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Comparison of performances of air standard Atkinson, Diesel and Otto cycles with constant specific heats of the working fluid

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Abstract

In this paper, the effects of input temperature and compression ratio on the net output work and efficiency of the air standard cycles, i.e. Atkinson cycle, Diesel cycle and Otto cycle are analyzed. We assume that the compression and power processes are adiabatic and reversible and any convective, conductive and radiative heat transfer to cylinder wall during the heat rejection process may be ignored. We compared efficiency of these cycles with constant maximum temperature of each cycle. The results of this comparison may provide guidance for performance evaluation and improvement of practical internal combustion engines.

Keywords: Thermodynamics; Atkinson cycle; Diesel cycle; Otto cycle; Efficiency

1. Introduction

Atkinson, Diesel and Otto cycles are three types of four-stroke engines. The Atkinson cycle was designed and built by James Atkinson in 1882, The Diesel cycle was invented by Rudolph Diesel in 1893 and The Otto cycle was developed by Nikolas August Otto in 1876 [1]. In recent years, many attentions have been paid to analyzing the performance of internal combustion cycles. Comparison of performances of air standard Atkinson and Otto cycles with heat transfer considerations by Hou [2]. Performance analyzing and parametric optimum criteria of an irreversible Atkinson heat-engine by Zhao [3] and Chen [4]. Optimization of Dual cycle considering the effect of combustion on power by Chen [5]. Effect of heat transfer on the performance of an air standard Diesel cycle by Akash [6]. Performance of an endoreversibe Atkinson cycle with variable specific heat ratio of working fluid by Ebrahimi [7]. In this paper, a comparative study for the performance of the Atkinson, Diesel and Otto cycles are investigated. Our analysis has been done on the base of a case, the constant maximum temperature of per cycle and variable input temperature.

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Nomenclature

C_p	constant pressure specific heat $(kJ/kg-K)$
C_v	constant volume specific heat $(kJ/kg-K)$
k	specific heat ratio (C_p/C_v)
q_{in}	heat added to working fluid (kJ/kg)
r	cut-off ratio
r_c	compression ratio
r_p	pressure ratio
s	entropy $(kJ/kg-K)$
T_i	temperature at state i (K)
V_i	volume at state i (m^3)
w	net work output (kJ/kg)

Greek

η	efficiency

Subscripts

1, 2, 3, 4	state points

2. Cycles models

The T-s diagrams of the Atkinson, Diesel and Otto cycles are shown in Figure 1.a., Figure 1.b. and Figure 1.c. The adiabatic compression and expansion processes are the same in the Atkinson, Diesel and Otto cycles. In the Atkinson cycle the heat added in the isochoric process $(2\rightarrow 3)$ and the heat rejected in the isobaric process $(4\rightarrow 1)$. In the Diesel cycle the heat added in the isobaric process $(2\rightarrow 3)$ and the heat rejected in the isochoric process $(4\rightarrow 1)$ and finally in the Otto cycle the heat addition and rejection process occur in the isochoric state $(2\rightarrow 3)$, $(4\rightarrow 1)$.

2.1. Thermodynamics analysis of the air standard Atkinson cycle

Following the assumption described above, process $(1\rightarrow 2)$ is an isentropic compression from bottom dead center (BDC) to top dead center (TDC). The heat addition takes place in process $(2\rightarrow 3)$, which is isochoric. The isentropic expansion process, $(3\rightarrow 4)$, is the power or expansion stroke. The cycle is completed by an isobaric heat rejection process, $(4\rightarrow 1)$. The heat added to the working fluid per unit mass is due to combustion. Assuming constant specific heats, the net work output per unit mass of the working fluid is given by the following equation:

$$w = C_v(T_3 - T_2) - C_p(T_4 - T_1), \tag{1}$$

where C_p and C_v are the constant pressure and constant volume specific heat, respectively; and T_1, T_2, T_3 and T_4 are absolute temperatures at states 1, 2, 3 and 4. For the isentropic process $(1 \rightarrow 2)$ and $(3 \rightarrow 4)$, we have

$$T_2 = T_1 r_c^{k-1}, \tag{2}$$

$$\frac{T_4}{T_3} = (\frac{V_3}{V_4})^{k-1} = (\frac{V_3}{V_1})^{k-1}(\frac{V_1}{V_4})^{k-1} = (\frac{V_2}{V_1})^{k-1}(\frac{V_1}{V_4})^{k-1} = r_c^{1-k}(\frac{V_1}{V_4})^{k-1}, \tag{3}$$

where r_c is the compression ratio (V_1/V_2) and k is the specific heat ratio (C_p/C_v). Additionally, since process $(4 \rightarrow 1)$ is isobaric, we have

$$\frac{V_1}{V_4} = \frac{T_1}{T_4}. \tag{4}$$

Substitution of Eqs. (2) and (4) into Eq. (3) yields

$$T_4 = T_1 (\frac{T_3}{T_2})^{\frac{1}{k}}. \tag{5}$$

The heat added per unit mass of the working fluid during the constant volume process $(2 \rightarrow 3)$ per cycle is represented by the following equation:

$$q_{in} = C_v (T_3 - T_2), \tag{6}$$

and finally

$$\eta = \frac{w}{q_{in}}. \tag{7}$$

2.2. Thermodynamics analysis of the air standard Diesel cycle

In the Diesel cycle, process $(1 \rightarrow 2)$ is an isentropic compression from bottom dead center (BDC) to top dead center (TDC). The heat addition takes place in process $(2 \rightarrow 3)$, which is isobaric. The isentropic expansion process, $(3 \rightarrow 4)$, is the power or expansion stroke. The cycle is completed by an isochoric heat rejection process, $(4 \rightarrow 1)$. The heat added to the working fluid per unit mass is due to combustion. Assuming constant specific heats, the net work output per unit mass of the working fluid is given by the following equation:

$$w = C_p (T_3 - T_2) - C_v (T_4 - T_1), \tag{8}$$

$$T_2 = T_1 r_c^{k-1}, \tag{9}$$

$$T_4 = T_1 (r)^k, \tag{10}$$

where r is cut-off ratio $(\frac{T_3}{T_2})$. The heat added per unit mass of the working fluid during the constant pressure process $(2 \rightarrow 3)$ per cycle is represented by the following equation:

$$q_{in} = C_p (T_3 - T_2), \tag{11}$$

and finally

$$\eta = \frac{w}{q_{in}}. \tag{12}$$

2.3. Thermodynamics analysis of the air standard Otto cycle

The air standard Otto cycle incorporates an isentropic compression ($1 \rightarrow 2$), an isochoric heat addition ($2 \rightarrow 3$), an isentropic expansion ($3 \rightarrow 4$) and an isochoric heat rejection processes ($4 \rightarrow 1$). The heat added to the working fluid per unit mass is due to combustion. Assuming constant specific heats, the net work output per unit mass of the working fluid is given by the following equation:

$$w = C_v (T_3 - T_2) - C_v (T_4 - T_1), \tag{13}$$

$$T_2 = T_1 r_c^{k-1}, \tag{14}$$

$$T_4 = T_1 (r). \tag{15}$$

The heat added per unit mass of the working fluid during the constant volume process ($2 \rightarrow 3$) per cycle is represented by the following equation:

$$q_{in} = C_v (T_3 - T_2), \tag{16}$$

and finally

$$\eta = \frac{w}{q_{in}}. \tag{17}$$

3. Figures

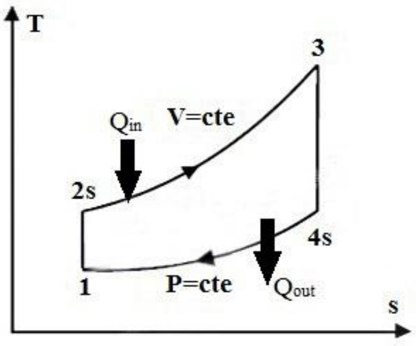

Figure 1.a. T-s diagram for Atkinson cycle.

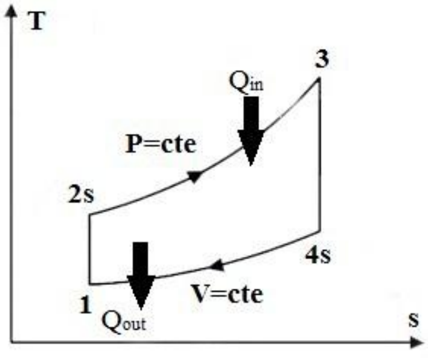

Figure 1.b. T-s diagram for Diesel cycle.

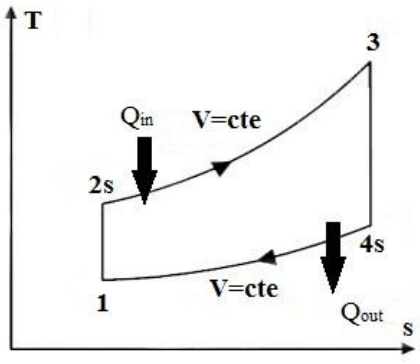

Figure 1.c. T-s diagram for Otto cycle.

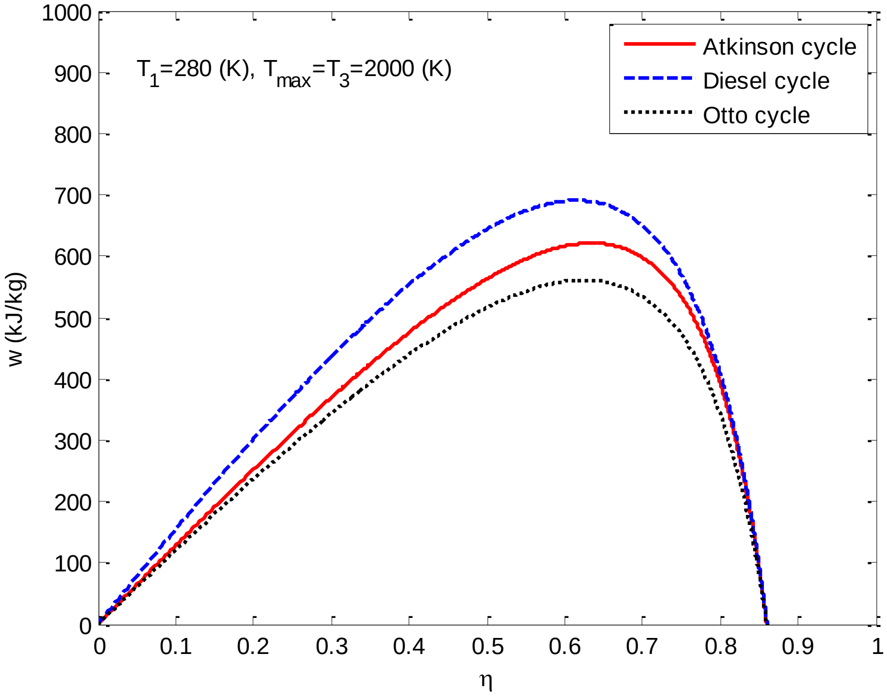

Figure 2. The comparison between the air cycles net work output versus efficiency characteristic.

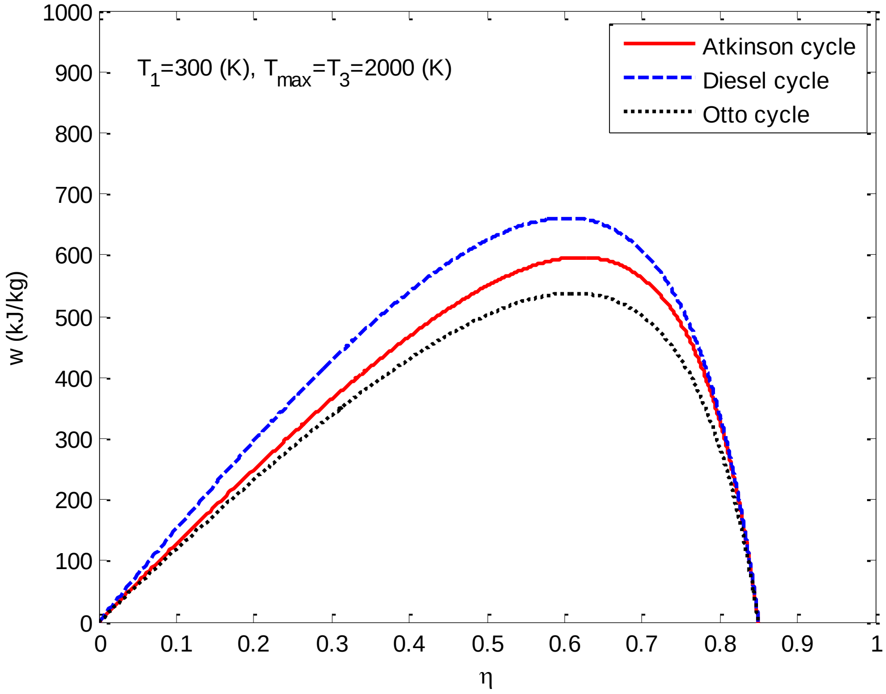

Figure 3. The comparison between the air cycles net work output versus efficiency characteristic.

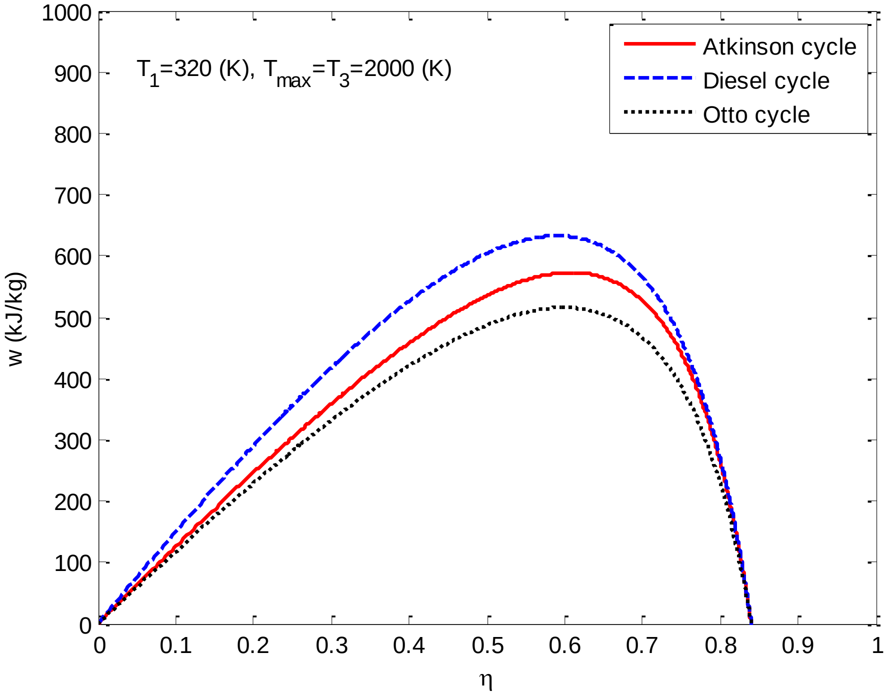

Figure 4. The comparison between the air cycles net work output versus efficiency characteristic.

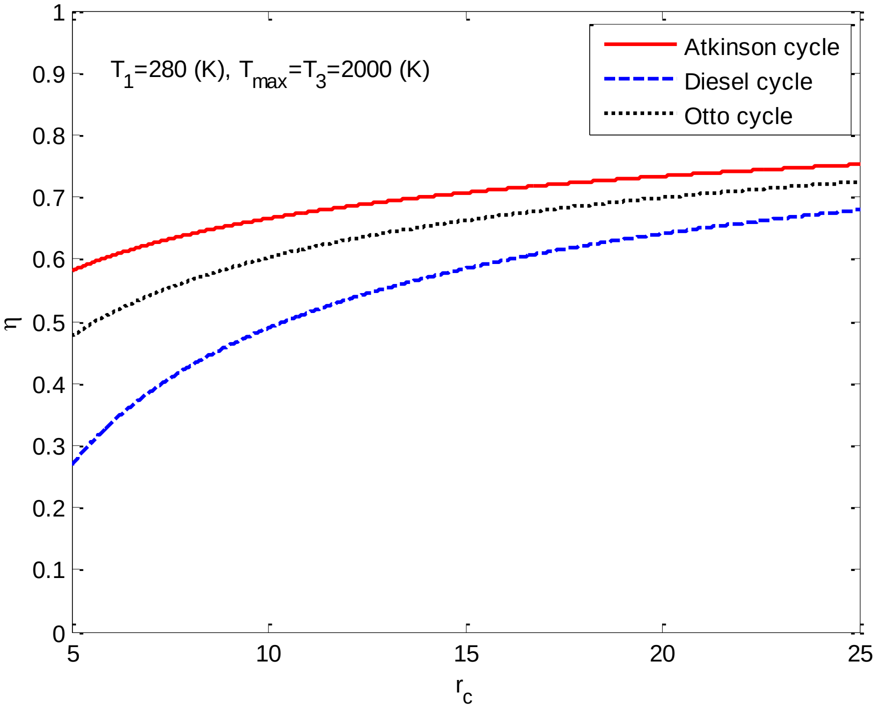

Figure 5. The comparison between the air cycles efficiency versus compression ratio.

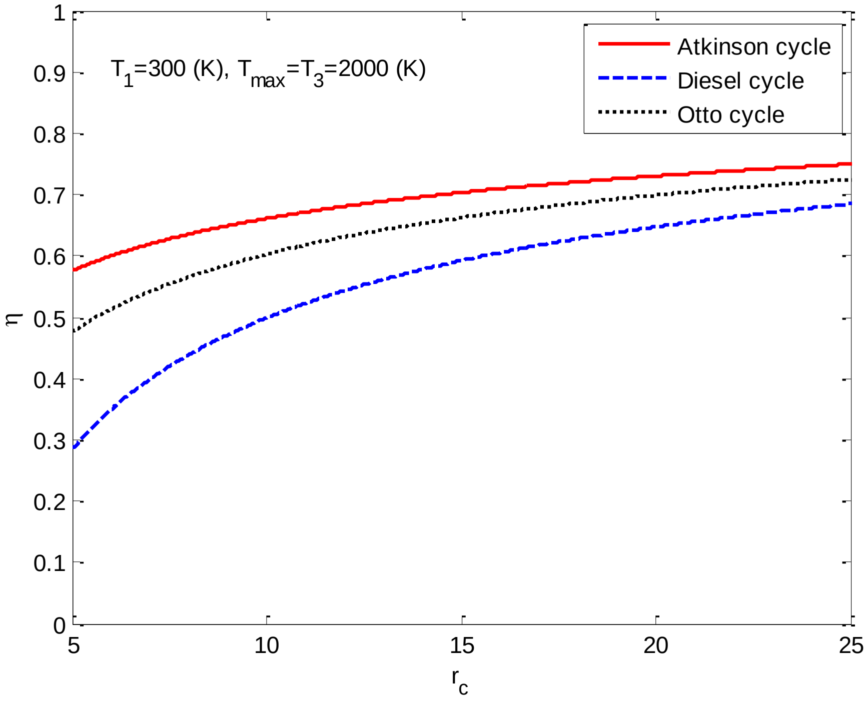

Figure 6. The comparison between the air cycles efficiency versus compression ratio.

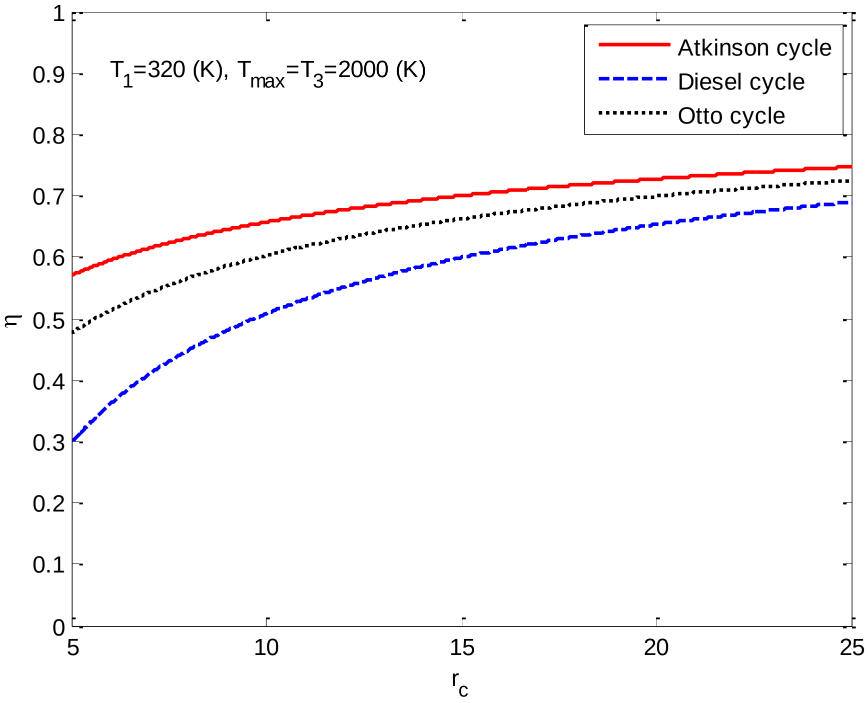

Figure 7. The comparison between the air cycles efficiency versus compression ratio.

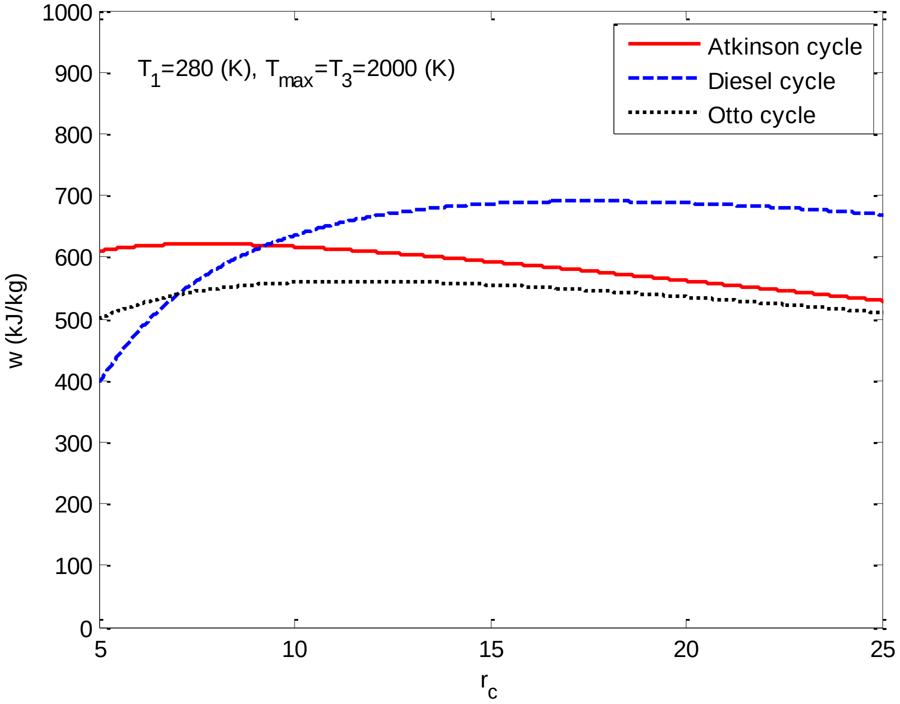

Figure 8. The comparison between the air cycles net work output versus compression ratio.

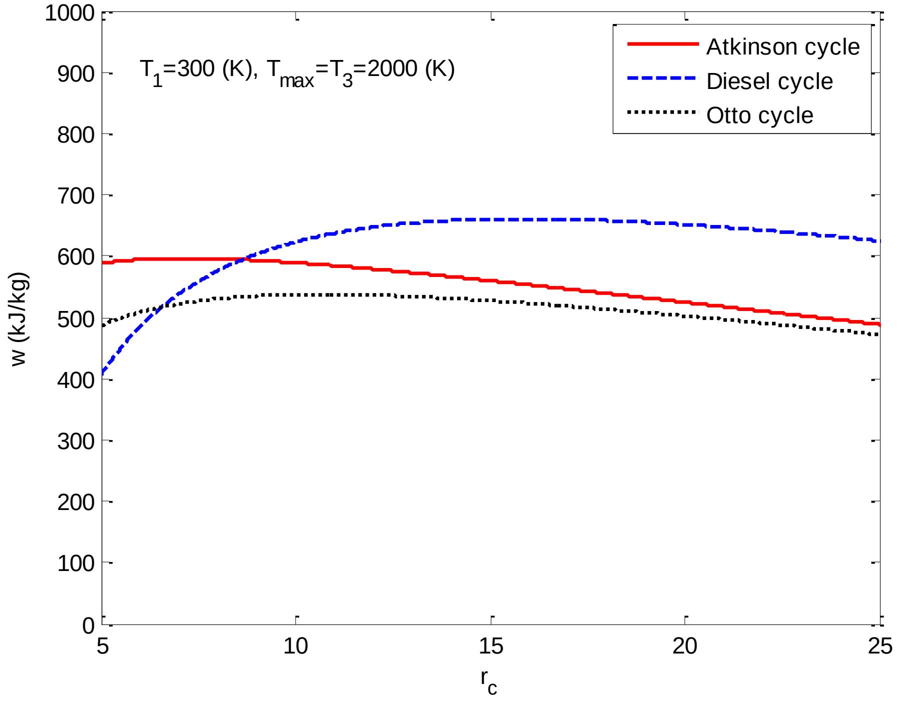

Figure 9. The comparison between the air cycles net work output versus compression ratio.

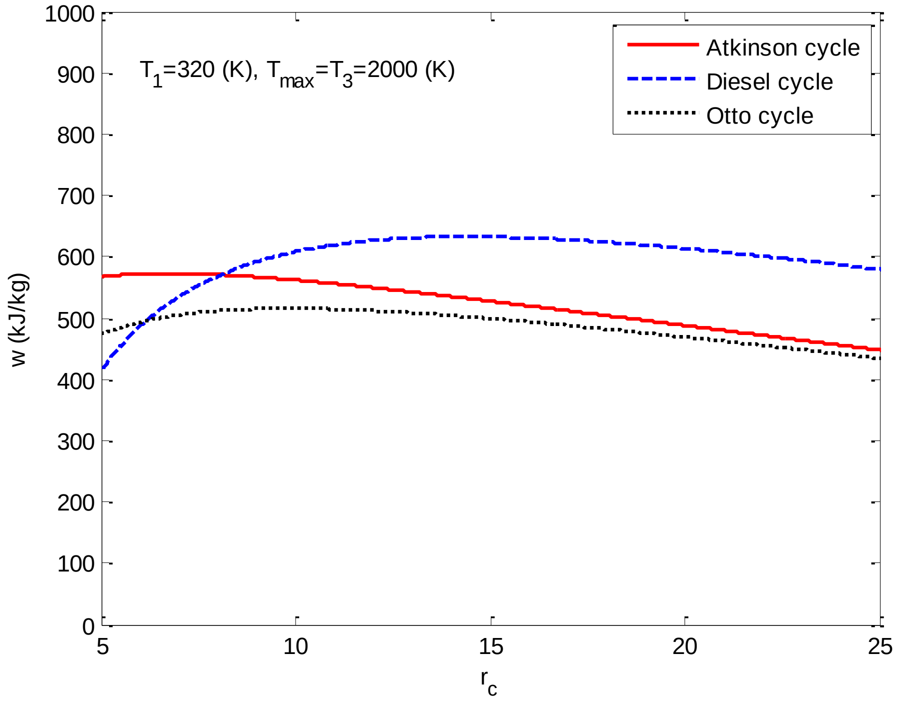

Figure 10. The comparison between the air cycles net work output versus compression ratio.

4. Results and discussion

In this paper, the following parameters are used: $T_1 = 280 - 320K$, $T_3 = 2000K$, $C_p = 1.003\ kJ/kg.K$, $C_v = 0.716\ kJ/kg.K$ and $k = C_p / C_v = 1.4$. The compression ratio (r_c) for Atkinson cycle is between $8-16$, for Diesel cycle is between $12-24$ and for Otto cycle is between $8-12$. Figs. 2-4 display the comparison between the air cycles (Atkinson, Diesel and Otto) net work output versus efficiency characteristic for the constant specific heat and constant maximum temperature (T_3) with difference input temperature (T_1). For the specific efficiency of all cycles, the net work output experience is maximum value, in which this maximum point has the greatest value for the Diesel cycle and the Otto cycle has the lowest value.

Figs. 5-7 displays the comparison between the air cycles efficiency. As the result, the maximum efficiency between the air cycles is related to the Atkinson cycle in the range of compression ratio which is studied in this article and minimum one is related to the Diesel cycle.

Figs. 8-10 displays the comparison between the air cycles net work output. The results show that for the low compression ratio, the maximum net work output is related to the Atkinson cycle and the minimum net work output is relevant to the Diesel cycle. When the compression ratio increases, the net work output of the Diesel cycle becomes more than the Otto cycle net work output. For the large value of compression ratio, the net work output of the Diesel cycle has the greatest value in compared with the other air cycles.

5. Conclusion

In this paper, we compared the performance of the air cycles (Atkinson, Diesel and Otto). The result show that, the highest efficiency is related to the Atkinson cycle, lowest efficiency is related to the Diesel cycle and the efficiency of Otto cycle is between Atkinson and Diesel cycles. We also showed the effects of input temperature variation on the performance of cycles.

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