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Energy balance of internal combustion engines using alternative fuels

M.J. Abedin*, H.H. Masjuki, M.A. Kalam, A. Sanjid, S.M. Ashrafur Rahman, B.M. Masum

Centre for Energy Sciences, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia

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ABSTRACT

This paper reviews the literature available concerning the energy balance of internal combustion engines operating on alternative fuels. Global warming and energy crisis are among the most important issues that threaten the peaceful existence of the man-kind. More usage of alternative fuels and energy loss minimization from automotive engines can be an effective solution to this issue. The energy balance analysis gives useful information on the distribution of supplied fuel energy in the engine systems and identifies the avoidable losses of the real engine process with respect to ideal process. It is a very widely used tool, mostly used for the layout of the engine components. The basic energy balance theory has been discussed in details along with the variations in energy balance approaches and terms. The wall energy loss may vary to a great extent depending on the selection of heat transfer correlations. The theoretical energy balance also explored in this paper with help of thermodynamic models. There are some significant variations observed in energy balance when the engine operating fuel is changed and devices like turbocharger, supercharger etc. are used to boost the intake air pressure. The review extends to the energy balance study of low heat rejection engines (LHR) as well as the effects of engine variables and design factors on energy balance.

Contents

Abbreviations: BSFC, brake specific fuel consumption [g/kW h]; BTDC, before top dead center; CNG, compressed natural gas; CR, compression ratio; DI, direct injection; EVO, exhaust valve opening; EHN, ethylexyl nitrate; EGR, exhaust gas recirculation; IVC, inlet valve closing; JME, jatropha methyl ester; LHV, lower heating value [KJ/Kg]; LPG, liquid petroleum gas; LHR, low heat rejection; MBT, maximum brake torque; POME, palm oil methyl ester; PFI, port fuel injection; SME, soybean oil methyl ester; TDC, top dead centre; WOT, wide-open throttle; YGME, yellow grease methyl ester.

* Correspondence to: Department of Mechanical Engineering, University of Malaya, 50603, Kuala Lumpur, Malaysia. Tel.: +60 149 901 927; fax: +60 379 675 317.
E-mail addresses: joynul06me@yahoo.com, joynul06me@siswa.um.edu.my (M.J. Abedin).

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1. Introduction

The fast depletion of fossil fuels, the alarming rate at which the Earth's atmosphere is getting polluted, the increased impact of global warming on Earth and the stringent anti-pollution laws imposed in certain countries have created a stimulus to explore and evaluate alternative fuels for internal combustion engines. As the cost of liquid hydrocarbons is increasing day by day, the interest in alternative fuels for automotive engines is more stimulated in recent years [1–3]. The use of alternative fuels like alcohols, biodiesels, hydrogen etc. in automotive engines is weighty in this context. However, the principal job is, the selected alternative fuel has to serve its purpose best.

An internal combustion (IC) engine is a complex of machinery, instrumentation and services, all of which must work together as a whole. IC engines can be considered as a thermodynamic 'open system', which is a powerful concept to understand the thermodynamic behaviour of a system. It is linked to the idea of 'control volume', a space enclosing the system and surrounded by an imaginary surface often known as 'control surface' (Fig. 1). The advantage of this concept is that once one has identified all the mass and energy flows into and out of a system, it is easy to visualize the inside picture of that system by drawing up an energy balance sheet of inflows and outflows [4]. This energy balance is useful at early stage of designing an IC engine and its subsystems such as cooling system, lubricating oil system, ventilation etc. The researchers have applied different methodology for IC engine energy balance. In this literature the authors will discuss two different methodologies that have found helpful as a means of pulling all the disparate elements together, and which is applied, explicitly or implicitly, throughout the paper. At present, the alternative fuels like alcohols, biodiesels, hydrogen etc. are being used frequently in IC engines. So, the energy balance study of IC engines using these fuels and also the investigation of the effects of different engine variables and design factors will accelerate the feasibility of alternative fuel usage in IC engines. The researchers have used various heat transfer correlations to calculate coolant heat loss or wall heat loss in those experiments; but it requires investigation to find out which one suits best for a particular engine. Moreover, the energy balance of a turbocharged or supercharged engine needs a separate calculation to consider the energy flows from in and out of the turbine, compressor and cooler. Besides, in-cylinder heat transfer characteristics of those engines are greatly effected in the sense that both devices consume fuel heat/exhaust energy which is utilized to achieve improvements in combustion process by increasing the charge quality (i.e. increasing the intake air density) to facilitate complete combustion. These are strong drivers for research, development and demonstration of new technology and alternative fuel for IC engines. The above information were very much scattered and needed to collect under one literature to understand the basic first law analysis (energy balance) of IC engines. Considering the depth of this topic, the multitude of recent studies as well as on-going efforts on this theme, its magnitude on future automotive industry and its intrinsic intricacy, the authors have tried to offer a comprehensive and extensive review article for the first time on this topic. Therefore, the review is aiming to provide the following contents and information.

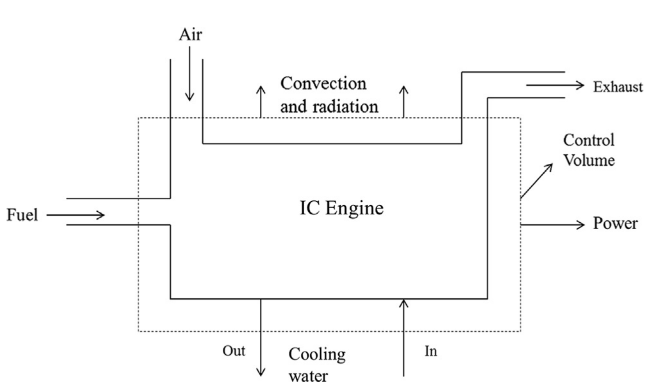

Fig. 1. Control volume of IC engine showing energy flows (re-drawn from [4]).

Two different approaches will be discussed to perform energy balance in IC engines in Section 2. In second approach, a suitable heat transfer correlation is required to compute the wall heat losses. So the details of some heat transfer correlations along with their mathematical models and engine performances for both diesel and gasoline engines will be talked over in Section 2.3. The energy balance using alternative fuels will be investigated in Section 3 considering the effects of thermo-chemical properties of those fuels and also the effects of engine variables on energy balance. A separate section (Section 4) will be allotted to the Low heat rejection (LHR) engine energy balance because in this type of engines, the coolant heat losses are intentionally reduced to a great extent by applying ceramic materials on cylinder walls, head, piston top etc. Theoretical investigations of energy balance and heat transfer modelling are effective tools for overall engine performance prediction, sensitivity analysis of various engine operating parameters, new technology developments and evaluation. These will be explored in Section 5. The effects of engine design factors and operating parameters on energy balance will be investigated in Section 6 and is followed by another section (Section 7) which introduces the turbocharging and supercharging effects on energy balance. Finally, the conclusion section summarizes the gaps remaining in this field and the core findings of this effort. The rest of the introduction and the whole paper follow this sequence.

The energy balance of IC engines yields the allocation of the supplied fuel energy to the various engine components. This type of analysis permits the designer to evaluate the internal energy variation as a function of the energy transfers across the boundaries as heat or work and the enthalpies associated with the mass flow crossing these boundaries [5]. The energy balance of IC engines is basically an analysis of the first law of thermodynamics which is also called as the energy balance or the heat balance or thermal balance. On the other, the second law analysis which is also known as the availability or exergy balance is more complicated and leads to the irreversibility identification [6,7]. The most of the studies concerning second law application to IC engines are based on a preceding first law mathematical modelling of the various in-cylinder processes and its subsystems. The thermodynamic details of a thermal system operation can be better understood by performing energy balance of the system.

The researchers have done the energy balance of the IC engines in different terms and ways but the foundation is the first law of