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Effect of Start of Injection Timing on Waste Heat Recovery Capacity in a Reactivity Controlled Compression Ignition Engine

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ABSTRACT: It is noteworthy that about one-third of the input energy to the cylinder of an internal combustion engine becomes useful work and the rest of the energy is lost by various factors. Therefore, providing solutions that can recover waste heat is remarkable and useful. In the current study, the effect of the start of injection timing on the reactivity controlled compression ignition engine on the waste heat recovery capacity has been investigated. After verifying the results, diesel fuel start of injection timing has been changed and their effects on exergy destruction, waste heat recovery capacity, power output and emissions have been investigated. The results showed that the advanced start of injection timing increases engine efficiency and decreases carbon monoxide and unburned hydrocarbons emissions. In addition, heat transfer exergy has increased due to the higher in cylinder temperature, and the higher temperature has led to an increase in irreversibility due to the increased number of reactions. Advanced fuel injection timing has improved utilization.

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1. INTRODUCTION

With the idea of low temperature combustion, the technology of internal combustion engines based on low temperature combustion is developed. Low temperature combustion leads to higher fuel economy and lower exhaust nitrogen oxides and particulate matter emissions. There are some studies focusing on the applicability of low temperature combustion engines in power, heating and cooling cycles. Khaljani et al. [1] utilized the waste heats from the homogeneous charge compression ignition engine cooling water and exhaust gases to drive two organic Rankine.

Reactivity controlled compression ignition engines are the new type of internal combustion engines that work based on low temperature combustion [2].

Because of low exhaust emission and high fuel economy, reactivity controlled compression ignition engines can be used in combined cooling, heating and power cycles. Li et al. [3] studied the exergy destruction in diesel engine, homogeneous charge compression ignition combustion engine and reactivity controlled compression ignition engine and showed exergy destruction in reactivity controlled compression ignition engines is lower than two other engines.

The main purpose of the current study is the investigation of the effect of injection timing on the capacity of waste heat recovery from exhaust gases and coolant of reactivity controlled compression ignition engines.

2. METHODOLOGY

In the current study reactivity controlled compression ignition engine is simulated utilizing a computational fluid dynamics code. The effects of injection timing on engine performance, emissions, exergy destruction and the capacity of waste heat are investigated.

2.1. Model validation

Two cases with different injection strategies are used for model validation. Table 1 shows the characteristics of the cases. Fig. 1 indicates both numerical and experimental in-cylinder pressure and heat release rates for both cases.

Table 1. Operating conditions for the light duty reactivity controlled compression ignition engine

Parameters	Case 1	Case 2
Speed (rpm)	1300	1500
BMEP (bar)	4	5
Diesel flow rate (gr/s)	0.071	0.107
NG flow rate (gr/s)	0.5	0.56
Air flow rate (kg/h)	60.736	55.95
SOI1- SOI2 (BTDC)	Single - 20	55-20
Split type (%/%)	Single	70/30
T_IVC (K)	380	378
Common Rail Pressure (bar)	400	400
BR %	89	85
EGR%	0%	20%

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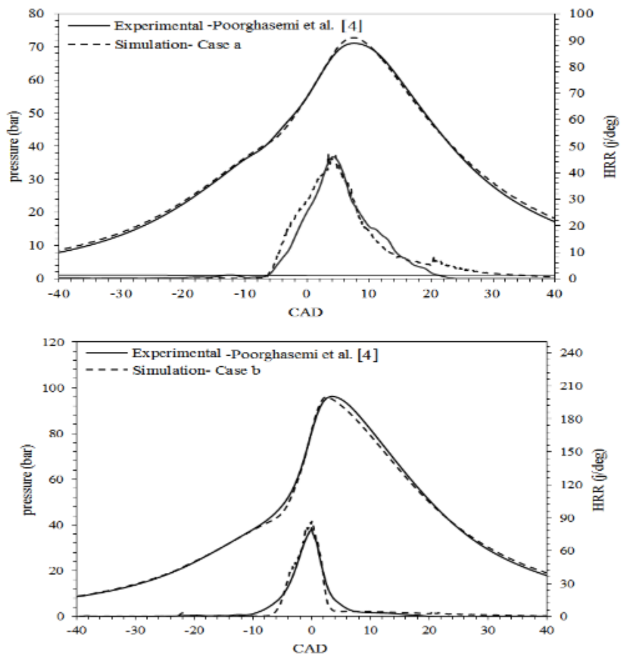

Fig. 1. The validation of in-cylinder pressure and heat release rate for both cases [4].

3. RESULTS AND DISCUSSION

Fig. 2 shows the exergy of engine exhaust gases. As it has been shown, the maximum exergy has occurred when the injection is started at 5 crank angle degree before top dead center. The minimum value of exergy of exhaust gases has occurred with the early start of injection timing at 25 crank angle degrees before top dead center. When the injection is started earlier the exergy of exhaust gases is increased again because of higher heat transfer to the cylinder wall and lower chemical reactions and incomplete combustion of hydrocarbons.

The results of the first and second law efficiencies are shown in Fig. 3. The figure shows that the lowest first and second law efficiencies have occurred when fuel injection is started at 5 crank angle degrees before top dead center. When the start of injection is delayed combustion is not complete

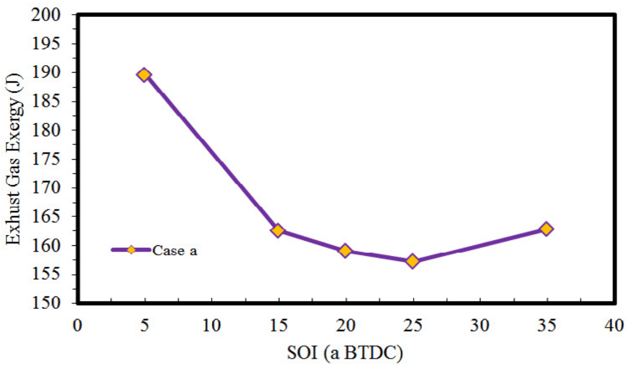

Fig. 2. Effects of the start of injection timing on Exhaust Gas Exergy

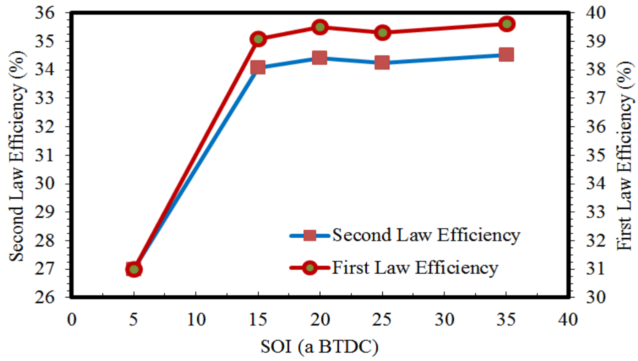

Fig. 3. Effects of the start of injection timing on first and second low Efficiency

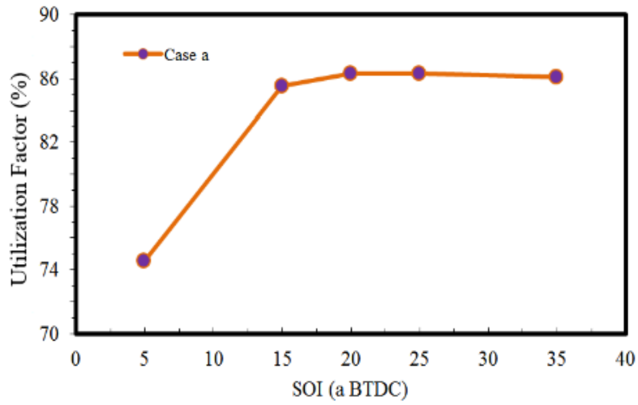

Fig. 4. Effects of the start of injection timing on utilization factor

and the work production is reduced.

The system utilization factor is the sum of the used (like work) and the recoverable exergy over the total chemical exergy of fuel. In the current study, the system utilization factor is calculated to achieve the conditions that lead to the best performance of the reactivity controlled compression ignition engine. Fig. 4 shows the effect of the time of the start of injection on the engine utilization factor. As shown in the figure, the system utilization factor is reduced by delaying the start of injection timing too much and by the start of injection timing too early. The best system utilization Factor is 20 crank angle degree before top dead center.

The combustion process in reactivity controlled compression ignition engines is controlled by chemical reactions; therefore it is important to find the reactions that play a critical role in the combustion process in these engines. The chemical reactions performed are the most important factor in controlling the performance and emissions of the engine and affect the waste heat recovered. Table 2 shows the important reactions at crank angle degree 50 when 50% of the total chemical energy of the fuel is released. According to the table, it can be concluded that the time of the start of injection, affects the rank and rate of important reactions. The time of the start of injection

Table 2. Important reaction at crank angle degree 50 for different start of injection timing

Rank	SOI= 5 BaTDC	SOI= 20 BaTDC	SOI= 35 BaTDC
1	OH+CH4<=>CH3+H2O	OH+CH4<=>CH3+H2O	OH+CH4<=>CH3+H2O
2	OH+CH2O<=>HCO+H2O	O+H+M<=>OH+M	O+H+M<=>OH+M
3	CH3+HCO=CH2O+CH2	OH+H2O2<=>HO2+H2O	OH+H2O2<=>HO2+H2O
4	CH3O2H=CH3O+OH	OH+CH2O<=>HCO+H2O	OH+CH2O<=>HCO+H2O
5	O+CH4<=>OH+CH3	H+O2+H2O<=>HO2+H2O	H+O2+H2O<=>HO2+H2O

changes the rate of heat transfer and chemical reactions in the combustion chamber and changes the in-cylinder temperature and leads to different rank and rate of chemical reactions.

4. CONCLUSIONS

In the present study, a computational fluid dynamics model coupled to a detailed chemical kinetics mechanism is applied to investigate the capacity of waste heat recovery from exhaust gases and coolant of reactivity controlled compression ignition engines. The results showed that with the advanced injection timing of fuel, both first and second law efficiencies are increased and the utilization factor of the engine is increased too.

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