

## **Diesel Cycle Analysis**

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## **Diesel Cycle Analysis**

**by**

**Engineering Software**

**Course Category: Engineers**

**Course Level: Intermediate**

**Credit: 1 Hour**

# Diesel Cycle Analysis

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## Course Description

The ideal cycle for a simple diesel engine is the Diesel Cycle. In this one hour course, the open, simple Diesel Cycle used for stationary power generation is considered.

The Diesel Cycle thermal efficiency is presented only for the air as the working fluid. The thermal efficiency derivation is presented with a simple mathematical approach. The Diesel Cycle is presented in the  $p - V$  and  $T - s$  diagrams and its major performance trends (thermal efficiency and power output) are plotted in a few figures as a function of compression and cut off ratio values, combustor outlet temperature and some fixed cylinder geometry. It should be noted that this online course does not deal with costs (capital, operational or maintenance).

In this course, the student gets familiar with the Diesel Cycle, its components,  $p - V$  and  $T - s$  diagrams, operation and major performance trends.

This course includes a multiple choice quiz at the end.

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### Performance Objectives

At the conclusion of this course, the student will:

- Understand basic energy conversion engineering assumptions and equations
- Know basic components of the Diesel Cycle and its p - V and T - s diagrams
- Be familiar with the Diesel Cycle operation
- Understand general Diesel Cycle performance trends

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## Introduction

Over the years, diesel engine has become the premier transportation system for intermediate and high loads. Diesel engines are compact, lightweight, easy to operate and come in sizes ranging from several kilowatts to a few megawatts. Diesel engines require relatively low capital investment, have high operating flexibility, high thermal efficiency and can be used for various transportation and industrial applications. Diesel engines can help provide reliable power to meet the future demand using both high and low heat content fuels, with low emissions.

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## Diesel Cycle Analysis

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### Diesel Cycle

This section provides a Diesel Cycle analysis when the working fluid is air.

#### *Analysis*

In the presented Diesel Cycle analysis, only air is considered as the working fluid behaving as a perfect gas -- specific heat has a constant value. Ideal gas state equation is valid --  $pv = RT$ .

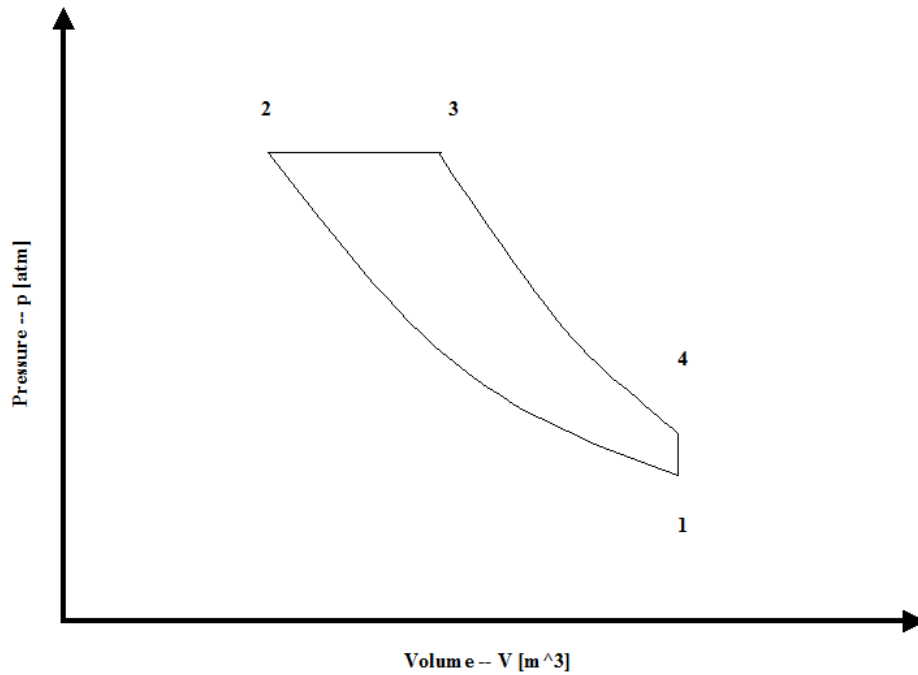
Air enters a cylinder at point 1 when compression starts and it ends at point 2. Isentropic compression is considered with no entropy change. Heat addition starts at point 2 and it ends at point 3. At a constant pressure, combustion takes place (fuel is added to the cylinder and the air temperature raises) and/or heat gets added to air. Expansion starts at point 3 and it ends at point 4. Isentropic expansion is considered with no entropy change. Air heat rejection starts at point 4 and it ends at point 1. At a constant volume, air gets cooled and the working fluid temperature goes down. It should be mentioned that air at point 1 enters the compression process again and the cycle is repeated.

Figure 1 presents a Diesel Cycle pressure vs volume diagram.

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## Diesel Cycle Analysis

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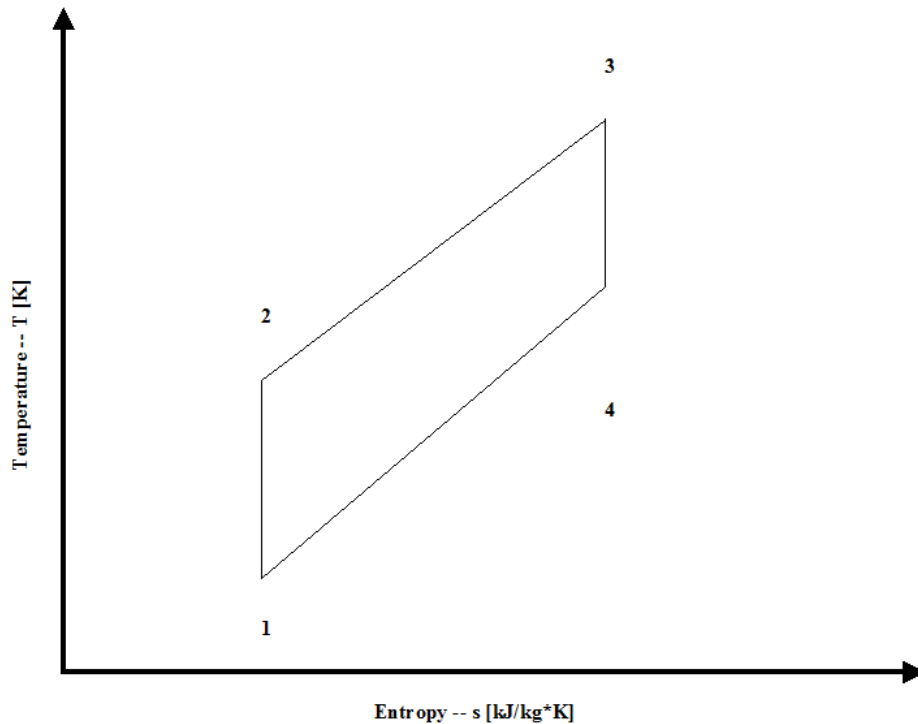
**Diesel Cycle p - V Diagram**

**Figure 1 - Diesel Cycle Pressure vs Volume Diagram**

Figure 2 presents a Diesel Cycle temperature vs entropy diagram.

## Diesel Cycle Analysis

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**Diesel Cycle T - s Diagram**

**Figure 2 - Diesel Cycle Temperature vs Entropy Diagram**

The thermal cycle efficiency can be given as a function of specific external work (specific net power output) and heat added to the working fluid as follows:

$$\eta = w/q_h = (w_e - w_c)/q_h = (q_h - q_l)/q_h$$

or

$$\eta = 1 - q_l/q_h = 1 - (c_v(T_4 - T_1))/(c_p(T_3 - T_2)) = 1 - (T_1(T_4/T_1 - 1))/(\gamma T_2(T_3/T_2 - 1))$$

where

$\eta$  - thermal efficiency [/]

$w$  - specific external work (specific net power output) [kJ/kg]

$w_e$  - expansion specific power output [kJ/kg]

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$w_c$  - compression specific power input [kJ/kg]

$W$  - external work (net power output) [kW]

$W_e$  - expansion power output [kW]

$W_c$  - compression power input [kW]

$q_h$  - heat added to the working fluid [kJ/kg]

$q_l$  - heat rejected from the working fluid [kJ/kg]

$c_p$  - specific heat at constant pressure [kJ/kg\*K]

$c_v$  - specific heat at constant volume [kJ/kg\*K]

$m$  - working fluid mass flow rate [kg/s]

$\varepsilon$  - compression ratio [/]

$\phi$  - cut off ratio [/]

For isentropic compression and expansion:

$$T_2/T_1 = (p_2/p_1)^{(\kappa-1)/\kappa} = (V_1/V_2)^{(\kappa-1)}$$

$$T_4/T_3 = (p_4/p_3)^{(\kappa-1)/\kappa} = (V_3/V_4)^{(\kappa-1)}$$

where

$\kappa = c_p/c_v$  - for air  $\kappa = 1.4$  [/]

$p_1, p_2, p_3, p_4$  - pressure values at points 1, 2, 3 and 4 [atm]

$T_1, T_2, T_3, T_4$  - temperature values at points 1, 2, 3 and 4 [K]

Knowing that

$$s_3 - s_2 = s_4 - s_1$$

and

$$s_3 - s_2 = c_p \ln(T_3/T_2)$$

$$s_4 - s_1 = c_v \ln(T_4/T_1)$$

$s_1, s_2, s_3, s_4$  - specific entropy values at points 1, 2, 3 and 4 [kJ/kg\*K]

It follows

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$$(T_3/T_2)^{\kappa} = T_4/T_1$$

It follows that

$$T_3/T_4 = T_2/T_1 = (V_1/V_2)^{(\kappa-1)} = \varepsilon^{(\kappa-1)}$$

When combustion takes place at a constant pressure:

$$T_3/T_2 = V_3/V_2$$

where

$$\varepsilon = V_1/V_2$$

$$\varphi = V_3/V_2$$

Therefore, after some mathematical operations the thermal efficiency is:

$$\eta = 1 - (T_1((T_3/T_2)^{\kappa} - 1))/(\kappa T_2(T_3/T_2 - 1))$$

If the temperature ratio is substituted in terms of the volume/compression ratio:

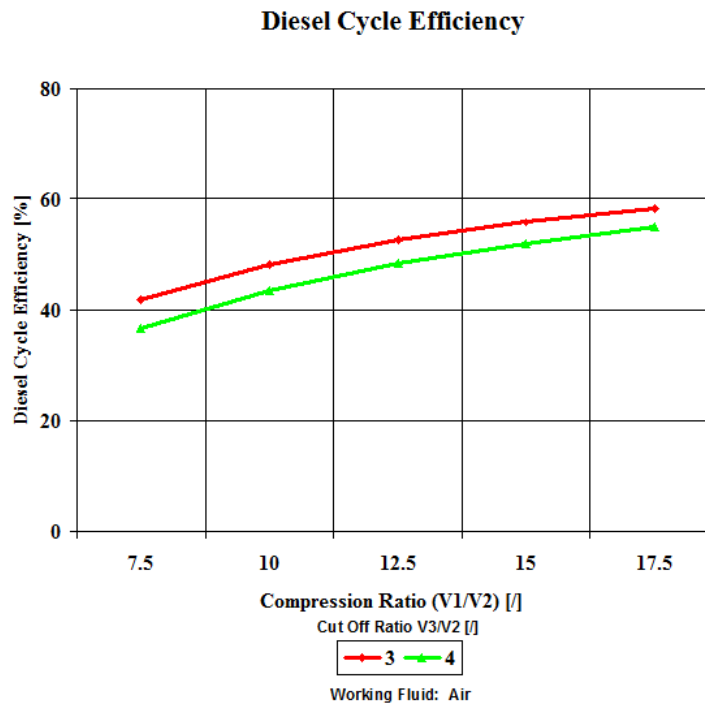
$$\eta = 1 - (\varphi^{\kappa} - 1)/(\kappa \varepsilon^{(\kappa-1)}(\varphi - 1))$$

Figure 3 presents the Diesel Cycle efficiency as a function of the compression ratio and cut off ratio values. It should be noted that the inlet conditions are standard ambient conditions: temperature of 298 [K] and absolute pressure of 1 [atm].

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## Diesel Cycle Analysis

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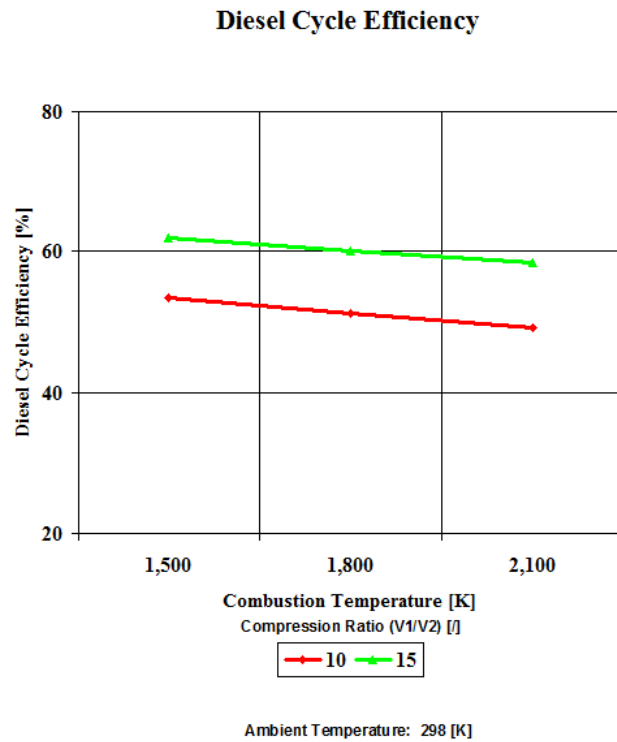


**Figure 3 - Diesel Cycle Efficiency**

Figure 4 presents the Diesel Cycle efficiency as a function of the compression ratio and combustion temperature values.

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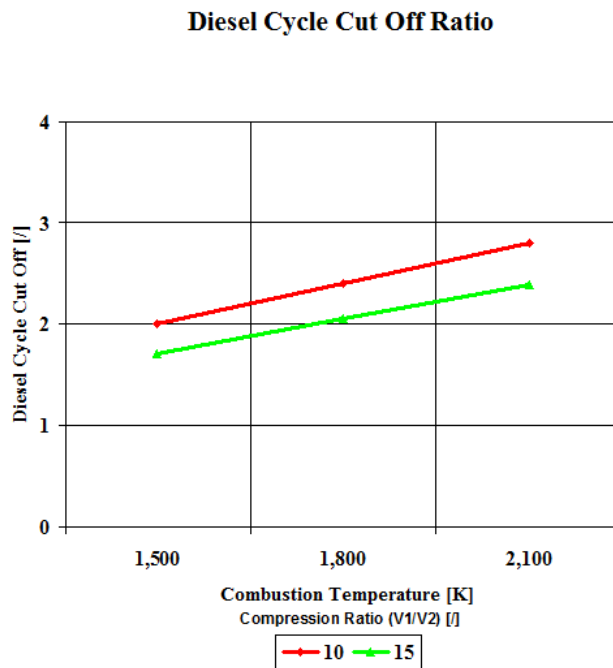
**Figure 4 - Diesel Cycle Efficiency**

Figure 5 presents the Diesel Cycle cut off ratio as a function of the combustion temperature and compression ratio values.

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## Diesel Cycle Analysis

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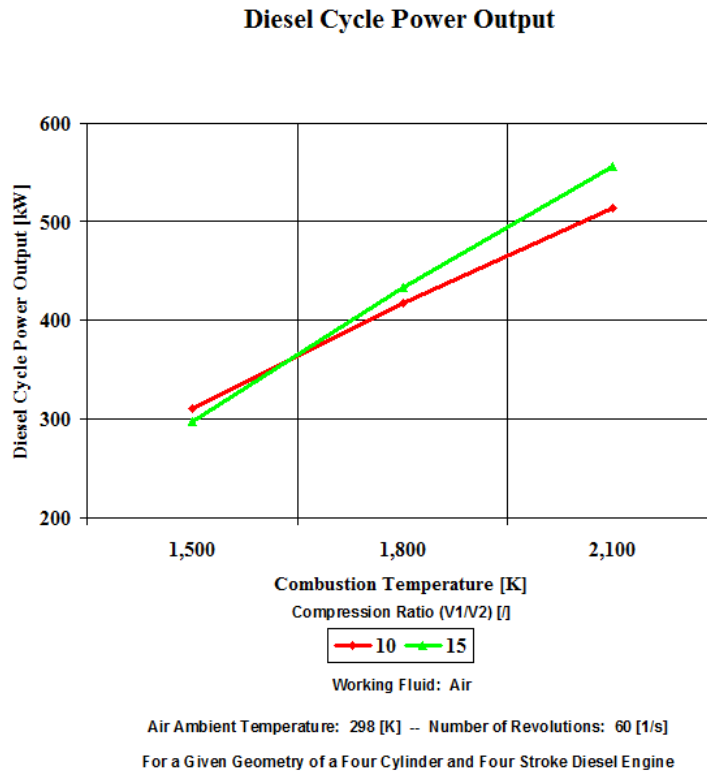
**Figure 5 - Diesel Cycle Cut Off Ratio**

Figure 6 presents the Diesel Cycle power output as a function the combustion temperature and compression ratio values. It should be noted that the number of revolutions is 60 [1/s] for a given geometry of a four cylinder and four stroke Diesel engine.

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## Diesel Cycle Analysis

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**Figure 6 - Diesel Cycle Power Output**

One can notice that the Diesel Cycle efficiency increases with an increase in the compression ratio and a decrease of the cut off ratio values. One can notice that the Diesel Cycle power output increases with an increase in the compression ratio and combustion temperature and that the Diesel Cycle power output is greater for lower cut off ratio values for given combustion temperature values.

### ***Assumptions***

Working fluid is air. There is no friction. Compression and expansion are isentropic -- there is no entropy change. During heat addition and heat rejection, the air temperature does change. Ideal gas state equation is valid --  $pV = RT$ . Air behaves as a perfect gas -- specific heat has a constant value.

## Diesel Cycle Analysis

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### Governing Equations

$$T_2/T_1 = (V_1/V_2)^{(\kappa-1)}$$

$$V_1/V_2 = (T_2/T_1)^{1/(\kappa-1)}$$

$$T_3/T_4 = (V_4/V_3)^{(\kappa-1)}$$

$$V_4/V_3 = (T_3/T_4)^{1/(\kappa-1)}$$

$$\kappa = c_p/c_v$$

$$pV = RT$$

$$w = q_h - q_l$$

$$w = c_p(T_3 - T_2) - c_v(T_4 - T_1)$$

$$W = (c_p(T_3 - T_2) - c_v(T_4 - T_1))m$$

$$\eta = 1 - (\phi^\kappa - 1)/(\kappa\varepsilon^{(\kappa-1)}(\phi - 1))$$

$$\varepsilon = V_1/V_2$$

$$\phi = V_3/V_2$$

### Input Data

$$T_1 = 298 \text{ [K]}$$

$$p_1 = 1 \text{ [atm]}$$

$$T_3 = 1,500, 1,800 \text{ and } 2,100 \text{ [K]}$$

$$\varepsilon = 7.5, 10, 12.5, 15 \text{ and } 17.5 \text{ []}$$

$$\phi = 3 \text{ and } 4 \text{ []}$$

$$c_p = 1.004 \text{ [kJ/kg}\cdot\text{K]}$$

$$\kappa = c_p/c_v - \text{for air } \kappa = 1.4 \text{ []}$$

## Diesel Cycle Analysis

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### Results

**Diesel Cycle Efficiency**

Diesel Cycle Efficiency [%]	Compression Ratio [/]				
Cut Off Ratio [/]	7.5	10	12.5	15	17
3	41.69	48.03	52.46	55.81	58.45
4	36.57	43.46	48.29	51.93	54.80

**Diesel Cycle Efficiency**

Diesel Cycle Efficiency [%]	Combustion Temperature [K]		
Compression Ratio [/]	1,500	1,800	2,100
10	53.39	51.12	49.20
15	61.94	60.12	58.49

**Diesel Cycle Cut Off Ratio**

Cut Off Ratio [/]	Combustion Temperature [K]		
Compression Ratio [/]	1,500	1,800	2,100
10	2.00	2.40	2.80
15	1.70	2.05	2.39

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Diesel Cycle Power Output

Power Output [kW]	Combustion Temperature [K]		
Compression Ratio [ $r$ ]	1,500	1,800	2,100
10	311	417	514
15	297	433	557

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### *Conclusions*

The Diesel Cycle efficiency increases with an increase in the compression ratio and a decrease in the cut off ratio values. Also, the Diesel Cycle power output increases with an increase in the compression ratio and combustion temperature and the Diesel Cycle power output is greater for lower cut off ratio values for given combustion temperature values.

Please use the material you just read to answer the quiz questions at the end of this course.

When you get a chance, please visit the following URL:

<http://www.engineering-4e.com>

The above URL provides lots of free online and downloadable e-material and e-solutions on energy conversion.