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ANALYSIS ON THE EXERGY OF AUTOMOBILE ENGINE INNER CYLINDER THERMODYNAMIC CYCLE

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ABSTRACT

Automobile engine inner Cylinder Thermal Cycle is fiercely connected with the second thermal theory, and obviously there is direction feature while the energy is exchanging with each other, for instance, mechanical energy is able to exchange into thermal energy entirely, and the theoretical efficiency is approaching 100 percent. This sort of infinity exchangeable energy is called ‘exergy’, machinery energy is exergy entirely. For these reasons, in habit, ‘valid work’ is as same as ‘infinity exchangeable energy’. However, reversely exchange from thermal to mechanical energy isn’t entire yet, the exchange ability is limited by the second thermal theory. Therefore, from the technical and economical views, the quality of first one is higher, and more valuable. This thesis is mainly on the contrasts of several cycles’ exergy.

KEYWORDS: Exergy, Otto Cycle, Diesel Cycle, Sabah Cycle.

INTRODUCTION

Exergy can be divided into heat and cold exergy. This article mainly discusses on heat exergy: in the T_0 environment temperature situation, the maximum efficient work value from which transfered provided by the heat of the system($T > T_0$) calls heat exergy, $E_{x,Q}$ expressed as .

The extraction of the exergy parameter, to evaluate the energy of ‘quantity’ and ‘mass’ provides a unified scale.The thermodynamic system exergy equilibrium analysis is established, The exergy equilibrium method provides the thermodynamic basis for the economic analysis of the thermal system and provides reference for the economic indicators of the thermodynamic cycle in the automobile engine cylinder.

Basic Formulas of Exergy Parameter

(1) Exergy and Exergy Efficiency

$$\eta_{e_x} = \frac{w_{net}}{e_{x,Q}} \qquad Q_B \qquad e_{x,Q} = Q_B - a_{n,Q} = (1 - \frac{T_0}{T_{1m}})Q_B = Q_B - T_0 \Delta s_1$$

Heat Exergy in Heat Absorption Capacity : (1-1)

Average Temperature of Heat Absorption: $T_{1m} = \frac{Q_B}{\Delta s_1}$ (1-2)

Exergy Efficiency: (1-3)

Among: $e_{x,Q}$ - Heat Exergy, *kJ/kg* ; $a_{n,Q}$ - Heat Anergy, *kJ/kg* ; T_{1m} - 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* ;

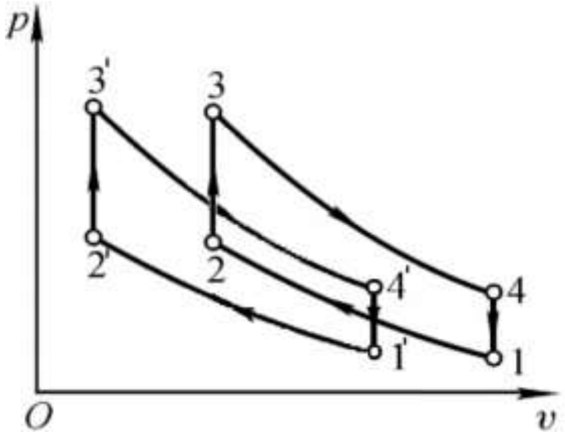
(2) Exergy Loss:

$$i = T_0 s_g = T_0(\Delta s_2 + \Delta s_0) = T_0(-\Delta s_1 + \frac{Q_2}{T_0}) = Q_2 - a_{n,Q} = Q_2 - T_0 \Delta s_1 \qquad (2\text{-}1)$$

Among: *i*-Exergy Loss, *kJ/kg* ; s_g -Entropy Generation, *kJ/(kg.K)* ; Δs_0 - Environment Entropy Increase during Exothermic Process, *kJ/(kg.K)* ; Q_2-Cycle Heat Release, *kJ/kg* ; Δs_2-Entropy Increase during Exothermic Process, *kJ/(kg.K)*

EXGERGY ANALYSIS OF GASOLINE OTTO CYCLE

The target of Otto cycle exergy analysis is 486 turbocharged gasoline. As shown in figure 1, 2 are Otto cycle's p-v chart and T-s chart, the numbers with '' are configured with a middle coolant, those numbers without it are not configured.Relevant data applied from [1][2].



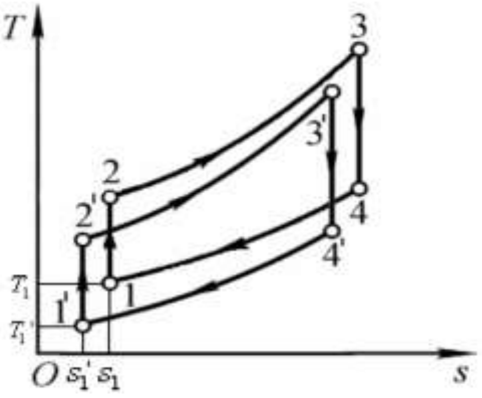


Figure 1.Otto Cycle p-v chart

Figure2.Otto Cycle T-s chart

Note:

1-1'Entropy Increase: $\Delta s_{11'} = c_p \ln \frac{T_1'}{T_1} - R_g \ln \frac{p_1'}{p_1} = 1.005 \ln\left(\frac{320}{350}\right) = -0.09 kJ/(kg\cdot K) < 0$

Therefore, the entropy increase of 1-1' is negative value, the T-s chart in figure 2 indicates that the point of state 1' is at the bottom left of state 1.

3-4 is constant entropy process, $T_4 v_4^{\kappa-1} = T_3 v_3^{\kappa-1}$

Then, $T_4 = T_3 \left(\frac{1}{\varepsilon_c}\right)^{\kappa-1}$, plug the relevant data[1][2] in the formulas, T_4 =800K, T_4'=731K;

Heat Release: $Q_2 = c_V (T_4 - T_1)$ =0.718kJ/(kg·K)×(800K-350K)=323.1kJ/kg;

$Q_2' = c_V (T_4' - T_1')$ =0.718kJ/(kg·K)×(731K-320K)=295.1kJ/kg

Efficient Exgergy(Cycle Work): $w_{net} = Q_B - Q_2 = 760.4 - 323.1 = 437.3 kJ/kg$

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Entropy Increase during Heat Absorption Process:

$$\Delta s_{23} = c_V \ln \frac{T_3}{T_2} + R_g \ln \frac{v_3}{v_2} = 0.718 \ln \frac{T_3}{T_2} = 0.718 \ln\left(\frac{1883}{824}\right) = 0.593 kJ/(kg\cdot K) = \Delta s_{2'3'}$$

Heat Anergy in Heat Absorption: $a_{n,Q} = T_0 \Delta s_{23} = 290 \times 0.593 = 172.0 kJ/kg = a_{n,Q}'$

Heat Exergy in Heat Absorption: $e_{x,Q} = Q_B - a_{n,Q} = 760.4 - 172.0 = 588 kJ/kg$

$e_{x,Q}' = Q_B' - a_{n,Q}' = 695.0 - 172.0 = 523 kJ/kg$

Average Temperature of Heat Absorption:

$$T_{1m} = \frac{Q_B}{\Delta s_{23}} = \frac{760.4}{0.593} = 1282 K, \quad T_{1m}' = \frac{Q_B'}{\Delta s_{2'3'}} = \frac{695.0}{0.593} = 1172 K$$

Exergy Efficiency:

$$\boldsymbol{\eta_{e_x} = \frac{w_{net}}{e_{x,Q}} = \frac{437.3}{588} = 74.37\% \quad \eta_{e_x}' = \frac{w_{net}'}{e_{x,Q}'} = \frac{399.9}{523} = 76.46\%}$$

The conditions above are inner reversible; however, system releases heat into the environment isn't reversible: the average temperature of heat release is higher than the environment temperature, there will be exergy loss, as below.

Exergy Loss:
$$i = T_0 s_g = Q_2 - a_{n,Q} = 323.1 - 172.0 = 151.1 kJ/kg$$
$$i' = T_0 s_g' = Q_2' - a_{n,Q}' = 295.1 - 172.0 = 123.1 kJ/kg$$

Table 1 is exergy analysis results of Otto cycle, through this table, we can find that, with the drop of intake temperature, heat exergy, average heat absorption temperature and exergy loss decline, however the exergy efficiency increases. Thus, the middle coolant configuration is more advanced with the exergy utility of gasoline engine.

Table 1. Exergy Analysis Results of Otto Cycle.

Middle Coolant	$e_{x,Q}$ (kJ/kg)	T_{1m} (K)	η_{e_x} (%)	i (kJ/kg)
Configured	588	1282	74.37	151.1
Not	523	1172	76.46	123.1

EXERGY ANALYSIS OF DIESEL SABAH CONTRAST WITH DIESEL CYCLE

The target of the exergy analysis contrast between Sabah and Diesel is Weicai National 6[3][4][5], as shown in figure 3, 4 are p-v chart and T-s chart of Diesel cycle. Relevant data applied from [1][2].

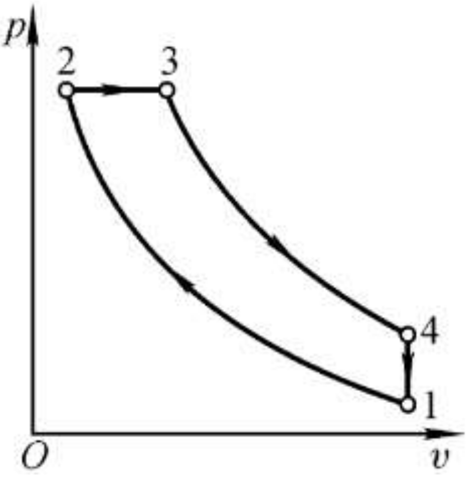


Figure3.Diesel Cycle p-v chart

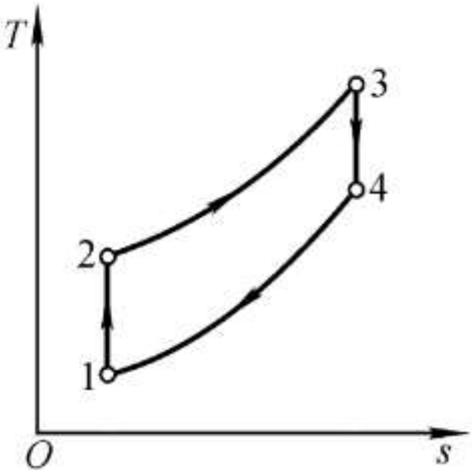


Figure4.Diesel Cycle T-s chart

Entropy Increase during Heat Absorption Process:

$$\Delta s_{23} = c_p \ln \frac{T_3}{T_2} - R_g \ln \frac{p_3}{p_2} = 1.005 \ln \rho = 1.005 \ln 2 = 0.697 kJ/(kg \cdot K)$$

Heat Anergy in Heat Absorption:
$$a_{n,Q} = T_0 \Delta s_{23} = 270 \times 0.697 = 188.2 kJ/kg$$

Heat Exergy in Heat Absorption:
$$e_{x,Q} = Q_B - a_{n,Q} = 936 - 188.2 = 748 kJ/kg$$

Average Temperature of Heat Absorption:
$$T_{1m} = \frac{Q_B}{\Delta s_{23}} = \frac{936}{0.697} = 1343K$$

Exergy Efficiency:
$$\boldsymbol{\eta_{e_x} = \frac{w_{net}}{e_{x,Q}} = \frac{583}{748} = 77.94\%}$$

Exergy Loss: $i = T_0 s_g = Q_2 - a_{n,Q} = 353 - 188.2 = 164.8 kJ/kg$

As shown in figure 5, 6 are p-v chart and T-s chart of Sabah cycle. Relevant data applied from [1][2].

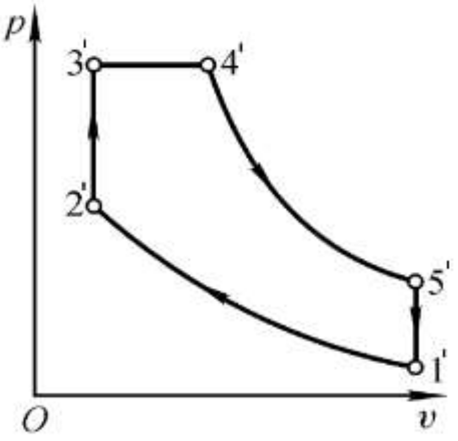


Figure5.Sabah Cycle p-v chart

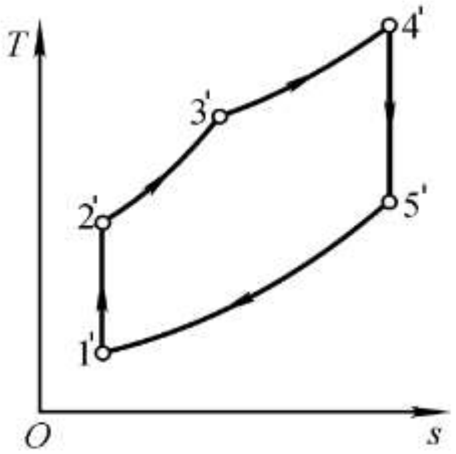


Figure6.Sabah Cycle T-s chart

Entropy Increase during Heat Absorption Process:

$$\Delta s_{2'4'}=c_p\ln\frac{T_{4'}}{T_{2'}}-R_g\ln\frac{p_{4'}}{p_{2'}}=1.005\ln\left(\frac{2057}{932}\right)-0.287\ln\left(\frac{140}{97.7}\right)=0.692kJ/(kg\,gK)$$

Heat Anergy in Heat Absorption: $a_{n,Q}'=T_0\Delta s_{2'4'}=270\times0.692=186.8kJ/kg$

Heat Exergy in Heat Absorption: $e_{x,Q}'=Q_B'-a_{n,Q}'=1015-186.8=828kJ/kg$

Average Temperature of Heat Absorption: $T_{1m}'=\frac{Q_B'}{\Delta s_{2'4'}}=\frac{1015}{0.692}=1467K$

Exergy Efficiency: $\eta_{e_x}'=\frac{w_{net}'}{e_{x,Q}'}=\frac{662}{828}=79.95\%$

Exergy Loss: $i'=T_0s_g'=Q_2'-a_{n,Q}'=353-186.8=166.2kJ/kg$

Table 2 is exergy analysis results of the contrast between Sabah and Diesel cycle,the heat exergy in heat absorption, the average temperature of heat absorption, the exergy efficiency and the exergy loss both increase. Thus, in the aspect of the exergy efficiency, Sabah cycle with common rail injection system is advanced.

Table 2. Exergy Analysis Results of the Contrast between Sabah and Diesel Cycle.

Cycle	(kJ/kg)	(K)	(%)	i (kJ/kg)
Diesel	748	1343	77.94	164.8
Sabah	828	1467	79.95	166.2

EXERGY ANALYSIS OF SABAH CYCLES IN DIFFERENT COMMON RAIL PRESSURES

The target of the exergy analysis of Sabah cycles in different rail conditions is also Weicai National 6, as shown in figure 7, 8 are p-v chart and T-s chart of Sabah cycles. Relevant data applied from [1][2].

Condition I: $p_3=p_4=128bar$

Entropy Increase during Heat Absorption Process:

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

Heat Anergy in Heat Absorption: $a_{n,Q}=T_0\Delta s_{24}=270\times0.891=240.6kJ/kg$

Heat Exergy in Heat Absorption: $e_{x,Q}=Q_B-a_{n,Q}=1434.5-240.6=1194kJ/kg$

Average Temperature of Heat Absorption: $T_{1m}=\frac{Q_B}{\Delta s_{24}}=\frac{1434.5}{0.891}=1610K$

Exergy Efficiency: $\eta_{e_x}=\frac{w_{net}}{e_{x,Q}}=\frac{904.5}{1194}=75.75\%$

Exergy Loss: $i = T_0 s_g = Q_2 - a_{n,Q} = 530 - 240.6 = 289.4 kJ/kg$

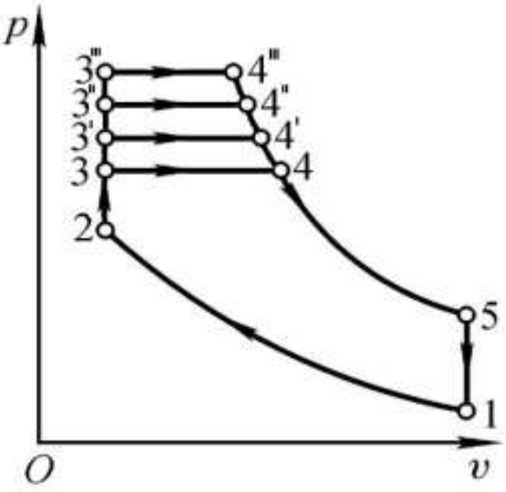


Figure7.Sabah Cycles p-v chart

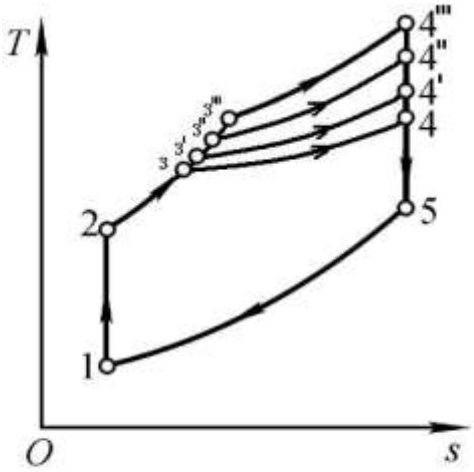


Figure8.Sabah Cycles T-s chart

Condition II: $\boldsymbol{p_{3'} = p_{4'} = 140bar}$

Entropy Increase during Heat Absorption Process:

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

Heat Anergy in Heat Absorption: $a_{n,Q}' = T_0 \Delta s_{24'} = 270 \times 0.887 = 239.5 kJ/kg$

Heat Exergy in Heat Absorption: $e_{x,Q}' = Q_B' - a_{n,Q}' = 1457 - 239.5 = 1218 kJ/kg$

Average Temperature of Heat Absorption: $T_{1m}' = \dfrac{Q_B'}{\Delta s_{24'}} = \dfrac{1457}{0.887} = 1643K$

Exergy Efficiency: $\boldsymbol{\eta_{e_x}' = \dfrac{w_{net}'}{e_{x,Q}'} = \dfrac{927}{1218} = 76.11\%}$

Exergy Loss: $i' = T_0 s_g' = Q_2 - a_{n,Q}' = 530 - 239.5 = 290.5 kJ/kg$

Condition III: $\boldsymbol{p_{3''} = p_{4''} = 160bar}$

Entropy Increase during Heat Absorption Process:

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

Heat Anergy in Heat Absorption: $a_{n,Q}'' = T_0 \Delta s_{24''} = 270 \times 0.887 = 239.5 kJ/kg$

Heat Exergy in Heat Absorption: $e_{x,Q}'' = Q_B'' - a_{n,Q}'' = 1499 - 239.5 = 1260 kJ/kg$

Average Temperature of Heat Absorption: $T_{1m}'' = \dfrac{Q_B''}{\Delta s_{24''}} = \dfrac{1499}{0.887} = 1690K$

Exergy Efficiency: $\boldsymbol{\eta_{e_x}'' = \dfrac{w_{net}''}{e_{x,Q}''} = \dfrac{969}{1260} = 76.90\%}$

Exergy Loss: $i'' = T_0 s_g'' = Q_2 - a_{n,Q}'' = 530 - 239.5 = 290.5 kJ/kg$

Condition IV: $\boldsymbol{p_{3'''} = p_{4'''} = 170bar}$

Entropy Increase during Heat Absorption Process:

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

Heat Anergy in Heat Absorption: $a_{n,Q}''' = T_0 \Delta s_{24'''} = 270 \times 0.889 = 240.0 kJ/kg$

Heat Exergy in Heat Absorption: $e_{x,Q}''' = Q_B''' - a_{n,Q}''' = 1522 - 240.0 = 1282 kJ/kg$

Average Temperature of Heat Absorption: $T_{1m}''' = \dfrac{Q_B'''}{\Delta s_{24'''}} = \dfrac{1522}{0.889} = 1712K$

Exergy Efficiency: $\boldsymbol{\eta_{e_x}''' = \dfrac{w_{net}'''}{e_{x,Q}'''} = \dfrac{992}{1282} = 77.38\%}$

Exergy Loss: $i''' = T_0 s_g''' = Q_2 - a_{n,Q}''' = 530 - 240.0 = 290.0 kJ/kg$

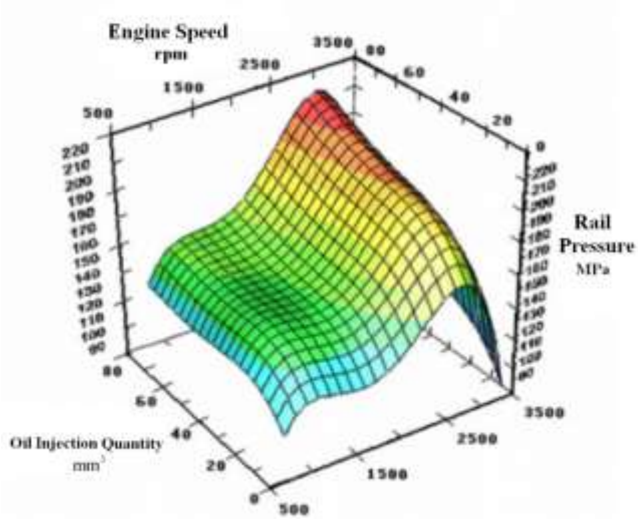
Table 3 is exergy analysis results of the Sabah cycles in different common rail pressures: with the rail pressure grows, the heat exergy in heat absorption, the average temperature of heat absorption and the exergy efficiency increase, however the exergy loss keeps in a stable range basically.

Table 3. 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

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 9 shows the orbital pressure MAP. It can be seen from figure 9 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.



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.

CONCLUSIONS

- This thesis focuses on the thermodynamic cycle of automobile engine cylinder.The parameters of exergy are analyzed and studied.
- With the decrease of inlet temperature, the heat exergy of Otto cycle, the average heat absorption temperature and the exergy loss decreased, while the exergy efficiency increased.
- The heat exergy of the diesel engine with common rail system, the average heat absorption temperature and the efficiency of exergy;
- 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 can 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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