IARJSET
ISSN (Online) 2393-8021
ISSN (Print) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
CETCME-2017
"Cutting Edge Technological Challenges in Mechanical Engineering"
Noida Institute of Engineering & Technology (NIET), Greater Noida
Vol. 4, Special Issue 3, February 2017

Energy and Exergy Analysis of Trendsetting Internal Combustion Engine: A Review

Pushpendra Upadhyay[1], Brajesh Tripathi[2]

Rajasthan Technical University Kota, Rajasthan, India[1,2]

Abstract: Demand for higher fuel economy and lower exhaust emission of combustion ignition engine need to be achieved either by reducing exergy loss or blending diesel with bio-fuel to reduce pollutant emission from transportation sector and meet satisfactory engine performance which is major technical challenge since the world is confronted with energy scarcity. Computational model of TDC was investigated to get energy and exergy distribution for different trendsetting internal combustion engine. The result indicated that the 50% heat release point (CA50) considerably affect fuel efficiency and ringing intensity. Heat transfer loss of CDC depends on temperature gradient, in case of homogeneous charge compression ignition (HCCI) and reactivity controlled compression ignition (RCCI) it depends on heat transfer area. Exergy destruction is related to different factor, temperature inside cylinder, air fuel ratio, chemical reaction rate, combustion duration and temperature. Considering these factor conventional diesel combustion (CDC) engine shows high exergy destruction compared to HCCI and RCCI. Overall change in exergy distribution obtained from second law of thermodynamic for three different combustion strategy are consistent with those obtained from first law of thermodynamic. HCCI shows the highest energy and exergy efficiency and CDC performs the worst.

Keywords: HCCI Homogeneous Charge Combustion Ignition, RCCI Reactivity Controlled Combustion, Ignition, CDC Conventional Diesel Combustion.

I. INTRODUCTION

Diesel engine is a mechanical device where chemical energy contained in fuel is converted into mechanical energy that is mainly used for the power generation, transportation and agriculture application. In such en-gine, air alone is sucked during the suction stroke and compressed with the compression ratio 12 to 24 and the fuel is injected near the top dead center (TDC) and is auto ignited. The process from the start of fuel injec-tion to start of combustion are very quiet complicated [13]. The main problem with diesel engine are higher smoke and particulate matter emission as well as higher nitrogen oxide emission due to heterogeneous air fuel mixture during combustion. The different fuel injection strategies can be conveniently used to control smoke and particulate emission simultaneously. The diesel engine can be made to run on renewable fuels like bio-fuel instead of diesel which is depleting day by day [13].

Reduction of harmful emission from internal com-bustion engine is an urgent task for vehicle man-ufactories, and it is attracting attention all around the world. Meanwhile, more stringent restriction on carbon dioxide raises great challenge for engine com-bustion system. The target of carbon dioxide emission in the European union is required to be below 130 g/km by 2015 for all new cars and below 95 g/km is expected to be demanded by 2021.
Therefore improvement of the in-cylinder combustion process to simultaneously obtain high fuel efficiency and low exhaust emission is imperative [15].

Because of diminishing fossil fuel resources and increasing pollution caused by an in increase in fuel consumption the need to solve this problem concur-rently necessary. Homogeneous charge compression ignition engine appears to be appropriate solution because it create less pollution and is highly efficient [21]. The two dominating engine concept commonly used today are diesel and spark ignition engine. The spark ignition engine equipped with catalytic conver-tor provides low emission but lack in efficiency. The diesel engine on other hand provides high efficiency but also produce high emission of nitrogen oxide and particulate matter. An engine concept capable of combining the efficiency of diesel and tailpipe emission of spark ignition engine is the homogeneous charge compression ignition (HCCI) [9].

It is characterized by the fact that the fuel and air are mixed before combustion start and the mixture auto ignite as a result of the temperature increase in the compression stroke. Thus HCCI is similar to spark ignition in the sense that both engine uses premixed charge and similar to compression ignition as both rely on auto-ignition to initiate combustion. producing high efficiency and low emission. The only challenge using this combustion strategy is uncon-trolled combustion temperature. The temperature is very high and leads to knocking. Reactivity controlled compression ignition (RCCI) engine is dual fuel en-gine technology, in which two fuel of different reactivity are blended inside cylinder. From port injection low reactivity fuel that is gasoline is injected and at the end of compression stroke direct injection of high reactivity fuel is injected for auto-ignition. By appropriately choosing the reactivity of fuel and their relative amount and injection timing, combustion can be controlled to have high efficiency and low emission of nitrogen oxide. There are few proposed RCCI fuel pairing that is gasoline and diesel, ethanol and diesel, gasoline and gasoline with small amount of cetane number booster ditert. Butyl peroxide (DTBP).

The first law of thermodynamics has been widely used to quantify the fuel efficiency of internal combustion engines[18]. However, besides the quantity of energy, the quality of energy is another important indicator for energy utilization, which cannot be obtained from the first law (energy) of thermodynamics. Thus, the second law (exergy) of thermodynamics is usually introduced to provide more thorough insight into the thermodynamic process during engine cycles. Consequently, the sources and magnitudes of the energy wasted in the system can be evaluated, and a guide to take full advantage of the system energy can be provided.

The exergy of a system under a given state, also known as availability, is the maximum output power that can be potentially extracted from the system when the system reaches thermal, mechanical, and chemical equilibrium with its surroundings while experiencing a reversible process. Thermal equilibrium is the state that the temperature of a system is equal to that of its surroundings. The state in which no pressure gradient exists between the system and its surroundings is defined as mechanical equilibrium. When all the components in a system cannot interact with its surroundings to produce work, it is called chemical equilibrium [8]. If a system is only in thermal and mechanical equilibriums, the state of the system is defined as the restricted dead state. When all the three equilibrium are obeyed, the state of the system is defined as the reference dead state. The selection of the reference dead state is very important since it determines the amount of system exergy. For the reference dead state, the pressure and temperature are usually taken as p_0 = 1.01325 bar and T_0 = 298.15 K, and the molar compositions of the environment are 20.35% O_2, 0.03% CO_2, 3.03% H_2O, and 0.92% various other substances [17].

For internal combustion engines, the input energy can be mainly divided in four parts according to the first law of thermodynamics, including incomplete combustion, heat transfer losses, exhaust losses, and indicated output power [14]. However, in the view of exergy analysis, energy degradation happens along the whole cycle due to irreversibility. Accordingly, exergy analysis should be performed to evaluate the maximum achievable engine efficiency. In conventional diesel combustion (CDC) engines, the major exergy destruction is produced from combustion, fuel-air mixing, friction, and throttling [2]. Under typical operating conditions, the combustion process ac-counts for more than 90% of the total exergy destruction [19], and the other exergy destructions from pumping and fuel/air mixing processes are usually one or two orders of magnitude smaller [23].

Advanced combustion strategies with premixed LTC, including homogeneous charge compression ignition (HCCI), premixed charge compression ignition (PCCI), and reactivity controlled compression ignition (RCCI), which manifest different combustion characteristics from CDC are attracting more and more attention due to their advantages in fuel economy and exhaust emissions. However, the fundamental reasons for their superiority in fuel efficiency have not been comprehensively revealed, and the potential of maximum work extraction from LTC engines still remains ambiguous. By coupling multi-dimensional models and a detailed chemical mechanism, the energy and exergy distributions of different combustion regimes are systematically analyzed and compared in this review. The important factors that affect exergy destruction are revealed, and the potential for energy utilizations for the different combustion regimes are identified [15].

II. NUMERICAL MODELS

The simulations conducted in this study were based on the updated KIVA-3V code, in which several improvements to the physical and chemical sub-models have been made to enhance prediction accuracy. A new generalized re-normalization group (RNG) turbulence model proposed by Wang [24] was adopted, which avoids the over-predicted turbulent energy in the RNG turbulence model by considering the flow strain rate. The hybrid Kelvin Helmholtz (KH)-Rayleigh Taylor (RT) model [20] was utilized to reproduce the spray droplet breakup process. Grid independence was improved by employing the spray collision model developed by Nordin. A new spray/wall interaction model proposed by Zhang et al.[25] was employed which is specifically improved for the conditions relevant to LTC engines. The wall heat transfer model developed by Han and Reitz [7] was employed because it is capable of characterizing the effect of variations of gas density and turbulent Prandtl number in wall boundary layers. The CHEMKIN solver [12] was integrated into the KIVA-3V code to describe the complex chemical kinetic combustion process. A skeletal oxidation mechanism of nheptane and iso-octane (primary reference fuel, PRF) [1] consisting of 49 species and 163 reactions was built through a decoupling methodology. It was demonstrated that the ignition and combustion characteristics of diesel and gasoline can be satisfactorily captured by the mechanism with nheptane and isooctane as the respective surrogates [3]. In addition, the extended Zeldovich nitrogen oxide (NO_x) sub-mechanism.

IARJSET
ISSN (Online) 2393-8021
ISSN (Print) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
CETCME-2017
"Cutting Edge Technological Challenges in Mechanical Engineering"
Noida Institute of Engineering & Technology (NIET), Greater Noida
Vol. 4, Special Issue 3, February 2017

3. EXERGY ANALYSIS METHODOLOGY

$$Ex^{th}_{exhaust} = \sum_{i=1}^{k} H_i(T_e) - H_i(T_o) - T_o X \quad (1)$$

where

$$X = [S_i(T_e) - S_i(T_o) - R \ln \frac{p_e}{p_o}] \quad (2)$$

$$Ex^{ch}_{exhaust} = RT_o \sum_{i=1}^{k} \ln \frac{x_i^e}{x_i^o} \quad (3)$$

$$Ex_{fuel} = \sum_{reactants} H_i - \sum_{products} H_i - T_o Y \quad (4)$$

where

$$Y = (\sum_{reactants} S_i - \sum_{products} S_i) \quad (5)$$

The exergy transfer through heat transfer(Ex_{heat})is associated with the temperature gradients in the heat transfer layer near cylinder walls, and it is defined as [15]:

$$Ex_{heat} = \int (1 - \frac{T_o}{T_g}) dQ \quad (6)$$

$$Ex_{work} = \int_{IVC}^{EVO} (p - p_o) dV \quad (7)$$

where p is the in-cylinder pressure, $dV/d\Phi$ denotes the variation of in-cylinder volume versus crank angle. In this study, only the engine working process from intake valve closing (IVC) to exhaust valve opening (EVO) is considered.
According to exergy balance, the exergy destruction ($Ex_{destruction}$) in an internal combustion engine can be estimated by [15]:

$$Ex_{destruction} = Ex_{fuel} - Ex_{work} - (Ex_{exhaust} - Ex_{intake}) - Z \quad (8)$$

where

$$Z = Ex_{heat} + Ex_{incomplete} \quad (9)$$

and the exergy efficiency (i.e the second law efficiency, η_{ex}) is defined as [15]

$$\eta_{ex} = \frac{Ex_{work}}{Ex_{fuel}} \quad (10)$$

It is worth mentioning that the heat transfer process in practical engines is very complex as it occurs through several media from the inner wall of the cylinder to the environment, while only the exergy transfer through heat transfer leaving the combustion chamber is estimated in this study. Thus, the predicted exergy transfer through heat transfer could be larger than that from measurements. Compared to the exergy transfer through heat transfer, the exergy transfer through exhaust can be more easily recovered by exhaust gas turbines. Thus, in some studies, the exergy contained in the exhaust gases is also regarded as output work exergy, and the exergy efficiency is defined as $_{ex}$ = (work exergy + exhaust exergy)/input fuel exergy [15].

4. MODEL VALIDATION

The experimental data used to validate the present computational models are from the work of Gingrich et al. [6], in which a series of experiments were performed to investigate the combustion characteristics of different combustion regimes in a light-duty diesel, single-cylinder research engine. There were two swirl control vanes that provided an adjustable swirl ratio from 1.5 to 4.8. Two low-pressure injectors equipped with the separate fuel system were placed in the intake port to supply gasoline and nheptane for HCCI or only gasoline for RCCI. A common rail injector was mounted in the cylinder for the direct-injected of diesel fuel near top dead center (TDC) for CDC or the multiple injections of diesel fuel for RCCI. The detailed specifications of the test engine are listed in Table 1. [15]

The exergy output work (Ex_{work}) is calculated as follows
To save computational time, a 1/7th sector mesh shown as in Fig. 1 was utilized in the simulations where Q denotes the amount of heat transfer and Tg is the gas temperature in the heat transfer boundary of the system.

TABLE 1: ENGINE SPECIFICATION

Displacement (L)	0.477
Bore (mm)	82.0
Stroke (mm)	90.4
Compression ratio	16.3
Piston bowl	Re-entrant
Swirl ratio	1.5
Intake valve closing (^{o}CA)	-132
Exhaust valve opening ^{o}CA	112
Port fuel injector	
Included spray angle (^{o})	20
Injection pressure (bar)	2-10
Common rail injector	
Number of holes	7
Included spray angle (^{o})	155
Injection pressure (bar)	250-100

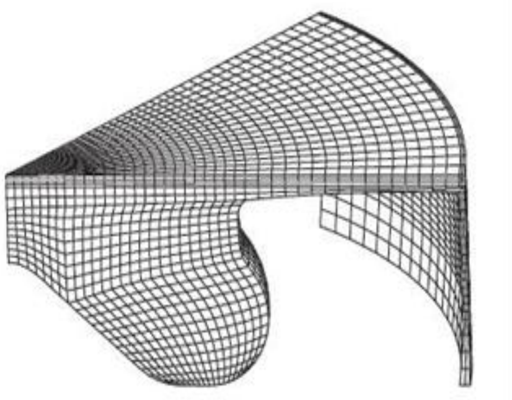

Fig. 1: Computational mesh at TDC [15].

with consideration of only one spray from the axis-symmetric injector nozzle, and periodic boundary conditions were applied at the sides of the computational domain. In this study the 50% heat release (CA50) point was used to represent the combustion phasing. For CDC, the combustion phasing was con-trolled by adjusting the injection timing of the diesel fuel. Different combustion phasings were achieved in HCCI combustion by varying the gasoline-to-diesel ratio in the intake manifold. In RCCI combustion, the mass fractions of diesel and gasoline, as well as the injection timing of diesel were adjusted to control combustion phasing without sacrificing output power. For all the cases, the engine was operated at a gross indicated mean effective pressure (IMEP) of 5.7 bar and 1900 rev/min and no EGR was used [15].

The computational results were used to compare the experimental result for CDC, HCCI, and RCCI strategy. From table 2,3,4 we see in cylinder pressure is maximum in HCCI and minimum in CDC at 50% heat release point [15].

III. RESULTS AND DISCUSSION

A. Comparison of Engine Performance among CDC, HCCI, and RCCI Combustion

TABLE 2: IN-CYLINDER PRESSURE AND HRR OF CDC

Pressure MPa	Crank Angle (^{0}CA)	HRR (J/^{0}CA)
2	-28	100
4	-14	200
6	1	300
8	5	400

TABLE 3: IN-CYLINDER PRESSURE AND HRR OF HCCI

Pressure MPa	Crank Angle (^{0}CA)	HRR (J/^{0}CA)
2	-28	100
4	-12	200
6	2	300
8	4	400

TABLE 4: IN-CYLINDER PRESSURE AND HRR OF RCCI

Pressure MPa	Crank Angle (^{0}CA)	HRR (J/^{0}CA)
2	-28	60
4	-12	120
6	-2	180
8	4	240

When various fuels with different lower heating values are employed in the dual-fuel engines, equivalent indicated specific fuel consumption (EISFC) [16] is introduced to estimate the fuel economy as follow: reactivity fuel and low-reactivity fuel, H_h, H_l and H_d are the lower heating value of the high-reactivity fuel, low-reactivity fuel, and diesel, respectively [15]. Moreover, ringing intensity (RI) [4] is employed to quantify the level of engine knock, which is calculated. where is the ratio of specific heat, $(dP=dt)_{max}$ is the maximum rate of pressure rise, P_{max} is the maximum in-cylinder pressure in one cycle, T_{max} is the maximum in-cylinder temperature, and R is the ideal gas constant [15]. Different ringing intensity (RI) value correspond-ing to equivalent indicated specific fuel consumption (EISFC) of CDC, RCCI and HCCI is shown in table 5. From table we see that RI decreases as CA50 is retarding . HCCI is having low EISFC which means high fuel efficiency followed by RCCI and then CDC. Thus CDC is having low fuel efficiency compared to HCCI and RCCI. Beside having high fuel efficiency, RI is also high in HCCI which leads to knocking in engine and consequently damage the cylinder. RCCI have lowest value of RI and CDC is having higher value of RI than RCCI but lower than HCCI.

B. Energy Analysis using the First Law of Thermodynamics

a. Incomplete combustion

TABLE 5: COMPARISION OF FUEL EFFICIENCY AND RINGING INTENSITY OF THREE COMBUSTION REGIMES.

Engine	RI (MW=m^2)	EISFC (g/KWh)
CDC	12	196
	7.5	200
	6	204
	7.5	207
HCCI	12.5	180
	9.5	179
	5	178
	2.5	183
RCCI	2	184
	2.5	186
	1.5	188
	1	195

Combustion efficiency gradually decreases with retarded CA50 for the three combustion regimes. The combustion efficiency of CDC is always higher than that of HCCI or RCCI at each CA50 due to its lower HC and CO emissions as mentioned above. Compared to RCCI, the combustion in HCCI is more complete, no matter where CA50 is located. This is primarily due to the stratification of equivalence ratio and fuel reactivity in the cylinder of

RCCI. That is, for the RCCI cases, the fuel-air mixture adjacent to the cylinder wall is leaner and less reactive than that in the HCCI cases. Thus, the temperature of the near-wall boundary in RCCI is lower than that of HCCI, resulting in higher HC and CO emissions [15].

$$EISFC = \frac{M_h H_h + M_l H_l}{H_d} \cdot \frac{1}{\oint p.dv} \qquad (11)$$

where M_h and M_l are respective the mass of high-reactivity fuel and low-reactivity fuel, H_h, H_l and H_d are the lower heating value of the high-reactivity fuel, low-reactivity fuel, and diesel, respectively [15].

Moreover, ringing intensity (RI) [4] is employed to quantify the level of engine knock, which is calculated as:

$$RI \approx \frac{1}{2\gamma} \cdot \frac{(0.05.(\frac{dP}{dt})_{max})^2}{P_{max}} \cdot \sqrt{\gamma RT_{max}} \qquad (12)$$

b. Heat transfer losses

At a fixed CA50, the energy fraction of heat transfer from chamber surfaces in HCCI is close to that in CDC, and both CDC and HCCI illustrate much larger heat transfer losses than RCCI. As demonstrated in Ref [5] a sharp temperature gradient exists in the boundary layer near the chamber walls due to the flame/chamber surface interactions in CDC, conse-quently resulting in a large amount of energy transfer through the boundary layer in CDC. Although there is lack of a temperature gradient in the boundary layer of HCCI, the high-temperature combustion region is more widespread and uniform compared to CDC. The extensive heat transfer area of HCCI results in the fi-nal energy fraction of wall heat transfer in HCCI being comparable to that in CDC [11]. As discussed above, the lower temperature of the near-wall regions in RCCI compared to those of HCCI, is a critical reason for its less intensive heat transfer. Furthermore, for the three combustion regimes, the heat transfer fraction monotonically decreases with retarded CA50, which is attributed to the lower combustion temperature and the shortened heat transfer duration [15].

c. Fuel efficiency

Under the combined effects of incomplete combustion, heat transfer losses, and exhaust losses, the indicated thermal efficiency of HCCI combustion is the highest at a fixed CA50, although the HC and CO emissions of HCCI are 5.66% more than those of CDC. This is mainly ascribed to the lower exhaust losses of HCCI, and thus more fuel energy is converted into output power. Because of the lower combustion efficiency, the fuel efficiency of RCCI is lower than that of HCCI, while it is still higher than that of CDC due to the lower exhaust and heat transfer losses. In addition, RCCI exhibits the greatest advantage in alleviating RI. But for HCCI and CDC, postponing CA50 and/or introducing EGR must be adopted to avoid serious engine knock. Because of the reduced combustion efficiency and increased exhaust losses with retarded CA50, the fuel efficiency derived from the first law of thermodynamics gradually reduces with retarded CA50 for all three combustion regimes [15].

C. Exergy Analysis in the Second Law of Thermodynamics

First law of thermodynamic gives information about quantity of energy, but does not tell about its quality. For quality exergy analysis is to be done, which is given by second law of thermodynamics. Exergy can be defined as maximum available energy that can be converted into useful work. The total exergy can be classified into three categories, i.e., exergy output power, exergy destruction, and exergy transfer including exergy transfer through heat transfer, exhaust, and incomplete combustion. By comparing it can be observed that the exergy fractions of exhaust losses, heat transfer, incomplete combustion, and net work are all smaller than their corresponding energy fractions. This is primarily due to the fact that the input fuel exergy is the inherent chemical energy of fuel, which is usually larger than the lower heating value of the fuel [22]. In addition, the degradation of each energy part during the conversion process also leads to lower exergy fractions in the second law. However, the overall variation trends of each part in the second law are consistent with those from the first law [15].

IV. CONCLUSIONS

An analysis using the first and second laws of thermodynamics is employed to investigate the energy and exergy distributions of CDC, HCCI, RCCI combustion. Position of 50% heat release rate (CA50) affects ringing intensity and fuel efficiency. Fuel efficiency is also affected by timing of CA90 and its advancement reduce exhaust loss. Exergy destruction is less in case of HCCI and RCCI when compared to CDC when working on same load this is because of premixed homogeneous charge distribution in in-cylinder. Energy and exergy analysis of different combustion regimes on various parameter shows similar distribution and it also shows that HCCI is having highest efficiency then RCCI and followed by CDC.

REFERENCES

[1] Yachao Chang, Ming Jia, Yaopeng Li, and Maozhao Xie. Ap-plication of the optimized decoupling methodology for the construction of a skeletal primary reference fuel mechanism focusing on engine-relevant conditions. Frontiers in Mechanical Engineering, 1:11, 2015.

[2] Venkateswarlu Chintala and KA Subramanian. Assessment of maximum available work of a hydrogen fueled compression ignition engine using exergy analysis. Energy, 67:162–175, 2014.

[3] Olivier Colin, Antonio´ Pires da Cruz, and Stephane´ Jay. Detailed chemistry-based auto-ignition model including low temperature phenomena applied to 3-d engine calculations. Proceedings of the Combustion Institute, 30(2):2649–2656, 2005.

[4] JA Eng. Characterization of pressure waves in hcci combus-tion. Technical report, SAE Technical Paper, 2002.

[5] Alessandro Franco and Luigi Martorano. Evaluations on the heat transfer in the small two-stroke engines. Technical report, SAE

IARJSET
ISSN (Online) 2393-8021
ISSN (Print) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
CETCME-2017
"Cutting Edge Technological Challenges in Mechanical Engineering"
Noida Institute of Engineering & Technology (NIET), Greater Noida
Vol. 4, Special Issue 3, February 2017

Technical Paper, 1998.
[6] Eric Gingrich. Experimental investigation of piston heat trans-fer in a light duty engine. Technical report, DTIC Document, 2014.
[7] Zhiyu Han and Rolf D Reitz. A temperature wall function formulation for variable-density turbulent flows with applica-tion to engine convective heat transfer modeling. International journal of heat and mass transfer, 40(3):613–625, 1997.
[8] Arif Hepbasli. A key review on exergetic analysis and assess-ment of renewable energy resources for a sustainable future. Renewable and sustainable energy reviews, 12(3):593–661, 2008.
[9] Mohammad Izadi Najafabadi and Nuraini Abdul Aziz. Homo-geneous charge compression ignition combustion: challenges and proposed solutions. Journal of combustion, 2013, 2013.
[10] M Jia, ZJ Peng, and MZ Xie. Numerical investigation of soot reduction potentials with diesel homogeneous charge com-pression ignition combustion by an improved phenomeno-logical soot model. Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering, 223(3):395– 412, 2009.
[11] Ming Jia, Eric Gingrich, Hu Wang, Yaopeng Li, Jaal B Ghandhi, and Rolf D Reitz. Effect of combustion regime on in-cylinder heat transfer in internal combustion engines. International Journal of Engine Research, 17(3):331–346, 2016.
[12] Robert J Kee, Fran M Rupley, and James A Miller. Chemkin-ii: A fortran chemical kinetics package for the analysis of gas-phase chemical kinetics. Technical report, Sandia National Labs., Livermore, CA (USA), 1989.
[13] SV Khandal, NR Banapurmath, VN Gaitonde, and SS Hire-math. Paradigm shift from mechanical direct injection diesel engines to advanced injection strategies of diesel homoge-neous charge compression ignition (hcci) engines-a compre-hensive review. Renewable and Sustainable Energy Reviews, 70:369–384, 2017.
[14] Sage Kokjohn, Reed Hanson, Derek Splitter, John Kaddatz, and Rolf D Reitz. Fuel reactivity controlled compression ignition (rcci) combustion in light-and heavy-duty engines. SAE International Journal of Engines, 4(2011-01-0357):360–374, 2011.
[15] Yaopeng Li, Ming Jia, Yachao Chang, Sage L Kokjohn, and Rolf D Reitz. Thermodynamic energy and exergy analysis of three different engine combustion regimes. Applied Energy, 180:849–858, 2016.
[16] Yaopeng Li, Ming Jia, Yaodong Liu, and Maozhao Xie. Numer-ical study on the combustion and emission characteristics of a methanol/diesel reactivity controlled compression ignition (rcci) engine. Applied energy, 106:184–197, 2013.
[17] Michael J Moran. Availability analysis: a guide to efficient energy use. 1982.
[18] Robert Morgan, Guangyu Dong, Angad Panesar, and Morgan Heikal. A comparative study between a rankine cycle and a novel intra-cycle based waste heat recovery concepts applied to an internal combustion engine. Applied Energy, 174:108–117, 2016.
[19] RJ Primus and PF Flynn. The assessment of losses in diesel engines using second law analysis. Computer-Aided Engineering and Energy Systems, 3:61–68, 1986.
[20] Rolf D Reltz and John E Dec. Comparisons of diesel spray liq-uid penetration and vapor fuel distributions with in-cylinder optical measurements. 2000.
[21] Abdul Siddique, Shaik Abdul Azeez, and Raffi Mohammed. Simulation and cfd analysis of various combustion chamber geometry of a ci engine using cfx. Simulation, 5(8):33–39, 2016.
[22] James P Szybist, Kalyana Chakravathy, and C Stuart Daw. Analysis of the impact of selected fuel thermochemical prop-erties on internal combustion engine efficiency. Energy & Fuels, 26(5):2798–2810, 2012.
[23] KY Teh, SL Miller, and CF Edwards. Thermodynamic re-quirements for maximum internal combustion engine cycle efficiency. part 1: optimal combustion strategy. International Journal of Engine Research, 9(6):449–465, 2008.
[24] Bao-Lin Wang, Chang-Wook Lee, Rolf D Reitz, Paul C Miles, and Zhiyu Han. A generalized renormalization group turbu-lence model and its application to a light-duty diesel engine operating in a low-temperature combustion regime. Interna-tional Journal of Engine Research, 14(3):279–292, 2013.
[25] Yanzhi Zhang, Ming Jia, Hong Liu, Maozhao Xie, Tianyou Wang, and Lei Zhou. Development of a new spray/wall interaction model for diesel spray under pcci-engine relevant conditions. Atomization and Sprays, 24(1), 2014.