

Researches on the Influences of Common Rail Pressures on the Diesel Engine's Sabah Cycle

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Abstract: There are directly effects on diesel's Sabah cycle of common rail pressure, at the same time, the common rail pressure also affects the property indices: pre-expansion ratio, thermal efficiency, exergy efficiency and average valid pressure. It takes Weicai National VI diesel as an instance, describes the simplifies, basic presumptions and formulas of inner cylinder thermal process, and mainly designs and researches on the property indices of Sabah Cycle in different common rail pressure conditions, includes: the rail pressure effects towards pressure inner cylinder, combustion temperature, etc.; and takes oil consumption as the optimizing target, optimized and gained the MAP of rail pressure, the oil consumption after optimizing are satisfied with the design requirements.

Keywords: Common Rail Pressure, Diesel Engine, Sabah Cycle

1. Introduction

This thesis takes Weicai National VI as a research target, this engine succeeds the primary one's features of advance technology, excellent function, high reliability, and may relay

on moving to the higher exhaust standard. As shown in table 1 is the main technical parameters [1, 2].

Table 1. Common Rail Diesel Engine Technical Parameters.

Emission Level	National 6
Model	Turbo & Middle Cooler, Electric Control High Pressure Common Rail
Exhaust Volume	11.596L
Cylinder Diameter×Piston Travel	126×155mm
Rational Power	245kW
Rational Rotate Speed	1900r/min
Maximum Torque	1600N·m
Compress Ration	17:1
Ignite Order	1-5-3-6-2-4
Turbo Ratio	1.85:1

The compositions of high pressure common rail fuel injection system mainly includes [3-5]: oil supply pump, common rail tube, high pressure oil tube, fuel injectors, electronic control unit and various sensors;

Its basic working principle is as follow: The fuel supply pump conveys the fuel to the common rail, and an oil supply method that electrically separates the generation of the

injection pressure from the injection process.

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

rail.

1.1. Basic Presumptions on the Calculations of Inner Cylinder Thermal Processes

For the establishment of inner cylinder combustion model, a quasi-dimensional model [1, 6, 7] has been adopted. Here is to explain: in the quasi-dimensional model, considering the non-uniformity in the cylinder, the fuel injection is divided into several small areas according to the empirical formula of non-uniform distribution of fuel air in the cylinder. Each small area is an independent one. The thermodynamic system also considers that the processes carried out in the relevant areas are all affected by the turbulent flow in the cylinder; the model is a process conceptualized by the diesel engine: fuel injection, spray crushing, mixture formation, heat release, heat transfer, and exhaust compositions.

1.2. Basic Formulas of Inner Cylinder Thermal Processes

Inner cylinder thermal processes in diesel engines are relatively complex, but there are always three parameters or (p, T, v) that represent the state of the gas in the cylinder; the process can be linked by energy, mass conservation equations, and equations of state.

(1) Basic Formula of Energy Conservation

According to the first theory of thermodynamics, established a formula of inner cylinder energy conservation:

$$\frac{d(mu)}{d\varphi} = -p \cdot \frac{dV_s}{d\varphi} + \frac{dQ_{Bm}}{d\varphi} - \sum \frac{dQ_{wi}}{d\varphi} - h_{ex} \cdot \frac{dm_{ex}}{d\varphi} \quad (1)$$

Among them: m -Inner cylinder working air quality, kg; u -Internal energy of inner cylinder air; p - Inner cylinder pressure, MPa; V_s -Cylinder working volume, L; Q_{Bm} - Heat absorption, kJ; Q_{wi} -Heat loss through the boundary of system, kJ; φ -Crank angel, °CA; h_{ex} -Exhaust enthalpy from cylinder, kJ/kg; $\frac{dm_{ex}}{d\varphi}$ -Exhaust flow rate from cylinder, kg/°CA

(2) Formula of Mass Conservation

The amount of change in gas mass in a diesel engine cylinder is equal to the mass of fuel injected into the cylinder, the mass of gas flowing into the cylinder, and the mass of the gas flowing out of the cylinder, the formula is as below

$$\frac{dm}{d\varphi} = \frac{dm_\beta}{d\varphi} + \frac{dm_s}{d\varphi} - \frac{dm_c}{d\varphi} \quad (2)$$

Among them: i -Exergy Loss, kJ/kg; s_g -Entropy Generation, kJ/(kg.K); Δs_0 - Environment Entropy Increase

Among them: m_β -Fuel mass injected into the cylinder, kg; m_s -Air mass flow into the cylinder, kg; m_c -Air mass flow out of the cylinder, kg

(3) Raw of Combustion and Heat Release

Utilizing Weber's combustion model as the engine cylinder heat release model for diesel engines, the empirical formulas for Weber's combustion are as below:

$$\frac{dx}{d\varphi} = \frac{\alpha}{\Delta\varphi_c} \cdot (m+1) \cdot y^m \cdot e^{-a \cdot y(m+1)} \quad (3)$$

$$dx = \frac{dQ_{Bm}}{Q_{Bm}} \quad (4)$$

$$y = \frac{\varphi - \varphi_0}{\Delta\varphi_c} \quad (5)$$

Among them: Q_{Bm} - Heat absorption, kJ; φ_0 -Combustion start, °CA; $\Delta\varphi_c$ -Combustion duration, °CA; m -Combustion quality index; α -weber parameter ($\alpha=6.9$); φ -Crank angel, °CA;

Exergy and Exergy Efficiency

Heat Exergy in Heat Absorption Capacity Q_B :

$$e_{x,Q} = Q_B - a_{n,Q} = (1 - \frac{T_0}{T_{lm}}) Q_B = Q_B - T_0 \Delta s_1 \quad (6)$$

Average Temperature of Heat Absorption:

$$T_{lm} = \frac{Q_B}{\Delta s_1} \quad (7)$$

Exergy Efficiency:

$$\eta_{ex} = \frac{w_{net}}{e_{x,Q}} \quad (8)$$

Among: $e_{x,Q}$ - Heat Exergy, kJ/kg; $a_{n,Q}$ - Heat Anergy, kJ/kg; T_{lm} - Average Temperature of Heat Absorption, K; Q_B - Cycle Heat Absorption Capacity, kJ/kg; T_0 - Environment Temperature, K; Δs_1 - Entropy Increase during Heat Absorption Process, kJ/(kg.K); w_{net} -Efficient Exergy (Cycle Work), kJ/kg;

Exergy Loss:

$$i = T_0 s_g = T_0 (\Delta s_2 + \Delta s_0) = T_0 (-\Delta s_1 + \frac{Q_2}{T_0}) = Q_2 - a_{n,Q} = Q_2 - T_0 \Delta s_1 \quad (9)$$

during Exothermic Process, kJ/(kg.K); Q_2 -Cycle Heat Release, kJ/kg; Δs_2 -Entropy Increase during Exothermic

Process, $kJ/(kg.K)$

2. Researches on Sabah Cycles in Different Common Rail Pressures

The target of the exergy analysis of Sabah cycles in different rail conditions is Weicai National 6, as shown in figure 1, 2 are p-v figure and T-s figure of Sabah cycles.

There is a comment: under different rail pressures, the highest temperatures and pressures are different, however, The ideal air inlet and outlet temperatures are the same at 1 point: the air states at 1 point and 5 point in Figures 1 and 2 do not change with the rail pressure. As shown in table 2 is sabah cycle relative parameters.

Table 2. Sabah Cycle Relative Parameters.

Sabah Cycle	Air intake temperature T_a	Air intake pressure p_a
Relative Parameters	27°C	1.85bar

Comments: Environment temperature T_0 is -3°C, No.-10 Diesel Oil, External Characteristics Rational Speed

Among them, the cycle average pressure is expressed as below:

$$\frac{p_t}{p_a} = \left(\frac{\eta_t Q_B}{c_v T_a} \right) \left(\frac{1}{\kappa - 1} \right) \left(\frac{\varepsilon_c}{\varepsilon_c - 1} \right) \quad (10)$$

Compress Ratio:

$$\varepsilon_c = 17 \quad (11)$$

Constant Entropy index:

$$\kappa = 1.4 \quad (12)$$

then,

$$c_v = 0.718 kJ / (kg \cdot K) \quad (13)$$

$$c_p = 1.005 kJ / (kg \cdot K) \quad (14)$$

Table 3. The Maximum Cycle Pressure Corresponding to Different Target Rail Pressures.

Sabah Cycle	I	II	III	IV
Target Rail Pressure	900bar	1200bar	1500bar	1700bar
Maximum Rail pressure	128bar	140bar	160bar	170bar

Condition I:

$$p_3 = p_4 = 128bar \quad (15)$$

constant pressure pre-expansion ratio

$$\rho = 2 \quad (16)$$

1-2 constant entropy process,

$$T_2 v_2^{\kappa-1} = T_a v_a^{\kappa-1} \quad (17)$$

thus

$$T_2 = T_a \varepsilon_c^{\kappa-1} \quad (18)$$

$$T_2 = 932K \quad (19)$$

$$p_2 v_2^{\kappa} = p_a v_a^{\kappa} \quad (20)$$

$$p_2 = p_a \varepsilon_c^{\kappa} \quad (21)$$

$$p_2 = 97.7bar \quad (22)$$

2-3 constant volume process,

$$\frac{p_3}{T_3} = \frac{p_2}{T_2} \quad (23)$$

$$T_3 = 1221K \quad (24)$$

the highest temperature:

$$T_4 = \rho \times T_3 = 2 \times 1221 = 2442K \quad (25)$$

Intake specific volume:

$$\frac{p_a v_a}{T_a} = R_g \quad (26)$$

$$v_2 = v_3 = \frac{v_a}{\varepsilon_c} = 0.0274 m^3 / kg \quad (27)$$

$$v_4 = \rho \times v_3 = 0.0548 m^3 / kg \quad (28)$$

$$v_a = v_5 = \frac{287 \times 300}{1.85 \times 10^5} = 0.465 m^3 / kg \quad (29)$$

4-5 constant entropy process,

$$T_5 v_5^{\kappa-1} = T_4 v_4^{\kappa-1} \quad (30)$$

$$T_5 = 1038K \quad (31)$$

Cycle heat absorption Q_B

$$Q_{23} = c_v (T_3 - T_2) = 0.718(1221 - 932) = 207.5 kJ / kg \quad (32)$$

$$Q_{34} = c_p (T_4 - T_3) = 1.005(2442 - 1221) = 1227 kJ / kg \quad (33)$$

$$Q_B = Q_{23} + Q_{34} = 207.5 + 1227 = 1434.5 kJ / kg \quad (34)$$

Cycle heat release:

$$Q_2 = c_v (T_5 - T_1) = 0.718(1038 - 300) = 530 kJ / kg \quad (35)$$

Cycle thermal efficiency:

$$\eta_t = \frac{w_{net}}{Q_B} = \frac{Q_B - Q_2}{Q_B} = \frac{1434.5 - 530}{1434.5} = \frac{904.5}{1434.5} = 63.05\% \quad (36)$$

Cycle average efficient pressure: through formula (10),

$$p_t = 20.6 \text{ bar} \quad (37)$$

$$p_5 = 6.4 \text{ bar} \quad (39)$$

Entropy Increase during Heat Absorption Process:

Irreversible constant volume process 5-1,

$$\frac{p_5}{T_5} = \frac{p_a}{T_a} \quad (38)$$

$$\Delta s_{24} = c_p \ln \frac{T_4}{T_2} - R_g \ln \frac{p_4}{p_2} = 1.005 \ln \left(\frac{2442}{932} \right) - 0.287 \ln \left(\frac{128}{97.7} \right) = 0.891 \text{ kJ} / (\text{kg} \cdot \text{K}) \quad (40)$$

Heat Energy in Heat Absorption Capacity:

$$a_{n,Q} = T_0 \Delta s_{24} = 270 \times 0.891 = 240.6 \text{ kJ} / \text{kg} \quad (41)$$

Condition II:

$$p_{3'} = p_{4'} = 140 \text{ bar} \quad (46)$$

Heat Exergy in Heat Absorption Capacity:

$$e_{x,Q} = Q_B - a_{n,Q} = 1434.5 - 240.6 = 1194 \text{ kJ} / \text{kg} \quad (42)$$

Average Temperature of Heat Absorption:

$$T_{lm} = \frac{Q_B}{\Delta s_{24}} = \frac{1434.5}{0.891} = 1610 \text{ K} \quad (43)$$

Exergy Efficiency:

$$\eta_e = \frac{w_{net}}{e_{x,Q}} = \frac{904.5}{1194} = 75.75\% \quad (44)$$

Exergy Loss:

$$i = T_0 s_g = Q_2 - a_{n,Q} = 530 - 240.6 = 289.4 \text{ kJ} / \text{kg} \quad (45)$$

The 1, 2, 5 points ideal air states are as the same as the results of condition I: The change of rail pressure in theoretical research content or experimental research content only involves and affects the heating process in the cylinder thermodynamic cycle, and doesn't involve any change in the exhaust system [8, 9], below are the same.

4'-5 constant entropy process,

$$p_{4'} v_{4'}^{\kappa} = p_5 v_5^{\kappa} \quad (47)$$

$$v_{4'} = \sqrt[\kappa]{\frac{p_5}{p_{4'}}} v_5 = 0.0513 \text{ m}^3 / \text{kg} \quad (48)$$

$$v_{3'} = v_2 = \frac{v_a}{\varepsilon_c} = 0.0274 \text{ m}^3 / \text{kg} \quad (49)$$

$$v_{3'} = v_2 = \frac{v_a}{\varepsilon_c} = 0.0274 \text{ m}^3 / \text{kg} \quad (50)$$

2-3' constant volume process,

$$\frac{p_{3'}}{T_{3'}} = \frac{p_2}{T_2} \quad (51)$$

$$T_{3'} = 1335.5 \text{ K} \quad (52)$$

3'-4' constant pressure process,

$$T_{4'} = \rho \times T_{3'} = 2497 \text{ K} \quad (53)$$

Thus,

$$Q_B'_{23'} = c_v (T_{3'} - T_2) = 0.718(1335.5 - 932) = 290 \text{ kJ} / \text{kg} \quad (54)$$

$$Q_B'_{3'4'} = c_p (T_{4'} - T_{3'}) = 1.005(2497 - 1335.5) = 1167 \text{ kJ} / \text{kg} \quad (55)$$

$$Q_B' = Q_B'_{23'} + Q_B'_{3'4'} = 290 + 1167 = 1457 \text{ kJ} / \text{kg} \quad (56)$$

Cycle thermal efficiency:

$$\eta_t' = \frac{w_{net}'}{Q_B'} = \frac{Q_B' - Q_2}{Q_B'} = \frac{1457 - 530}{1457} = \frac{927}{1457} = 63.62\% \quad (57)$$

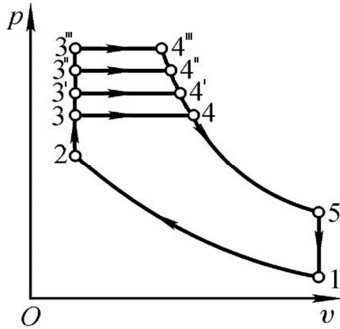


Figure 1. Sabah Cycles p-v chart.

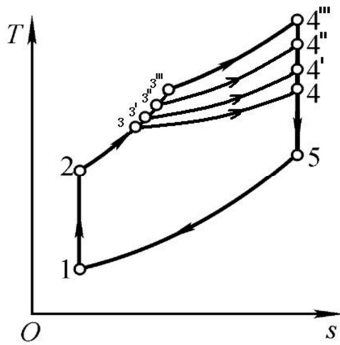


Figure 2. Sabah Cycles T-s chart.

Cycle average efficient pressure: through formula (10),

$$p_t' = 21.1 \text{ bar} \quad (58)$$

Entropy Increase during Heat Absorption Process:

$$\Delta s_{24'} = c_p \ln \frac{T_{4'}}{T_2} - R_g \ln \frac{p_{4'}}{p_2} = 1.005 \ln \left(\frac{2497}{932} \right) - 0.287 \ln \left(\frac{140}{97.7} \right) = 0.887 \text{ kJ} / (\text{kg} \cdot \text{K}) \quad (59)$$

Heat Anergy in Heat Absorption Capacity:

$$a_{n,Q}' = T_0 \Delta s_{24'} = 270 \times 0.887 = 239.5 \text{ kJ} / \text{kg} \quad (60)$$

$$p_{4''} v_{4''}^\kappa = p_5 v_5^\kappa \quad (66)$$

Heat Exergy in Heat Absorption Capacity:

$$e_{x,Q}' = Q_B' - a_{n,Q}' = 1457 - 239.5 = 1218 \text{ kJ} / \text{kg} \quad (61)$$

$$v_{4''} = \sqrt[\kappa]{\frac{p_5}{p_{4''}}} v_5 = 0.0467 \text{ m}^3 / \text{kg} \quad (67)$$

Average Temperature of Heat Absorption:

$$T_{1m}' = \frac{Q_B'}{\Delta s_{24'}} = \frac{1457}{0.887} = 1643 \text{ K} \quad (62)$$

$$v_{3''} = v_2 = \frac{v_a}{\varepsilon_c} = 0.0274 \text{ m}^3 / \text{kg} \quad (68)$$

$$\rho'' = \frac{v_{4''}}{v_{3''}} = 1.70 \quad (69)$$

Exergy Efficiency:

2-3'' constant volume process,

$$\eta_{e_x}' = \frac{w_{net}'}{e_{x,Q}'} = \frac{927}{1218} = 76.11\% \quad (63)$$

$$\frac{p_{3''}}{T_{3''}} = \frac{p_2}{T_2} \quad (70)$$

Exergy Loss:

$$T_{3''} = 1526 \text{ K} \quad (71)$$

$$i' = T_0 s_g' = Q_2 - a_{n,Q}' = 530 - 239.5 = 290.5 \text{ kJ} / \text{kg} \quad (64)$$

3''-4'' constant pressure process,

Condition III:

$$T_{4''} = \rho'' \times T_{3''} = 2594 \text{ K} \quad (72)$$

$$p_{3''} = p_{4''} = 160 \text{ bar} \quad (65)$$

Thus,

The 1, 2, 5 points ideal air states are as the same as the results of condition I,

$$Q_B''_{23} = c_v (T_{3''} - T_2) = 0.718(1526 - 932) = 426 \text{ kJ} / \text{kg} \quad (73)$$

4''-5 constant entropy process,

$$Q_B''_{34} = c_p (T_{4''} - T_{3''}) = 1.005(2594 - 1526) = 1073 \text{ kJ} / \text{kg} \quad (74)$$

$$Q_B'' = Q_B''_{23} + Q_B''_{34} = 426 + 1073 = 1499 \text{ kJ} / \text{kg} \quad (75)$$

Cycle thermal efficiency:

$$\eta_t'' = \frac{w_{net}''}{Q_B''} = \frac{Q_B'' - Q_2}{Q_B''} = \frac{1499 - 530}{1499} = \frac{969}{1499} = 64.64\% \quad (76)$$

Cycle average efficient pressure: through formula (10),

$$p_t'' = 22.1 \text{ bar} \quad (77)$$

Entropy Increase during Heat Absorption Process:

$$\Delta s_{24''} = c_p \ln \frac{T_{4''}}{T_2} - R_g \ln \frac{p_{4''}}{p_2} = 1.005 \ln \left(\frac{2594}{932} \right) - 0.287 \ln \left(\frac{160}{97.7} \right) = 0.887 \text{ kJ} / (\text{kg} \cdot \text{K}) \quad (78)$$

Heat Anergy in Heat Absorption Capacity:

$$a_{n,Q}'' = T_0 \Delta s_{24''} = 270 \times 0.887 = 239.5 \text{ kJ} / \text{kg} \quad (79)$$

Heat Exergy in Heat Absorption Capacity:

$$e_{x,Q}'' = Q_B'' - a_{n,Q}'' = 1499 - 239.5 = 1260 \text{ kJ} / \text{kg} \quad (80)$$

Average Temperature of Heat Absorption:

$$T_{1m}'' = \frac{Q_B''}{\Delta s_{24}''} = \frac{1499}{0.887} = 1690K \quad (81)$$

Exergy Efficiency:

$$\eta_{e_x}'' = \frac{w_{net}''}{e_{x,Q}''} = \frac{969}{1260} = 76.90\% \quad (82)$$

Exergy Loss:

$$i'' = T_0 s_g'' = Q_2 - a_{n,Q}'' = 530 - 239.5 = 290.5 kJ/kg \quad (83)$$

Condition IV:

$$p_{3'''} = p_{4'''} = 170bar \quad (84)$$

The 1, 2, 5 points ideal air states are as the same as the results of condition I,

4'''-5 constant entropy process,

$$p_{4'''} v_{4'''}^{\kappa} = p_5 v_5^{\kappa} \quad (85)$$

2-3''' constant volume process,

$$\frac{p_{3'''}}{T_{3'''}} = \frac{p_2}{T_2} \quad (89)$$

$$T_{3'''} = 1622K \quad (90)$$

3'''-4''' constant pressure process,

$$T_{4'''} = \rho''' \times T_{3'''} = 2644K \quad (91)$$

Thus,

$$Q_B'''_{23} = c_V (T_{3'''} - T_2) = 0.718(1622 - 932) = 495 kJ/kg \quad (92)$$

$$Q_B'''_{34} = c_p (T_{4'''} - T_{3'''}) = 1.005(2644 - 1622) = 1027 kJ/kg \quad (93)$$

$$Q_B''' = Q_B'''_{23} + Q_B'''_{34} = 495 + 1027 = 1522 kJ/kg \quad (94)$$

Cycle thermal efficiency:

$$\eta_t''' = \frac{w_{net}'''}{Q_B'''} = \frac{Q_B''' - Q_2}{Q_B'''} = \frac{1522 - 530}{1522} = \frac{992}{1522} = 65.18\% \quad (95)$$

Cycle average efficient pressure: through formula (10),

$$p_t''' = 22.6bar \quad (96)$$

Entropy Increase during Heat Absorption Process:

$$\Delta s_{24}''' = c_p \ln \frac{T_{4'''}}{T_2} - R_g \ln \frac{p_{4'''}}{p_2} = 1.005 \ln \left(\frac{2644}{932} \right) - 0.287 \ln \left(\frac{170}{97.7} \right) = 0.889 kJ/(kg \cdot K) \quad (97)$$

Heat Anergy in Heat Absorption Capacity:

$$a_{n,Q}''' = T_0 \Delta s_{24}''' = 270 \times 0.889 = 240.0 kJ/kg \quad (98)$$

Heat Exergy in Heat Absorption Capacity:

$$e_{x,Q}''' = Q_B''' - a_{n,Q}''' = 1522 - 240.0 = 1282 kJ/kg \quad (99)$$

Average Temperature of Heat Absorption:

$$T_{1m}''' = \frac{Q_B'''}{\Delta s_{24}'''} = \frac{1522}{0.889} = 1712K \quad (100)$$

Exergy Efficiency:

$$v_{4'''} = \sqrt{\kappa \frac{p_5}{p_{4'''}}} v_5 = 0.0447 m^3/kg \quad (86)$$

$$v_{3'''} = v_2 = \frac{v_a}{\varepsilon_c} = 0.0274 m^3/kg \quad (87)$$

$$\rho''' = \frac{v_{4'''}}{v_{3'''}} = 1.63 \quad (88)$$

2-3''' constant volume process,

$$\frac{p_{3'''}}{T_{3'''}} = \frac{p_2}{T_2} \quad (89)$$

$$T_{3'''} = 1622K \quad (90)$$

3'''-4''' constant pressure process,

$$T_{4'''} = \rho''' \times T_{3'''} = 2644K \quad (91)$$

Thus,

$$Q_B'''_{23} = c_V (T_{3'''} - T_2) = 0.718(1622 - 932) = 495 kJ/kg \quad (92)$$

$$Q_B'''_{34} = c_p (T_{4'''} - T_{3'''}) = 1.005(2644 - 1622) = 1027 kJ/kg \quad (93)$$

$$Q_B''' = Q_B'''_{23} + Q_B'''_{34} = 495 + 1027 = 1522 kJ/kg \quad (94)$$

Cycle thermal efficiency:

$$\eta_t''' = \frac{w_{net}'''}{Q_B'''} = \frac{Q_B''' - Q_2}{Q_B'''} = \frac{1522 - 530}{1522} = \frac{992}{1522} = 65.18\% \quad (95)$$

Cycle average efficient pressure: through formula (10),

$$p_t''' = 22.6bar \quad (96)$$

Entropy Increase during Heat Absorption Process:

$$\Delta s_{24}''' = c_p \ln \frac{T_{4'''}}{T_2} - R_g \ln \frac{p_{4'''}}{p_2} = 1.005 \ln \left(\frac{2644}{932} \right) - 0.287 \ln \left(\frac{170}{97.7} \right) = 0.889 kJ/(kg \cdot K) \quad (97)$$

Heat Anergy in Heat Absorption Capacity:

$$a_{n,Q}''' = T_0 \Delta s_{24}''' = 270 \times 0.889 = 240.0 kJ/kg \quad (98)$$

Heat Exergy in Heat Absorption Capacity:

$$e_{x,Q}''' = Q_B''' - a_{n,Q}''' = 1522 - 240.0 = 1282 kJ/kg \quad (99)$$

Average Temperature of Heat Absorption:

$$T_{1m}''' = \frac{Q_B'''}{\Delta s_{24}'''} = \frac{1522}{0.889} = 1712K \quad (100)$$

Exergy Efficiency:

Exergy Loss:

$$i''' = T_0 s_g''' = Q_2 - a_{n,Q}''' = 530 - 240.0 = 290.0 kJ/kg \quad (102)$$

Table 4 is the contrast results among the 4 different rail pressure, the this table, it'll be able to discover that: with the rail pressure raise up, the cycle heat absorption Q_B , cycle thermal efficiency η_t , exergy efficiency η_{e_x} , cycle average efficient pressure p_t are increased, however, the constant pressure pre-expansion ratio ρ declined.

Table 4. Results Comparison among 4 rail pressures.

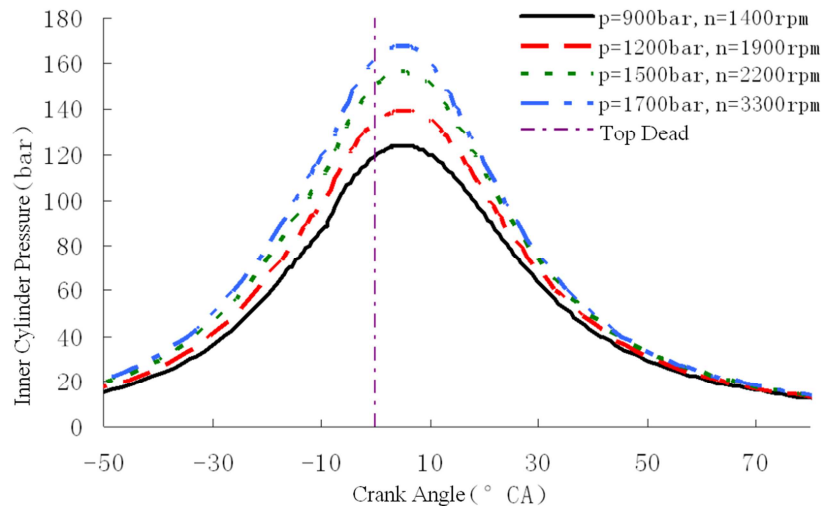
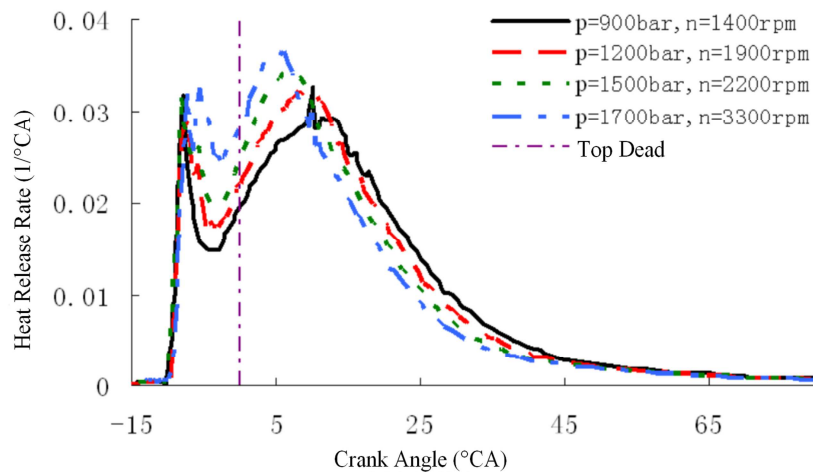
	I	II	III	IV
Q_B (kJ/kg)	1434.5	1457	1499	1522
ρ	2	1.87	1.70	1.63
η_t (%)	63.05	63.62	64.64	65.18
η_{e_x} (%)	75.75	76.11	76.90	77.38
P_t (bar)	20.6	21.1	22.1	22.6

Table 5 is exergy analysis results of the Sabah cycles in different common rail pressures: with the rail pressure grows, the heat exergy in heat absorption, the average temperature of heat absorption and the exergy efficiency increase, however the exergy loss keeps in a stable range basically.

Table 5. Exergy Analysis Results of the Sabah Cycles in Different Rail Conditions.

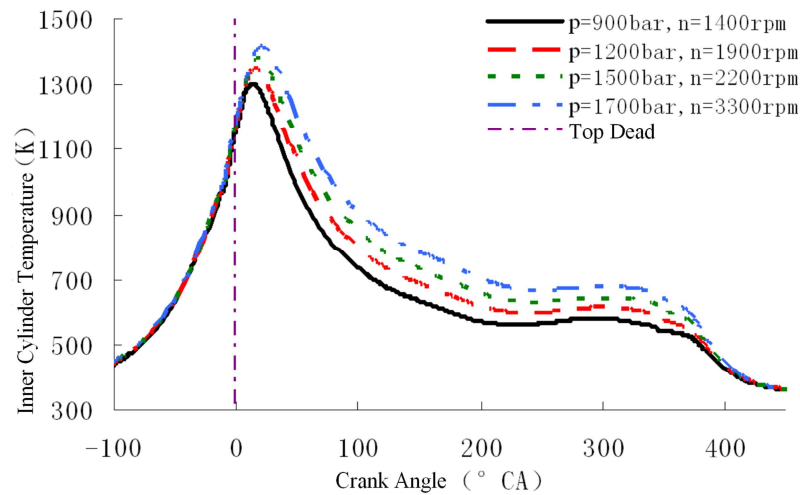
Condition	$e_{x,Q}$ (kJ/kg)	T_{1m} (K)	η_{e_x} (%)	i (kJ/kg)
I	1194	1610	75.75	289.4
II	1218	1643	76.11	290.5
III	1260	1690	76.90	290.5
IV	1282	1712	77.38	290.0

Figure 3 is the effect of rail pressure on inner cylinder

**Figure 3.** Effect of Rail Pressure on Inner cylinder Pressure.

pressure. It could be analyzed that the combustion pressure, temperature, and cycle thermal efficiency of the four different target rail pressures increase with the rail pressure, the maximum explosion pressure and the combustion temperature in the cylinder increase, and the heat release rate increases at the initial stage of combustion and the peak heat release rate increases, as it shown in figure 4, the later heat release rate decreases, and the combustion time decreases.

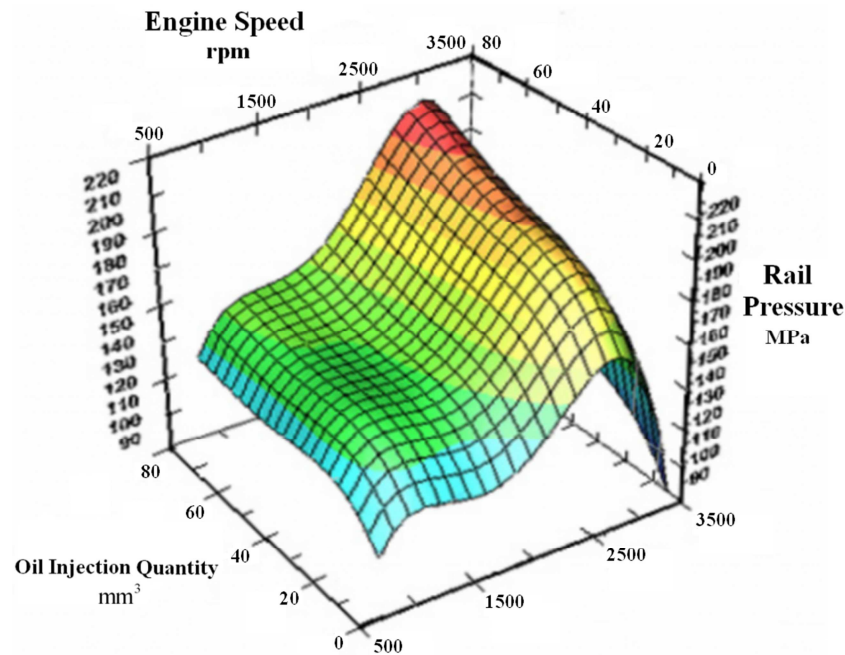
This is mainly due to the rise of the rail pressure of the common rail, which increases the oil supply pressure of the oil supply pump and prolongs the oil supply time, resulting in an actual rail pressure [10]. When the pressure rises, the injection pressure and the injection rate increase, the injection rate and the injection pressure increase, and the injection duration of the fuel is shortened. At the same time, the formation process and the combustion process of the higher quality combustible mixture are shortened. Diffusion combustion period, these make the diesel engine cylinder combustion more similar to the constant volume combustion, enhances the diesel engine's cycle thermal efficiency, the kinetic energy of the flow in the cylinder is increased, the kinetic energy increase can improve the oil and gas mixture, thereby increasing the combustion pressure and temperature in the cylinder, as it shown in figure 5.

Figure 4. Effect of Rail Pressure on Heat Release Rate.**Figure 5.** Effect of Rail Pressure on Inner Cylinder Temperature.

3. Rail Pressure Optimization Design

The horizontal coordinate of the rail pressure MAP is the diesel engine speed, the vertical coordinate is the fuel injection volume [1, 2]. Figure 6 shows the orbital pressure MAP. It could be seen from figure 6 that the maximum rail pressure reaches about 200MPa. Through the above research,

promote common rail pressure makes the diesel engine cylinder maximum combustion pressure, maximum combustion temperature were significantly increased, so the high pressure common rail to improve diesel engine fuel consumption and exhaust smoke, improve engine thermal efficiency is valid [6-7].

**Figure 6.** Rail Pressure MAP.

Through the experiment, rail pressure in common rail pressure MAP in 500-1500r/min speed significantly lower than the other speed of rail pressure, that's because at this time in order to guarantee the torque at low speed, fuel injection quantity set more, therefore, the combustion temperature is higher, is not conducive to reduce emissions, to reduce rail pressure control of combustion temperature and

maximum pressure in cylinder.

Table 6 is the optimized fuel economic results, through the economic index of this table, it could be found that, the external fuel consumption rate under the maximum torque speed, rated power speed, and maximum power speed are all lower than the requirements of the design target value to meet the design requirements [10].

The above content selects the appropriate optimization algorithm and constraints, the fuel consumption is optimized target and the rail pressure MAP is optimized. The optimized fuel consumption rate meets the design requirements. Among

them, the fuel consumption rate of the external characteristic maximum torque rotation speed, rated power rotation speed, and maximum power rotation speed is relative to the required margin of the design index: -1.90%, -5.05%, and -7.93%.

Table 6. Optimized external fuel economy results.

Speed Fuel Consumption	Unit	Research Result	Design Requirement	Margin (%)
Maximum torque speed	$g/(kW \cdot h)$	181.48	≤ 185	-1.90
Rated power speed	$g/(kW \cdot h)$	175.65	≤ 185	-5.05
Maximum power speed	$g/(kW \cdot h)$	170.32	≤ 185	-7.93

4. Conclusions

This article established the basic formulas of the thermal process in the cylinder; compared with the data of cyclic heat absorption, cyclic heat efficiency, exergy efficiency, mean effective pressure, etc. of the Sabah cycle under the four different rail pressures of the common rail system, the research results show that: The rail pressure increases, the circulating heat absorption, the cycle thermal efficiency, the exergy efficiency, and the average effective pressure, etc., have increased.

For the constant pressure pre-expansion ratio, the Sabah cycle increases with the rail pressure and the constant pressure pre-expansion ratio Reduce; Introduce combustion in common cylinder system of diesel engine. With the increase of rail pressure, the heat and heat of the sabah cycle is increased with the average heat absorption temperature and exergy efficiency; Optimized the common rail oil pressure MAP, and obtained the economic optimization results to meet the design requirements.

Thus, it could be seen that the economic and energy efficiency of the thermodynamic cycle of automobile engine can be improved by adopting the necessary technical means, and the design requirements are constantly met.

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