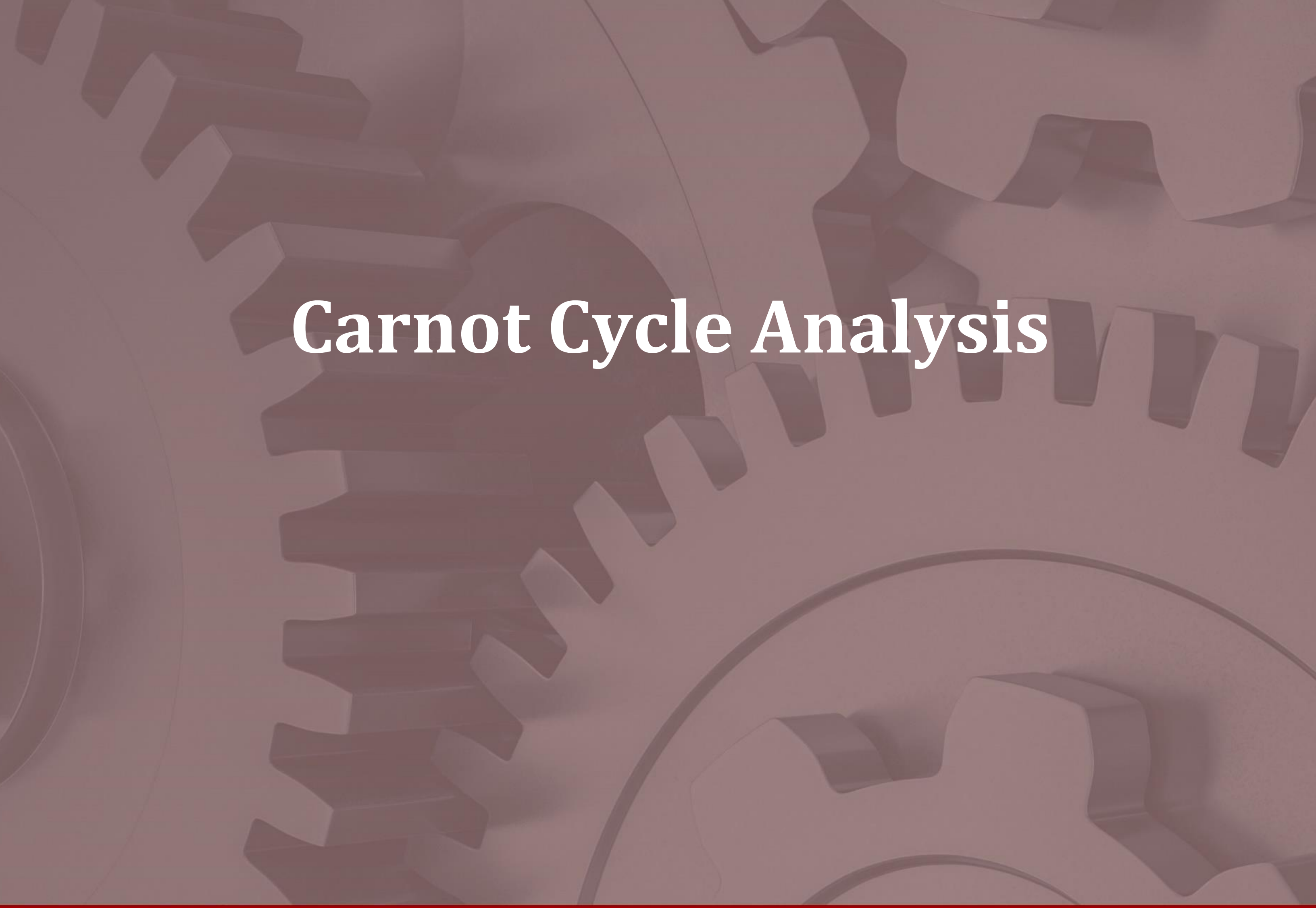

Carnot Cycle Analysis

An Online Continuing Education Course for Engineers

Course Number: M-1030

Credit: 1 Hour / 1 PDH / 1 CPD

Carnot Cycle Analysis

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Introduction

The Carnot Cycle is an ideal simple cycle consisting of isentropic compression and expansion and isothermal heat addition and heat rejection. The Carnot Cycle thermal efficiency determines the highest thermal efficiency that a heat engine can achieve.

Therefore, for a heat engine, the maximum thermal efficiency is determined by the Carnot Cycle efficiency and it is not dependent on the physical properties of the working fluid.

The Carnot Cycle efficiency can be very helpful when studying the impact of ambient temperature on the installed power generation capacity and available electric power generation -- what happens with the amount of available electric power generation capacity when the ambient temperature changes one way or the other.

Course Description

The Carnot Cycle is an ideal simple cycle consisting of isentropic compression and expansion and isothermal heat addition and heat rejection. The Carnot Cycle thermal efficiency determines the highest thermal efficiency that a heat engine can achieve. In this one hour course, the closed, simple Carnot Cycle used for stationary power generation is considered.

The Carnot 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 Carnot Cycle is presented in a T - s diagram and its major performance trends are plotted in a few figures as a function of heat addition and heat rejection temperature values.

In this course, the student gets familiar with the Carnot Cycle, its components, T - s diagram, operation and major performance trends.

Performance Objectives

At the conclusion of this course, the student will:

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

Carnot Cycle

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

Analysis

In the presented Carnot 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 compressor at point 1 and it exits the compressor at point 2. Isentropic compression is considered with no entropy change. Air enters a heat exchanger -- heat addition -- at point 2 and it exits the heat exchanger at point 3. At a constant temperature, heat addition takes place. Air enters a turbine at point 3 and it exits the turbine at point 4. Isentropic expansion is considered with no entropy change. Air enters a heat exchanger -- heat rejection -- at point 4, and exits the heat exchanger at point 1. At a constant temperature, heat rejection takes place. It should be mentioned that air at point 1 enters the compressor and the cycle is repeated.

Figure 1 presents a Carnot Cycle schematic layout.

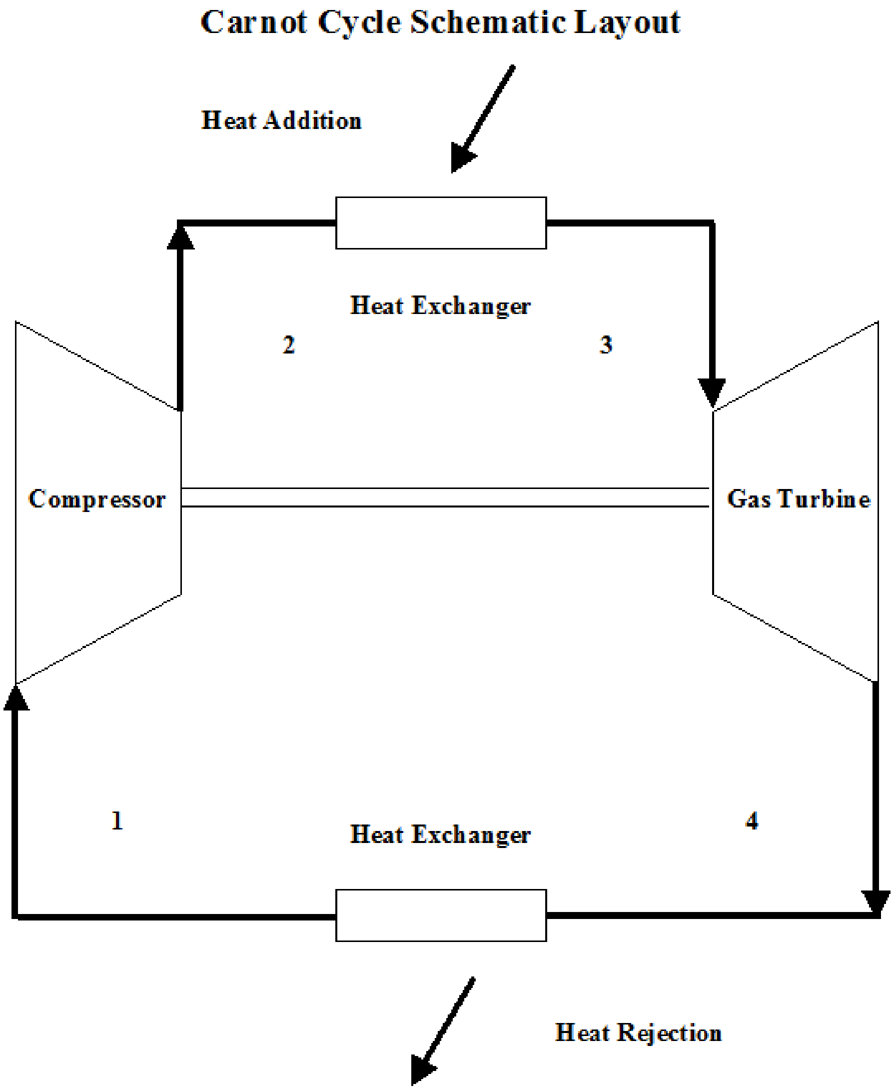

Figure 1 - Carnot Cycle Schematic Layout

Figure 2 presents a Carnot Cycle temperature vs. entropy diagram.

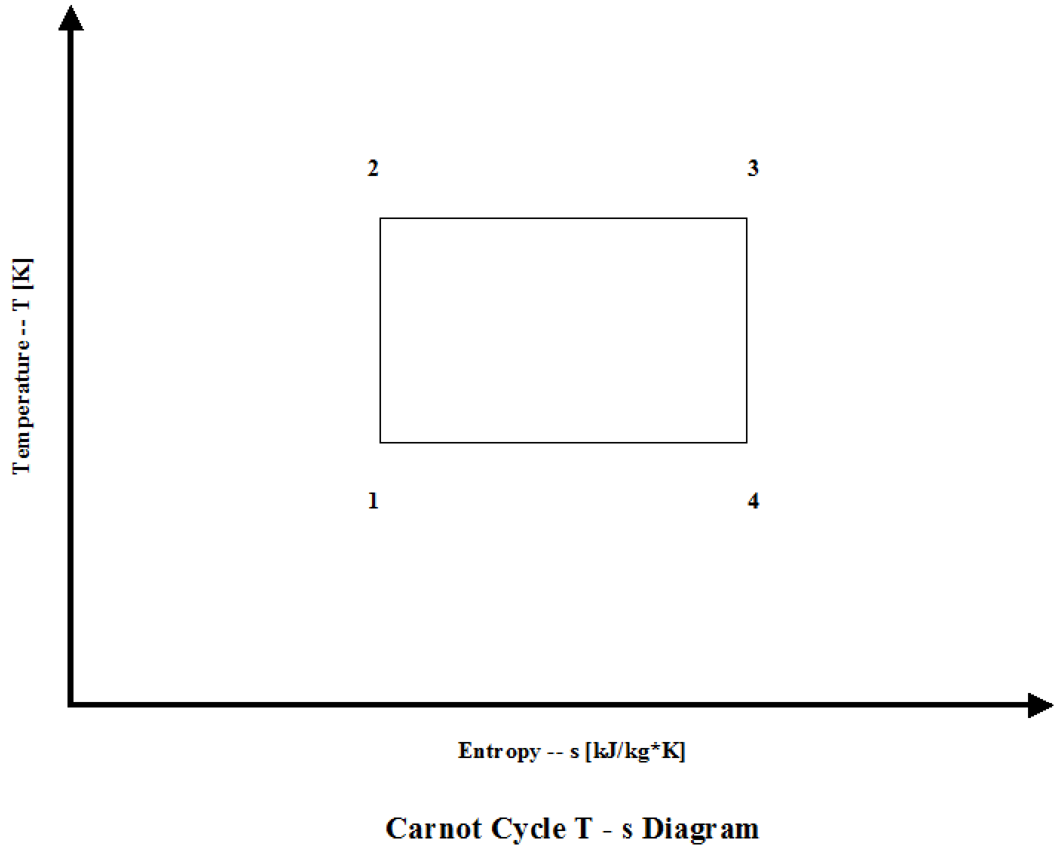

Figure 2 - Carnot Cycle Temperature vs. Entropy Diagram

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:

$$\eta = w/q_h = (w_t - w_c)/q_h = (q_h - q_l)/q_h = 1 - q_l/q_h = 1 - T_1\Delta s/T_2\Delta s = 1 - T_1/T_2 = 1 - T_R/T_A$$

where

η - thermal efficiency [/]

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

w_t - expansion specific power output [kJ/kg]

w_c - compression specific power input [kJ/kg]

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

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

Δs - entropy change during heat addition and heat rejection [kJ/kg*K]

T_A - temperature during heat addition [K]

T_R - temperature during heat rejection [K]

For isentropic compression and expansion:

$$T_2/T_1 = (p_2/p_1)^{(\varkappa-1)/\varkappa} = T_3/T_4 = (p_3/p_4)^{(\varkappa-1)/\varkappa}$$

and

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

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]

Again, it follows that

$$\eta = 1 - T_1/T_2 = 1 - T_R/T_A$$

The Carnot Cycle efficiency is not dependent on the working fluid properties.

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

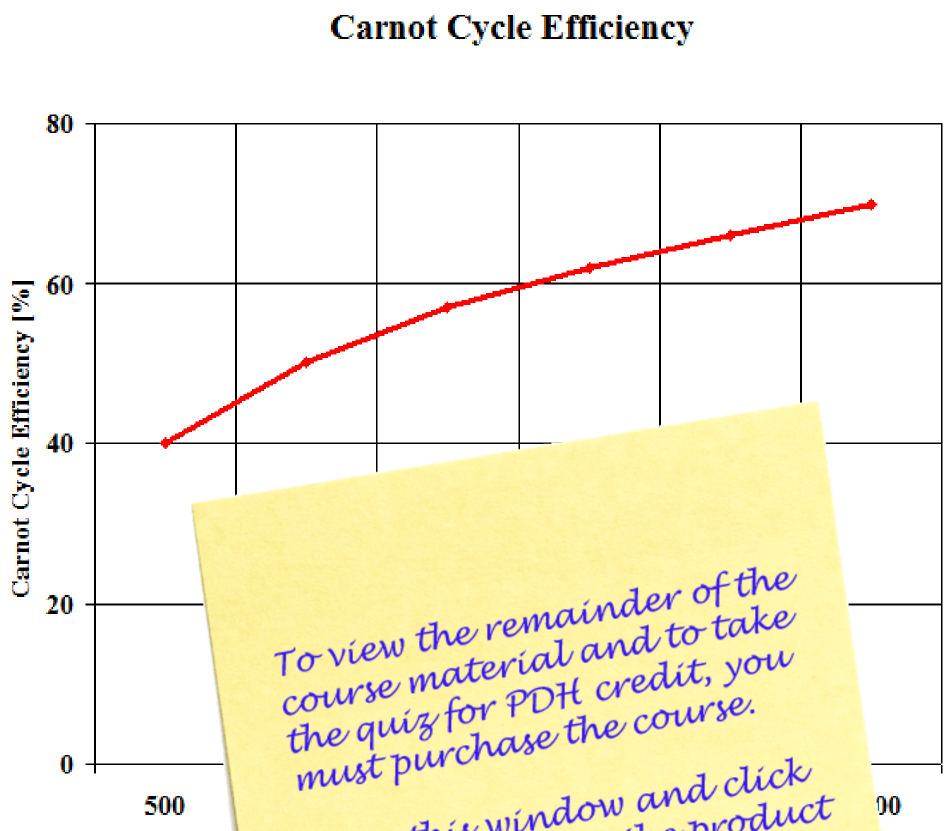

Figure 3 - Carn

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