Engineering Software
P.O. Box 2134, Kensington, MD 20891
Phone: (301) 919-9670
E-Mail: info@engineering-4e.com
Web Site: http://www.engineering-4e.com

Diesel Cycle Analysis

by

Engineering Software

Course Category: Engineers

Course Level: Intermediate

Credit: 1 Hour

Diesel Cycle Analysis

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 and combustion temperature for 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.

Diesel Cycle Analysis

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

Diesel Cycle Analysis

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.

Diesel Cycle Analysis

Table of Contents

Diesel Cycle..2
Analysis 2
Assumptions..10
Governing Equations 11
Input Data 12
Results 12
Conclusions..14

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 decreases. 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.

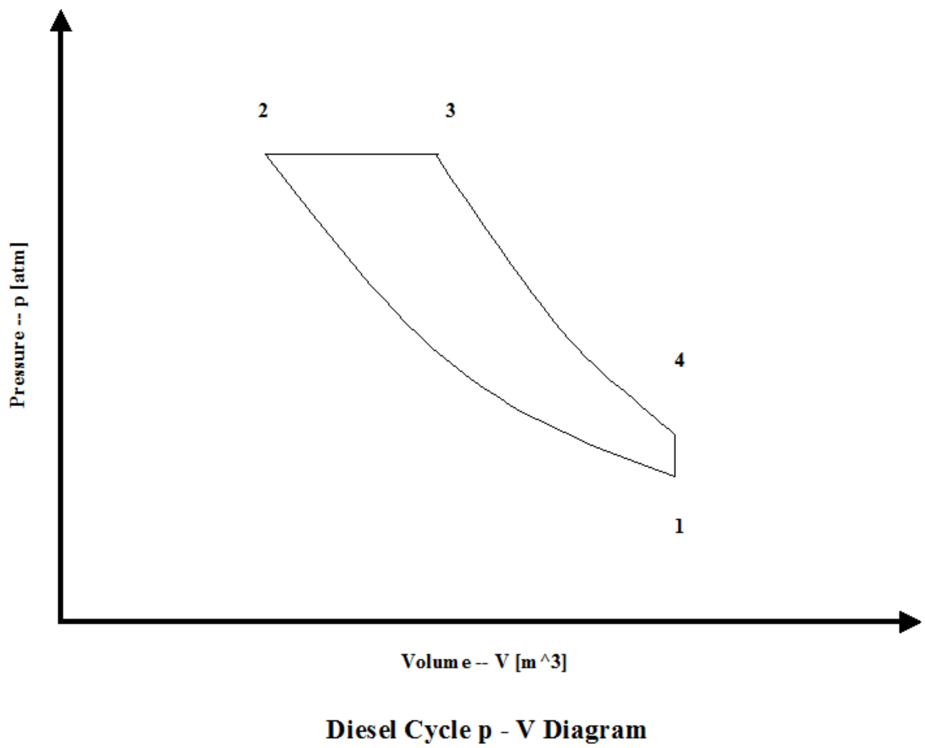

Figure 1 - Diesel Cycle Pressure vs Volume Diagram

Figure 2 presents a Diesel Cycle temperature vs entropy diagram.

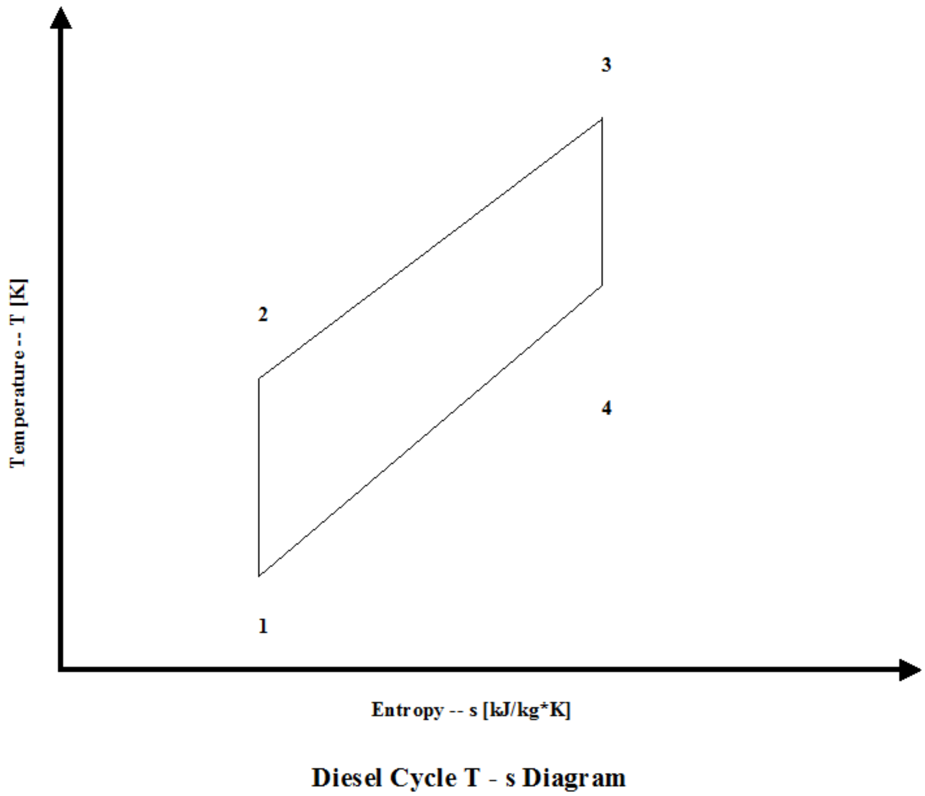

Figure 2 - Diesel Cycle Temperature vs Entropy Diagram

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

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

where

η - thermal efficiency [/]

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

w_e - expansion specific power output [kJ/kg]

Diesel Cycle Analysis

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]

ε - compression ratio [/]

φ - cut off ratio [/]

For isentropic compression and expansion:

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

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

where

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

V_1, V_2, V_3, V_4 - volume values at points 1, 2, 3 and 4 [m^3]

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

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

It follows that

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

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:

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

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

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

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

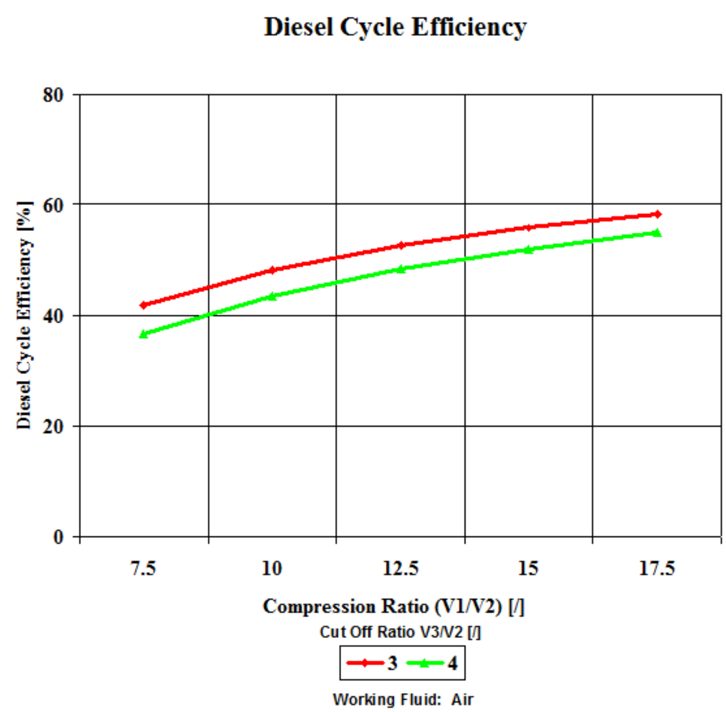

Figure 3 - Diesel Cycle Efficiency

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

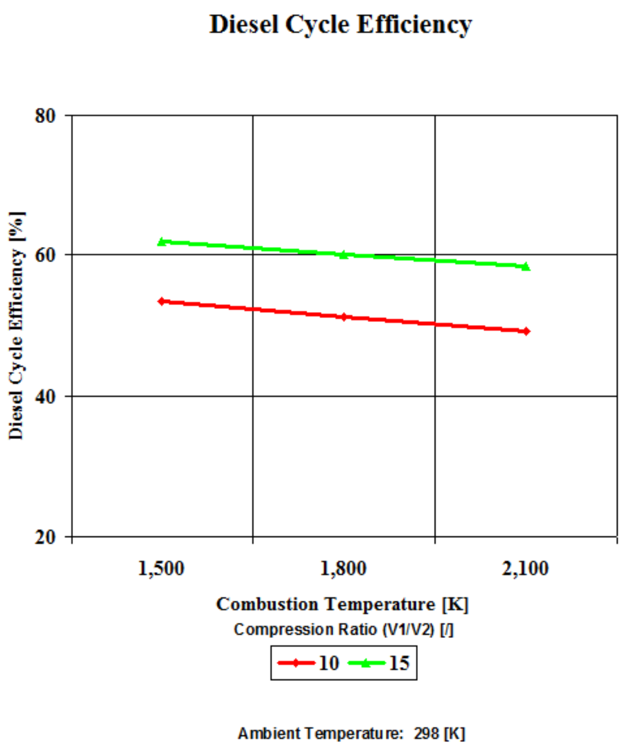

Figure 4 - Diesel Cycle Efficiency

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

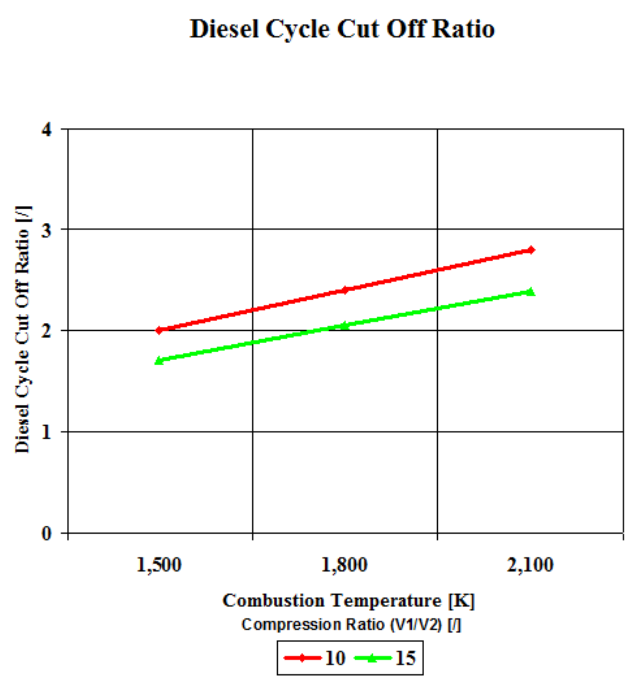

Figure 5 - Diesel Cycle Cut Off Ratio

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

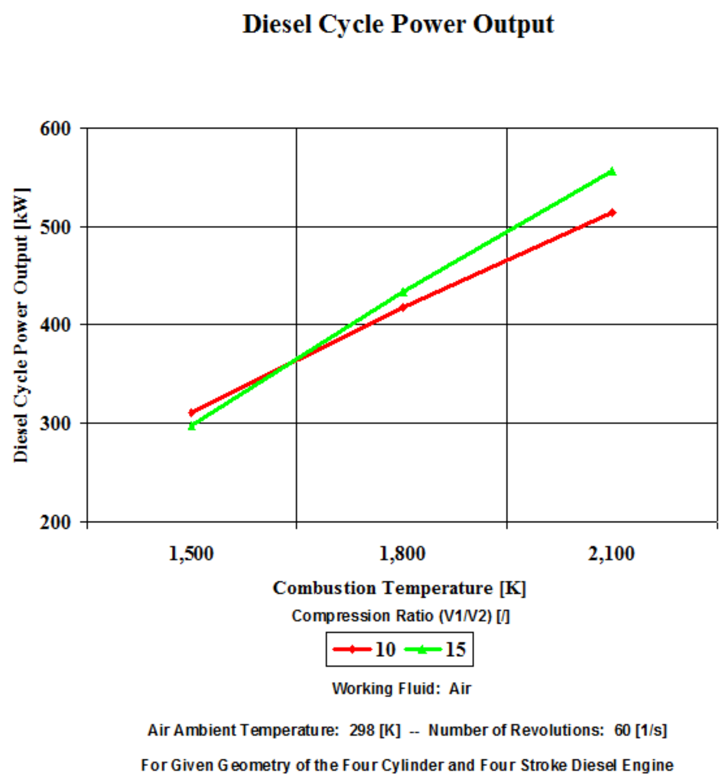

Figure 6 - Diesel Cycle Power Output

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 values.

Assumptions

Working fluid is air. There is no friction. Compression and expansion are isentropic -- there is no entropy change. Ideal gas state equation is valid -- pv = RT. Air behaves as a perfect gas -- specific heat has a constant value.

Diesel Cycle Analysis

Governing Equations

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

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

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

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

$$\varkappa = c_p/c_v$$

$$c_p - c_v = R$$

$$pv = RT$$

$$w = q_h - q_l$$

$$q_{h =} c_p(T_3 - T_2)$$

$$q_{l =} c_v(T_4 - T_1)$$

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

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

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

$$\varepsilon = V_1/V_2$$

$$\varphi = V_3/V_2$$

Diesel Cycle Analysis

Input Data

T_1 = 298 [K]

p_1 = 1 [atm]

T_3 = 1,500, 1,800 and 2,100 [K]

ε = 7.5, 10, 12.5, 15 and 17.5 [/]

φ = 3 and 4 [/]

R = 0.2867 [kJ/kg*K]

c_p = 1.004 [kJ/kg*K]

ϰ = 1.4 [/]

Results

Diesel Cycle Efficiency

Diesel Cycle Efficiency [%]	**Compression Ratio [/]**				
Cut Off Ratio [/]	7.5	10	12.5	15	17.5
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

Diesel Cycle Analysis

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

Diesel Cycle Power Output

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

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 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.