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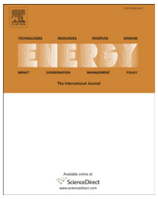

# The effects of the engine design and running parameters on the performance of a Otto–Miller Cycle engine

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## ABSTRACT

In this paper, a thermodynamic analysis for an irreversible Otto–Miller Cycle (OMC) has been presented by taking into consideration heat transfer effects, frictions, time-dependent specific heats, internal irreversibility resulting from compression and expansion processes. In the analyses, the influences of the engine design parameters such as cycle temperature ratio, cycle pressure ratio, friction coefficient, engine speed, mean piston speed, stroke length, inlet temperature, inlet pressure, equivalence ratio, compression ratio, and bore-stroke length ratio on the effective power, effective power density and effective efficiency have been investigated relations with efficiency in dimensionless form. The dimensionless power output and power density and thermal efficiency relations have been computationally obtained versus the engine design parameters. The results demonstrate that the engine design and running parameters have considerable effects on the cycle thermodynamic performance. of a OMC. The results showed that the cycle efficiency increased up to 50%, as cycle temperature ratio increases from 6 to 8, the effective power raised to 11 kW from 5 kW at this range. Other parameters such as engine speed, mean piston speed, cycle pressure ratio affected the performance up to 30%, positively. However, friction coefficient and inlet temperature have negative effect on the performance. As the friction coefficient increases from 12.9 to 16.9, a performance reduction was seen up to 5%. Increase of the inlet temperature abated the performance by 40%.

## 1. Introduction

Gas turbines and ICE (internal combustion engines) are well known indispensable machines in the modern life. But, emissions released from these machines have harmful effects on the human life and environment. For this reason, diesel engines must be designed by taking into account environmental limitation as other engines using global fuel resources. Researches regarding fuel economy and exhaust emissions in internal combustion engines continue to increase as a challenge. Running processes of several types of ICE can be eased as different thermodynamic cycles such as Miller cycle, Dual cycle, Otto cycle and Atkinson cycle. Therefore there have been lots of studies conducted in order to optimize performance of the thermodynamic cycle engines.

Zhu et al. [1] investigated the effects of the turbine cross section, turbocharger efficiency, excess air coefficient, load and waste gate on the turbocharged Dual cycle based on a calibrated diesel engine model. Ge et al. [2] analyzed the influences of the losses resulting from internal irreversibilities, heat transfer and friction on the performance of the irreversible OC (Otto Cycle) by considering the temperature-dependent specific heat of the working fluid. Chen et al. [3,4] investigated the performance and efficiency characteristics of the reversible Otto cycle [3] and irreversible Otto cycle [4]. Ge et al. [5] performed an ecological optimization for an irreversible Otto cycle. Ge et al. [6] examined the influences of heat transfer and variable specific heats of working fluid on the performance of the reversible Otto cycle [6] and irreversible Otto cycle [7]. Ust et al. [8,9] investigated the heat transfer and combustion effects on the irreversible Otto cycle engine [8] and Dual Cycle engine [9].

Chen et al. [10] also performed an optimization study and performance analysis for the air-standard DC considering the influences of the heat transfer, based on FTT (finite-time thermodynamics). Al-Hinti et al. [11] evaluated net power output and cycle thermal efficiency of air-standard DC (Dual-Cycle) by using realistic parameters such as air-fuel ratio, fuel mass flow rate, intake temperature, etc. Chen et al. [12] performed a thermo dynamical performance analysis of an air-standard DDC (Dual Diesel Cycles) by taking heat-transfer and friction-like loss terms

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**Nomenclature**

| | |
|---|---|
| $C_v$ | constant volume specific heat (kJ/kg·K) |
| $C_p$ | constant pressure specific heat (kJ/kg·K) |
| d | bore (m) |
| FTT | finite-time thermodynamics |
| ICE | internal combustion engines |
| L | stroke length (m) |
| m | mass (kg) |
| $\dot{m}$ | time-dependent mass rate (kg/s) |
| N | engine speed (rpm) |
| P | pressure (bar), power (kW) |
| $P_d$ | effective Power Density (kW/dm$^3$) |
| $r$ | compression ratio |
| R | gas constant (kJ/kg·K) |
| SFC | specific fuel consumption |
| $\bar{S}_P$ | mean piston speed (m/s) |
| $\dot{Q}$ | rate of heat transfer (kW) |
| T | temperature (K) |
| V | volume (m$^3$) |

*Greek letters*

| | |
|---|---|
| $\alpha$ | cycle temperature ratio, atomic number of carbon |
| $\lambda$ | cycle pressure ratio |
| $\mu$ | friction coefficient (Ns/m) |
| $\eta_{ef}$ | effective Efficiency |

*Subscripts*

| | |
|---|---|
| 1 | at the beginning of the compression process |
| ef | effective |
| fr | friction |
| max | maximum |
| min | minimum |
| out | output |

into consideration. Gahruei et al. [13] analyzed and compared the performance of the DDC with that of the DAC (Dual—Atkinson cycle) by taking heat-transfer, friction losses and temperature-dependent specific-heats into consideration. Ge et al. [14] examined the effects of heat transfer and friction losses on the performance of an endoreversible AC (Atkinson-Cycle) heat engine. Zhao and Chen [15] parametrically investigated an irreversible AC by taking account of irreversibilities arising from the adiabatic processes, finite-time processes and heat transfer losses. Gonca [16–19] carried out different studies to investigate the performance of the DAC [16–18] and DMC (Dual Miller Cycle) [19]. Ge et al. [20,21] examined the heat transfer effects and friction on the performance of the reversible Miller cycle [20] and irreversible Miller cycle [21]. Chen et al. [22] analyzed the performance of a Miller cycle considering heat transfer, friction and variable specific heats. Chen et al. [23] used a FTTM (finite-time thermodynamic model) to analysis the performance of an irreversible Miller cycle.

Sarkhi et al. [24,25] investigated the impacts of the variable specific heats of the working fluid on the performance for an air standard reversible miller cycle [24] and irreversible miller cycle [25]. In the other study, Sarkhi et al. [26] analyzed the cycle performance by using the maximum power density criteria. Zhao and Chen [27] conducted a performance analysis for an-air standard irreversible miller cycle with respect to the change of the pressure ratios. Ebrahimi [28] analyzed an air standard reversible Miller cycle with respect to variation of engine speed and variable specific heat ratio of working fluid and Ebrahimi [29] analyzed an air standard irreversible Miller cycle with respect to the variation of relative air-fuel ratio and stroke length based on finite-time thermodynamics. Rinaldini et al. [30] carried out an experimental and numerical study by using KIVA code to investigate the potential and the limits of the Miller cycle application to a HSDI (High Speed Direct Injection) Diesel engines in terms of abating $NO_x$ and soot. At the same maximum temperature conditions Lin and Hou [31] stated that MC (Miller cycle) has a superiority compared to OC in terms of the performance. Wu et al. [32] carried out a simulation to apply MC into a supercharged OC engine and an escalation was seen in work output. Zhao and Chen [27] conducted a performance analysis for an-air standard irreversible MC with respect to the change of the pressure ratios. Gonca et al. [33–35] performed many studies on diesel engines with running MC based on parametric studies [33], single zone [34] and two-zone [35,36] combustion simulations. They [37,38] experimentally and theoretically investigated the performance and $NO_x$ emissions of miller cycle diesel engine with steam injection method and also they [39] theoretically determined the optimum steam temperatures and mass ratios based on thermo dynamical analyses for turbocharged internal combustion engines. Cesur et al. [40] and Kokkulunk et al. [41] proved that NOx emissions could be decreased by the application of the steam injection method into the spark ignition engines [40] and compression ignition engines [41]. Kokkulunk et al. [42,43] showed that EGR (exhaust gas recirculation) applications remarkably abate the NOx emissions. There have been many studies carried out for different cycles in the literature [44–59]. Capaldi [44] investigated the design and the overall performance of a 10 kW electric power microco generation plant suitable for local energy production, based on an Atkinson-cycle ICE prototype and totally set by Istituto Motori of the Italian National Research Council. A new six stroke diesel engine is presented in Chen et al. [45] paper. It refers Rankine cycle inside cylinder. Total exhaust gas is recompressed and at a relatively low back pressure in the fourth stroke water is injected to which maintains liquid phase until the piston moves to the TDC (Top Dead Center). Their results show that the work increases with the advance of water injection timing and the quality of water. The cycle is more efficient and the new engine has potential for saving energy. Gonca et al. [46] has been experimentally carried out the application of the Miller cycle and turbo charging methods into a single cylinder, four-stroke, direct injection diesel engine. The results show that combination of the proposed methods may be applied into the diesel engines to minimize $NO_x$ and advanced engine performance. In the study of Asad et al. [47], a PPAC (Premixed Pilot Assisted Combustion) strategy comprising of the port fuel injection of ethanol, ignited with a single diesel pilot injection near the top dead center has been investigated on a single-cylinder high compression ratio diesel engine. Gonca and Sahin [48] decreased the NOx emission of hydrogen-enriched diesel engine by applying the steam injection method. Moreover, Gonca [49,50] investigated the effects of steam injection method on a diesel engine fueled with different bio fuels. Benajes et al. [51] investigated two strategies for implementing the mixing-controlled LTC (Low Temperature Combustion) concept. The first strategy relied on decreasing the intake oxygen concentration introducing high rates of cooled EGR (exhaust gas recirculation). The second strategy consisted of