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Comparison of steam injected diesel engine and Miller cycled diesel engine by using two zone combustion model

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ABSTRACT

Emissions, especially NO_x, released from diesel engines must be decreased to limit values described by the regulations because emissions have many bad effects on the environment. One of the known methods for reduction NO_x emissions is to apply Miller Cycle to a diesel engine. In this study, Miller cycle is carried out by lowering the compression ratio according to the expansion ratio with closing the intake valve 30° crank angle later from the BDC (Bottom Dead Center) compared to standard diesel engine. Another method used is steam injection into diesel engine to decrease NO_x emissions. And also, this method could be used to improve the performance and efficiency. Because of these positive effects, Miller cycle and steam injection methods could be implemented into diesel engines together. In this paper, Miller cycled diesel engine with steam injection has been modeled by using zero-dimensional two-zone combustion model. The obtained results have been compared with conventional diesel engine, Miller Cycled diesel engine and steam injected diesel engine in terms of performance and NO emissions. In the results, Miller Cycled diesel engine with steam injection is more efficient at low and medium engine speeds and has less NO emissions than conventional diesel engine, steam injected diesel engine and Miller Cycled diesel engine in all conditions.

1. Introduction

Diesel engines have a prominent place in the modern life. Diesel engines must be designed by considering environmental reasons as other engines using global fuel resources. Because of environmental restrictions, particularly the reduction of NO_x emissions is needed.

One of the known methods to decrease NO_x emissions is to apply Miller cycle to the diesel engine. Applying Miller cycle to the diesel engine could reduce the NO_x emissions released from the diesel engine was shown by Wang et al. [1] experimentally. Mikalsen et al. [2] studied on effects of using Miller Cycle on natural gas engine by comparing with Otto cycle. In the study, the fuel efficiency of natural gas engine is increased but at the cost of a less powerful engine. Wang et al. [3] applied the Miller Cycle to a petrol engine to lessen NO_x emissions by closing intake valve lately. In their study a comparison of the characteristics of Miller cycle with Otto cycle and thermodynamic analysis of the Miller cycle is presented. The compression pressure and temperature were decreased in the cylinder at the end of the compression stroke hence; NO_x formation and combustion temperature diminish as well. Ge et al. [4] studied on the effects of friction loss and heat transfer loss on the performance of an air standard Miller cycle by using finite-time thermodynamics. In the another study, Ge et al. [5] analyzed and compared the Reciprocating heat-engine cycles by using finite-time thermodynamics and also, it is showed that the performance of the Miller cycle by using numerical examples. Al-Sarkhi et al. [6] analyzed an air standard Miller cycle in terms of thermal efficiency, compression and expansion ratios. In this study, it is expressed that the effect of the temperature-dependent specific heat of the working fluid on the irreversible Miller cycle was essential. Lin and Hou [7] conducted an analysis of an air-standard Miller cycle taking into account of heat loss as a percentage of fuel's energy, friction and variable specific heats of working fluid under the restriction of peak temperature of the cycle. They compared the Miller cycle with Otto cycle in terms of power output and efficiency and showed that the

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Nomenclature

A	heat transfer area (cm^2)
C_v	constant volume specific heat($J\ g^{-1}\ K^{-1}$)
C_p	constant pressure specific heat($J\ g^{-1}\ K^{-1}$)
C	blow by coefficient
B	bore (cm)
F	fuel-air ratio
h	specific enthalpy ($J\ g^{-1}$)
h_{tr}	heat transfer coefficient ($W\ m^{-2}\ K^{-1}$) of burned and unburned zone
H	enthalpy ($J\ g^{-1}$)
H_u	low heat value ($J\ g^{-1}$)
m	mass (g)
$\dot{m}$	time-dependent mass rate ($g\ s^{-1}$)
M	molecular weight
n	injection constant
P	pressure (bar)
R	gas constant ($J\ g^{-1}\ K^{-1}$)
NR	revolution per minute
NY	total mole number
Q	loss heat passed through the cylinder wall (J)
$\dot{Q}$	rate of heat transfer (W)
RGF	residual gas fraction
s	specific entropy ($J\ g^{-1}\ K^{-1}$)
S	stroke (cm)
$\bar{S}_p$	mean piston velocity ($m\ s^{-1}$)
T	temperature (K)
u	specific internal energy ($J\ g^{-1}$)
v	specific volume ($cm^3\ g^{-1}$)
V	volume (cm^3)
W	work output (J)
x	burn fraction
$\dot{x}_i$	fraction rate of the total injected fuel mass
$Y_{\%}$	ratio of the steam mass to the fuel mass

Greek letters

ε	ratio of half stroke to rod length
ϕ	equivalence ratio
$\Gamma(n)$	gamma function
θ	crank angle (degree)
τ	time (ms)
ω	angular velocity ($rad\ s^{-1}$)

Subscripts

0	at the beginning of compression for steam injected condition
1	at the beginning of compression for standard condition
a	air
b	burned zone
cyl	cylinder
di	injection duration parameter
dif	diffusive combustion phase
f	fuel
fi	injected fuel
id	ignition delay(ms)
l	leak, loss
pre	premixed combustion phase
r	reference
si	start of fuel injection (degree)
st	stoichiometric
ste	steam
tfmep	total friction mean effective pressure
u	unburned zone
w	cylinder walls

performance of the Miller cycle was better than Otto cycle. Al-Sarkhi et al. [8] conducted a research on a Miller engine in terms of different specific heat models. Wu et al. [9] performed an analysis of supercharged Miller Cycled Otto engine. According to the study, they expressed that the Miller Cycle Otto engine has more work output and could have less engine knock problem. Kesgin [10], applied the Miller cycle to a V20 engine. The Miller cycle was analyzed experimentally and computationally. The efficiency of the engine was increased and NO_x emissions were kept under the limit.

Uzuneanu and Panait [11] indicated that the thermal efficiency of a supercharged Miller Cycle depends on various engine parameters. Zhao and Chen [12] performed a study on an irreversible Miller Cycle model considering some irreversibilities in the compression, expansion, finite time processes and heat loss through the cylinder wall. In their study, an optimization was carried out with respect to the pressure ratios. The optimum criteria of the power output, efficiency and pressure ratio were defined. Gonca et al. [13,14] applied the miller cycle to the diesel engine by using two-zone combustion model and compared the results of conventional diesel and miller cycled diesel engine. Gonca et al. [15] conducted a study on a diesel engine running with miller cycle by using single-zone combustion model. Gonca et al. [16] performed a numerical analysis based on the maximum power output and maximum thermal efficiency criteria for an air-standard irreversible dual miller cycle with late inlate valve closing version.

In many studies, it is expressed that maximum combustion temperature and NO_x emissions were decreased in the case of using diesel fuel with water in the engine [17–22]. Bedford et al. [23] studied on the effects of in-cylinder water injection on a direct injection (DI) Diesel engine by using a computational fluid dynamics (CFD) program. In their study, NO_x and smoke formation rates were reduced. Armas et al. [24] conducted a study on the effect of water–oil emulsions on the engine performance and pollutant emissions. Results presented that the water emulsification had a potential to improve the brake efficiency and decrease the formation of emissions. Abu-Zaid [25], conducted a study on using water-diesel emulsions in diesel engine to investigate the effect on the engine performance and gases exhaust temperature. In his study, results indicated that the addition of water in form of emulsion increases the engine torque, power and brake thermal efficiency and decreases brake specific fuel consumption and exhaust gas temperature. Sarvi et al. [26] investigated the influence of direct water injection (DWI) and Common Rail (CR) technology on emissions released from a multivariable large-scale medium-speed diesel engine. They showed that Combining CR with DWI resulted in lower NO_x and HC emissions but slightly higher CO and smoke emissions. Ayhan [27] investigated the effect of steam injection on the reduction of NO_x emissions released from a diesel engine with direct injection system. Parlak et al. [28] and Kokkulunk et al. [29] applied the steam injection technique to a diesel engine and Cesur et al. [30] applied this method to a gasoline engine. Gonca [31] examined the effects of steam injection on a diesel engine running with ethanol-diesel blend. Parlak et al. [32] investigated the influences of the steam injection on a diesel engine fueled with tobacco seed oil methyl ester. Gonca et al. [33] carried