torque $T=20$ Nm. For this load the engine was fuelled only with diesel oil. In order to put higher load an increasing dose of natural gas was supplied when the diesel oil dose was nearly