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Research on the Comparisons between Sabah Cycle and Diesel Cycle of Common Rail Injection Diesel Engine

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Abstract. Pressure constant pre-expansion ratio has directly influenced on the highest temperature of Diesel cycle. The common rail injection system also has directly influenced on the highest temperature and pre-expansion ratio, thereby it also affects the technical indices, such as thermal efficiency and average valid pressure. Taking National VI emission standard diesel from Weicai Company as an instance, the highest temperature and other technical indices of Sabah cycle with a common rail injection system and Diesel cycle without a common rail injection system were compared.

1. INTRODUCTION

Diesel cycle is an inner reversible cycle of a diesel's pressure constant ideally heating: constitutes with an irreversible volume constant heat releasing process, a reversible pressure constant heat absorption process, and double entropy constant processes. It mainly applies for diesel engine.

The research on the common rail diesel engine in this thesis is based on the diesel engine of the Weicai National VI emission standard. The diesel engine is designed and improved on the basis of the diesel engine of the national V emission standard [1], inheriting the advanced technology of Weicai excellent performance and high reliability[2][3][4][5], and then can move toward higher emission standards. The technical parameters related to the diesel engine are shown in Table 1.

Table 1. Relevant Parameters of Common Rail Engine

Emission Standard	National VI
Model	Turbo & Middle Cooler, Electric Control (High Pressure Common Rail Injection System)
Exhaust Volume	11.596L
Cylinder Diameter×Piston Travel	126×155mm
Rated Power	245kW
Rated Speed	1900r/min
Maximum	1600N·m



Torque	
Compress Ratio	17: 1
Ignition Order	1-5-3-6-2-4
Turbo Ratio	1.85: 1

The composition of the high pressure common rail fuel injection system mainly includes[2][3][4][5]: oil supply pump, common rail pipe, high pressure oil pipe, fuel injector, electronic control unit and various sensors;

Its basic working principle is as follows: the oil supply pump delivers the fuel to the common rail, and the oil supply method is completely independent of the injection process by the electronic control method;

The high-pressure oil pump of the common rail system mainly uses the CP3.3N-16/18 high-pressure oil pump; the mechanical part of the high-pressure common rail fuel injection system and the actuator are Bosch related parts, and the injector is a CRIN2 type injector. The electronic control unit adopts EDC7, and the common rail pipeline adopts LWRN3 type common rail.

2. Diesel Cycle and Sabah Cycle

Configured with a common rail injection system, there are extremely directly influences on the diesel engine's thermal cycle. This thesis mainly researches on the cycle efficiency and average pressure comparing with the Sabah cycle configured with a common rail system and the Diesel cycle configured without a common rail system.

Sabah cycle is mixing heating ideally inner reversible cycle.

2.1. Diesel Cycle

The p-v chart of a diesel engine's Diesel cycle configured without a common rail injection system is shown in figure 1, and figure 2 is its T-s chart. Table 2 is its initial relevant parameters.

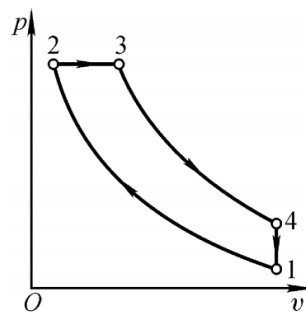


Figure 1. Diesel Cycle's p-v Chart

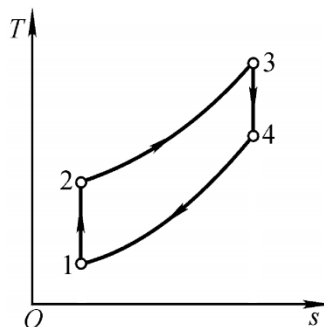


Figure 2. Diesel Cycle's T-s Chart

Table 2. Relevant Parameters of Diesel Cycle(Comments: the environment temperature is -3°C, No. - 10 diesel fuel, external characteristic rated speed)

Diesel Cycle	Air Intake Temperature	Intake Pressure	Pressure Constant Pre-Expansion
Relevant Parameters	27°C	1.85bar	2

Among them, the average pressure could be expressed as below:

$$\frac{p_t}{p_a} = \left(\frac{\eta_t Q_B}{c_v T_a} \right) \left(\frac{1}{\kappa - 1} \right) \left(\frac{\varepsilon_c}{\varepsilon_c - 1} \right) \quad (1)$$

Compress Ratio: $\varepsilon_c = 17$ (2)

Entropy constant index: $\kappa = 1.4$ (3)

Point 1 Status: $p_a = 1.85\text{bar}$ (4)

$$T_a = 300\text{K} \quad (5)$$

$$c_v = 0.718\text{kJ} / (\text{kg} \cdot \text{K}) \quad (6)$$

$$c_p = 1.005\text{kJ} / (\text{kg} \cdot \text{K}) \quad (7)$$

Research Results

1-2 is entropy constant process,

$$T_2 v_2^{\kappa-1} = T_a v_a^{\kappa-1} \quad (8)$$

$$T_2 = T_a \varepsilon_c^{\kappa-1} = T_a (17)^{\kappa-1} \quad (9)$$

Substitute the corresponding data,

$$T_2 = 931.75 \approx 932\text{K} \quad (10)$$

$$T_3 = \rho \times T_2 = 1863.5 \approx 1864\text{K} \quad (11)$$

Intake specific volume: $\frac{p_a v_a}{T_a} = R_g \quad (12)$

$$v_a = \frac{287 \times 300}{1.85 \times 10^5} = 0.465\text{m}^3 / \text{kg} = v_4 \quad (13)$$

$$v_2 = \frac{v_a}{\varepsilon_c} = 0.0274\text{m}^3 / \text{kg} \quad (14)$$

$$v_3 = \rho \times v_2 = 0.0548\text{m}^3 / \text{kg} \quad (15)$$

3-4 is entropy constant process,

$$T_4 v_4^{\kappa-1} = T_3 v_3^{\kappa-1} \quad (16)$$

$$T_4 = 792\text{K} \quad (17)$$

Cycle Heat Absorption Q_B

$$Q_B = c_p (T_3 - T_2) = 1.005 \times (1863.5 - 931.75) = 936\text{kJ/kg} \quad (18)$$

Cycle Heat Release:

$$Q_2 = c_v (T_4 - T_1) = 0.718 \times (792 - 300) = 353\text{kJ/kg} \quad (19)$$

Cycle Heat Efficiency:

$$\eta_t = \frac{w_{net}}{Q_B} = \frac{Q_B - Q_2}{Q_B} = \frac{936 - 353}{936} = \frac{583}{936} = 62.286\% \quad (20)$$

Cycle Average Efficient Pressure:

From formula 1: $p_t = 13.3\text{bar} \quad (21)$

Entropy Constant Process, $p_2 v_2^\kappa = p_a v_a^\kappa$ (22)

$$p_2 = p_a \varepsilon_c^\kappa \quad (23)$$

$$p_2 = 97.7 \text{ bar} \quad (24)$$

Irreversible volume constant process,

$$\frac{p_4}{T_4} = \frac{p_a}{T_a} \quad (25)$$

$$p_4 = 4.88 \approx 4.9 \text{ bar} \quad (26)$$

2.2. Sabah Cycle

Figure 3 is the p-v chart of the diesel's Sabah cycle configured with a common rail injection system, figure 4 is its T-s chart, table 3 is the initial relevant parameters of the Sabah cycle. The common rail injection pressure is high, therefore, the highest pressure of the cycle is high, and the value is 140bar. The initial air status parameters refer to Diesel cycle.

Compress Ratio: $\varepsilon_c = 17$ (27)

Entropy constant index: $\kappa = 1.4$ (28)

Table 3. Relevant Parameters of Sabah Cycle(Comments: the environment temperature is -3°C, No. - 10 diesel fuel, external characteristic rated speed)

Sabah Cycle	Air Intake Temperature	Intake Pressure	Cycle Highest Pressuren
Relevant Parameters	27°C	1.85bar	140bar

Among them, $p_{3'} = 140 \text{ bar} = p_{4'}$ (29)

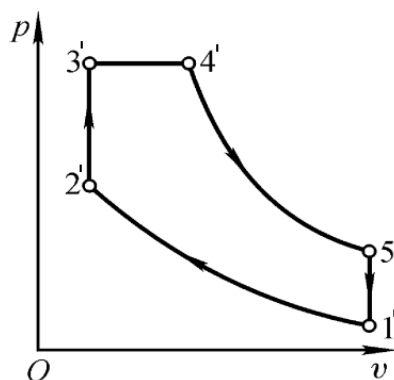


Figure 3. Sabah Cycle's p-v Chart

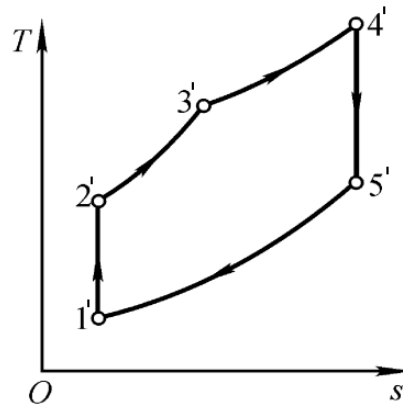


Figure 4. Sabah Cycle's T-s Chart

Whether the common rail system is equipped only involves and affects the heating process of the in-cylinder thermodynamic cycle, and does not involve any change of the exhaust system. The ideal exhaust gas state of the diesel engine is the same.

Therefore, $v_{5'} = v_4 = v_{1'} = v_1 = 0.465 \text{ m}^3 / \text{kg}$ (30)

$$T_{5'} = T_4 = 792 \text{ K} \quad (31)$$

Entropy constant process,

$$p_{4'} v_{4'}^\kappa = p_{5'} v_{5'}^\kappa \quad (32)$$

$$p_{5'} = p_4 = 4.88 \approx 4.9 \text{ bar} \quad (33)$$

$$v_{4'} = \sqrt[\kappa]{\frac{p_{5'}}{p_{4'}}} v_{5'} = \sqrt[1.4]{\frac{4.88}{140}} v_{5'} = 0.0423 \text{ m}^3 / \text{kg} \quad (34)$$

2'-3' reversible volume constant,

$$v_{3'} = v_{2'} = v_2 = 0.0274 \text{ m}^3 / \text{kg} \quad (35)$$

The pressure constant pre-expansion:

$$\rho' = \frac{v_{4'}}{v_{3'}} = \frac{0.0423}{0.0274} = 1.54 < \rho = 2 \quad (36)$$

$$\frac{T_{3'}}{p_{3'}} = \frac{T_{2'}}{p_{2'}} = \frac{T_2}{p_2} \quad (37)$$

$$T_{3'} = T_2 \times \frac{140}{97.7} = 1335.5 \text{ K} \quad (38)$$

3'-4' reversible pressure constant,

$$T_{4'} = \rho' \times T_{3'} = 2057 \text{ K} \quad (39)$$

Cycle heat absorption Q_B'

2'-3' reversible volume constant process,

$$Q_{B' 2'3'} = c_v (T_{3'} - T_{2'}) = 0.718(1335.5 - 932) = 290 \text{ kJ} / \text{kg} \quad (40)$$

3'-4' reversible pressure constant process,

$$Q_{B'3'4'} = c_p(T_{4'} - T_{3'}) = 1.005(2057 - 1335.5) = 725 \text{ kJ/kg} \quad (41)$$

$$Q_{B'} = Q_{B'2'3'} + Q_{B'3'4'} = 290 + 725 = 1015 \text{ kJ/kg} > Q_B \quad (42)$$

Cycle heat release:

$$Q_2 = Q_2' = 353 \text{ kJ/kg} \quad (43)$$

Cycle heat efficiency:

$$\eta_i' = \frac{w_{net}'}{Q_{B'}} = \frac{Q_{B'} - Q_2'}{Q_{B'}} = \frac{1015 - 353}{1015} = \frac{662}{1015} = 65.22\% > \eta_i \quad (44)$$

Cycle average efficient pressure p_i'

$$\text{From formula 1, } p_i' = 15.1 \text{ bar} > p_i \quad (45)$$

It can be inferred that under the same initial parameter conditions, the Sabah cycle is stronger than the Diesel cycle in terms of cycle heat absorption, cycle heat efficiency, and cycle average effective pressure.

However, in terms of pressure constant pre-expansion ratio, the Sabah cycle is lower than the Diesel cycle. The heat absorption of the Diesel cycle constant pressure process increases, and the cycle heat efficiency decreases, because this part of the heat is added in the downward expansion stroke of the piston, and the functional force is relatively low, and this is also the Diesel cycle pressure constant pre-expansion ratio's higher cause.

3. Common Rail Technology Advantages

1) The common rail system increases the in-cylinder pressure, combustion temperature, heat release rate, and reduces soot emissions[6][7][8];

2) The improvement of the injector can increase the pressure in the cylinder and the combustion temperature;

3) The optimization of the relevant fuel injection parameters by the electronic control unit raises the peak value of the cylinder pressure, temperature and heat release rate; and the fuel consumption is reduced, and the indicated torque and the indicated power are increased[9].

In short, the common rail system will be improved from the in-cylinder thermal process of the diesel engine, or from the emission, economy and power of the diesel engine.

4. Conclusions

(1) This paper introduces the concept of diesel common rail system and the structure and working principle of the common diesel system of Weicai 6 diesel engine;

(2) Comparing the Sabah cycle with the common rail system and the Diesel cycle diesel engine without the common rail system, and through calculation and calculation, the cycle heat absorption and circulation of the diesel Diesel cycle and the Sabah cycle are obtained. The results of thermal efficiency and average effective pressure show that the Sabah cycle has certain advantages in terms of cycle heat absorption, cycle heat efficiency, and average effective pressure.

(3) In terms of pressure constant pre-expansion ratio, the common-bar system Sabah cycle is significantly lower than the Diesel cycle;

(4) This thesis introduced the advantages of the diesel common rail system in all aspects of the diesel engine.

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