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The influences of the engine design and operating parameters on the performance of a turbocharged and steam injected diesel engine running with the Miller cycle

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ABSTRACT

This study reports the influences of the engine design and operating parameters on the performance of a turbocharged, steam injected and Miller cycle diesel engine by using a simulation model based on the finite-time thermodynamics. The model is validated with experimental data and the effects of various engine design and operating 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, steam ratio, retarding angle and bore-stroke length ratio on the effective power and effective efficiency are investigated. Furthermore, the energy losses originating from incomplete combustion, friction, heat transfer and exhaust output are demonstrated by using figures. The results show that the engine performance increases with increasing some parameters such as cycle temperature ratio, cycle pressure ratio, inlet pressure; with decreasing some parameters such as friction coefficient, inlet temperature, steam ratio, retarding angle of intake valve closing. However, the engine performance could increase or decrease with respect to different conditions for some parameters such as engine speed, mean piston speed, stroke length, equivalence ratio and compression ratio.

1. Introduction

Nitrogen oxides (NOx) emissions have detrimental effects on the environment, therefore they must be decreased. It is known that formation of NOx is very sensitive to combustion temperatures in the internal combustion engines (ICEs) [1–28]. They can be abated by reducing combustion temperatures. Recently, so many searches have been performed on the steam injection method (SIM) to lower NOx emissions released from the ICEs. The SIM leads to a high decrease rate in the formation of NOx emissions. Because, the steam in the charge decreases combustion temperatures due to higher specific heat of steam and slower combustion process is carried out. [1–12]. Another NOx reduction method is the Miller cycle application. The Miller cycle is carried out by lowering the compression ratio according to the expansion ratio. It can be achieved by retarding intake valve closing during the compression process or earlier closing intake valve during suction process. Hereby, maximum combustion temperatures and NOx can be decreased [13–38]. Turbo charging systems are commonly used to increase specific power of the internal combustion engines (ICE) [39–50]. The combination of these three methods could be used in the diesel engines in order to acquire maximum NOx reduction rate with higher power output.

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Nomenclature

A	heat transfer area (m^2)
C_v	constant volume specific heat (kJ/kg.K)
C_p	constant pressure specific heat (kJ/kg.K)
d	bore (m)
F	fuel-air ratio
FTTM	finite-time thermodynamic model
h_{tr}	heat transfer coefficient (W/ m^2K)
H_u	lower heat value of the fuel (kJ/kg)
ICE	Internal combustion engines
l	loss
L	stroke length (m), energy loss percentage (%)
m	mass (kg)
$\dot{m}$	time- dependent mass rate (kg/s)
N	engine speed (rpm)
P	pressure (bar), power (kW)
P_a	turbo charging pressure
r	compression ratio
r_M	Miller cycle ratio
R	gas constant (kJ/kg.K)
$\bar{S}_P$	mean piston speed (m/s)
$\dot{Q}$	rate of heat transfer (kW)
S	stroke (m)
SIM	steam injection method
T	temperature (K)
v	specific volume (m^3/kg)
V	volume (m^3)
x	ratio of steam to fuel

Greek letters

α	cycle temperature ratio
β	pressure ratio
δ	expansion ratio
ε	stroke ratio
ϕ	equivalence ratio
ψ	cut-off ratio
λ	cycle pressure ratio
μ	friction coefficient (Ns/m)
ρ	density (kg/m^3)
η_C	Isentropic efficiency of compression
η_E	Isentropic efficiency of expansion

Subscripts

1	at the beginning of the compression process
a	air
c	combustion, clearance
cyl	cylinder
ef	effective
ex	exhaust
f	fuel
fr	friction
ht	heat transfer
i	initial condition
ic	incomplete combustion
in	input
l	loss
max	maximum
me	mean