Otto Cycle Ideal vs Real Operation Analysis

An Online Continuing Education Course for Engineers

Course Number: M-1038

Credit: 1 Hour / 1 PDH / 1 CPD

Otto Cycle Ideal vs Real Operation Analysis

Gordan Feric, P.E.

Course Description

In this one hour course, the open, simple Otto Cycle used for stationary power generation is considered.

The Otto 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 Otto 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 ratio, combustor outlet temperature, some fixed cylinder geometry and both isentropic compression and expansion efficiency. 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 Otto Cycle, its components, p - V and T - s diagrams, ideal and real operation and major performance trends.

This course includes a multiple-choice quiz at the end.

Performance Objectives

At the conclusion of this course, the student will:

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

Introduction

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

Otto Cycle

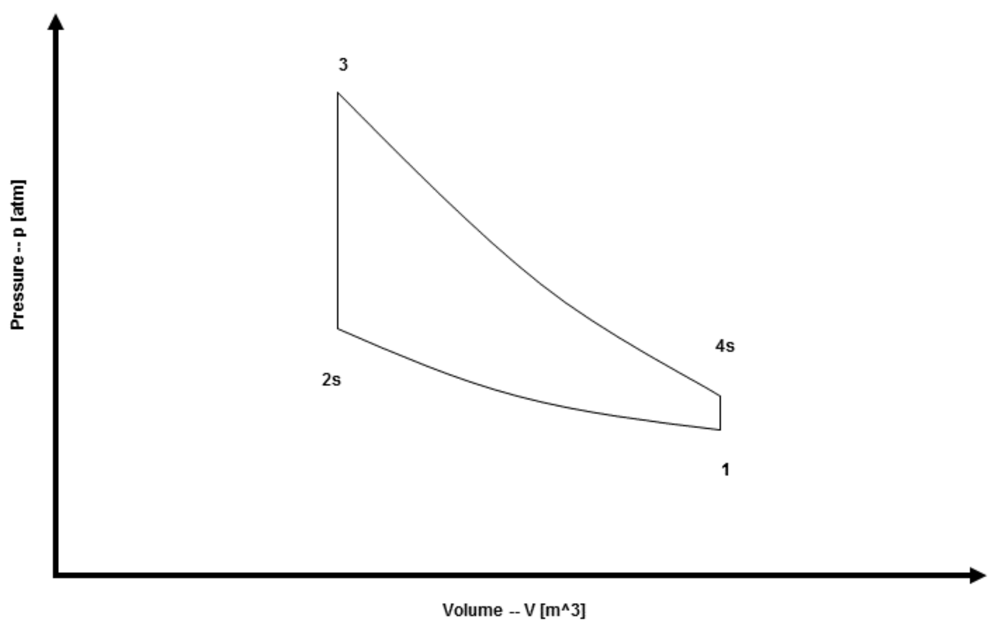
This section provides an Otto Cycle analysis when the working fluid is air.

Analysis

In the presented Otto 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. Heat addition starts at point 2 and it ends at point 3. At a constant volume, 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. 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 an Otto Cycle pressure vs volume diagram.



Otto Cycle p - V Diagram

Figure 1 - Otto Cycle Pressure vs Volume Diagram

Figure 2 presents an Otto Cycle temperature vs entropy diagram.

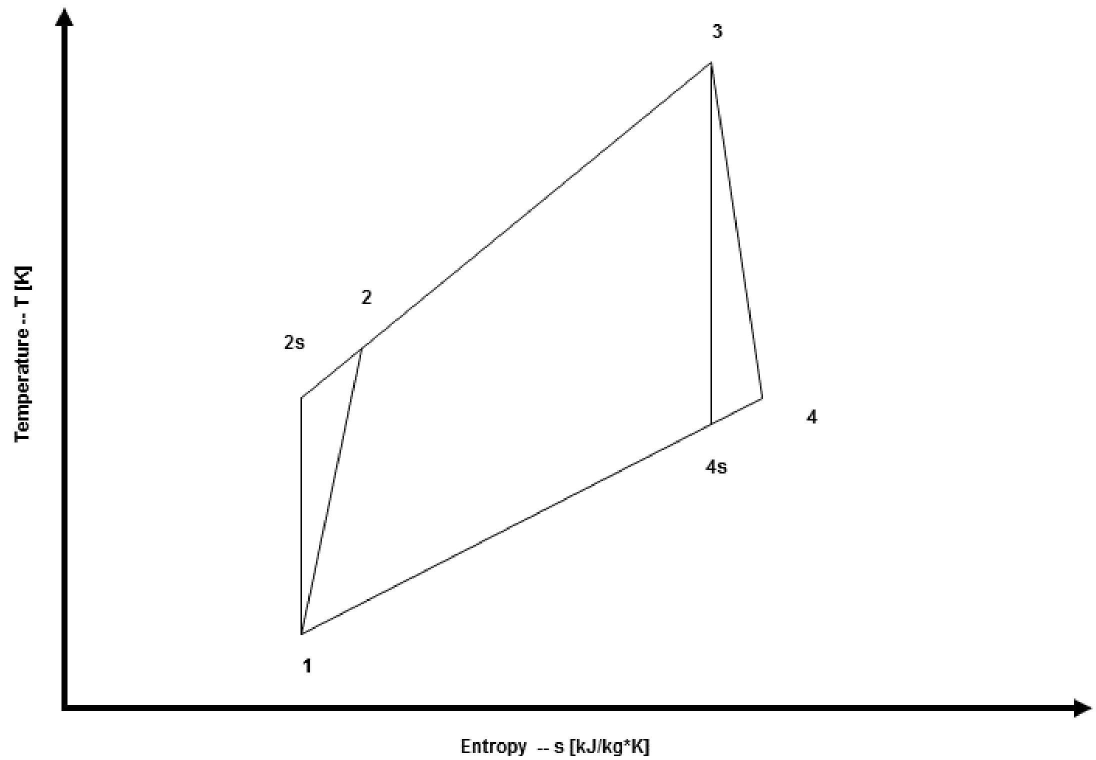


Figure 2 - Otto Cycle Temperature vs Entropy Diagram

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

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

or

$$\eta = 1 - (T_4 - T_1)/(T_3 - T_2)$$

where

η - thermal efficiency [/]

η_c - isentropic compression efficiency [/]

η_e - isentropic expansion efficiency [/]

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

w_e - expansion specific power output [kJ/kg]

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 [/]

For isentropic compression and expansion:

$T_{2s}/T_1 = (p_2/p_1)^{(\varkappa-1)/\varkappa} = (V_1/V_2)^{(\varkappa-1)}$

$T_{4s}/T_3 = (p_4/p_3)^{(\varkappa-1)/\varkappa} = (V_3/V_4)^{(\varkappa-1)}$

Knowing that

$V_3/V_4 = V_2/V_1$

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]

$T_1, T_{2S}, T_2, T_3, T_{4S}, T_4$ - temperature values at points 1, 2_S, 2, 3, 4_S and 4 [K]

$\eta_c = (T_{2S} - T_1)/(T_2 - T_1)$

$T_2 = T_1 + (T_{2S} - T_1)/\eta_c$

$\eta_e = (T_3 - T_4)/(T_3 - T_{4S})$

$T_4 = T_3 - (T_3 - T_{4S})\eta_e$

It follows that

$T_3/T_{4S} = T_{2S}/T_1 = (V_1/V_2)^{(\varkappa-1)} = \varepsilon^{(\varkappa-1)}$

where

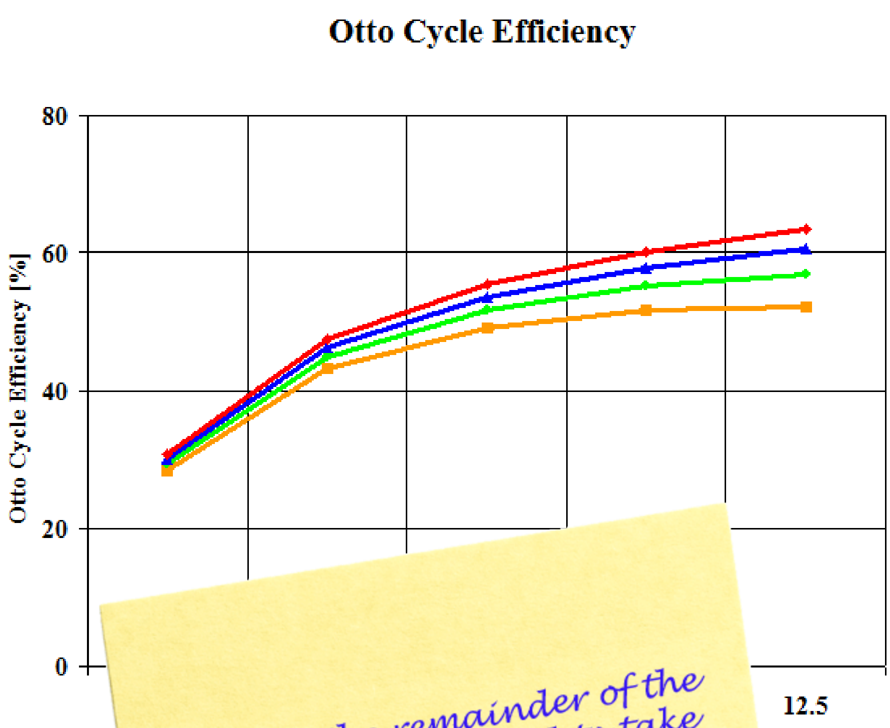
$\varepsilon = V_1/V_2$

In this Otto Cycle ideal vs real operation analysis, three different case studies are presented - A, B and C.

Case Study A

In this Otto Cycle analysis, compression is both ideal and real, while expansion is only ideal.

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



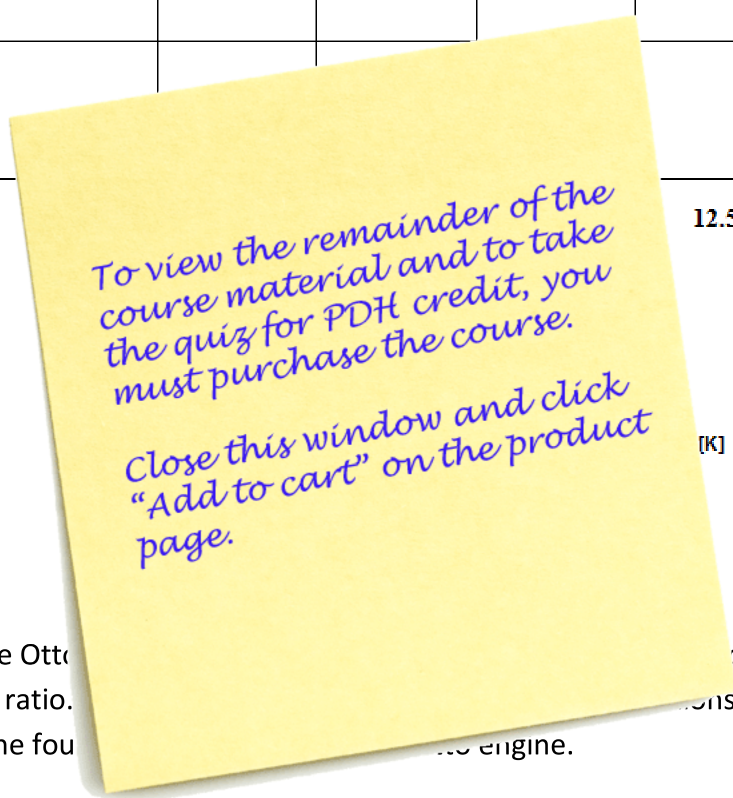


Figure 4 presents the Otto ... on temperature for a fixed compression ratio. ... ons is 60 [1/s] for given geometry of the fou ... engine.