Brayton Cycle (Gas Turbine) Ideal vs Real Operation for Power Application Analysis

An Online Continuing Education Course for Engineers

Course Number: M-1036

Credit: 1 Hour / 1 PDH / 1 CPD

Brayton Cycle (Gas Turbine) Ideal vs Real Operation for Power Application Analysis

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

The Brayton 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 Brayton Cycle is presented in a T - s diagram and its major performance trends (thermal efficiency, specific power output and power output) are plotted in a few figures as a function of compression ratio, gas turbine inlet temperature, working fluid mass flow rate 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 Brayton Cycle, its components, T - s diagram, ideal and real 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 Brayton Cycle (Gas Turbine) and its T - s diagram
- Be familiar with the Brayton Cycle ideal and real operation
- Understand general Brayton Cycle performance trends

Introduction
Over the years, gas turbine has become the premier electric generation system for peak and intermediate loads. Gas turbines are compact, lightweight, easy to operate and come in sizes ranging from several hundred kilowatts to hundreds of megawatts. Gas turbines require relatively low capital investment, have high operating flexibility, high thermal efficiency and can be used for various industrial applications. Gas turbines can help provide reliable power to meet the future demand using both high and low heat content fuels, with low emissions.

Brayton Cycle (Gas Turbine) for Power Application

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

Analysis
In the presented Brayton 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.

A gas turbine is a heat engine that uses a high temperature, high pressure gas as the working fluid. Combustion of a fuel in air is usually used to produce the needed temperatures and pressures in the gas turbine, which is why gas turbines are often referred to as combustion turbines. Expansion of the high temperature, high pressure working fluid takes place in the gas turbine. The gas turbine shaft rotation drives an electric generator and a compressor for the working fluid, air, used in the gas turbine combustor. Many gas turbines also use a heat exchanger called a recouperator to impart turbine exhaust heat into the combustor's air/fuel mixture. Gas turbines produce high quality heat that can be used to generate steam for combined heat and power and combined-cycle applications, significantly enhancing efficiency.

Air is compressed along line 1-2 by a compressor and it enters a combustor. At a constant pressure, combustion takes place (fuel is added to the combustor and the air temperature raises) and/or heat gets added to air. High temperature air exits the combustor at point 3. Then air enters a gas turbine where expansion occurs, producing power. Air exits the gas turbine at point 4. It should be mentioned that air at point 1 enters the compressor and the cycle is repeated.

Figure 1 presents a Brayton Cycle schematic layout.

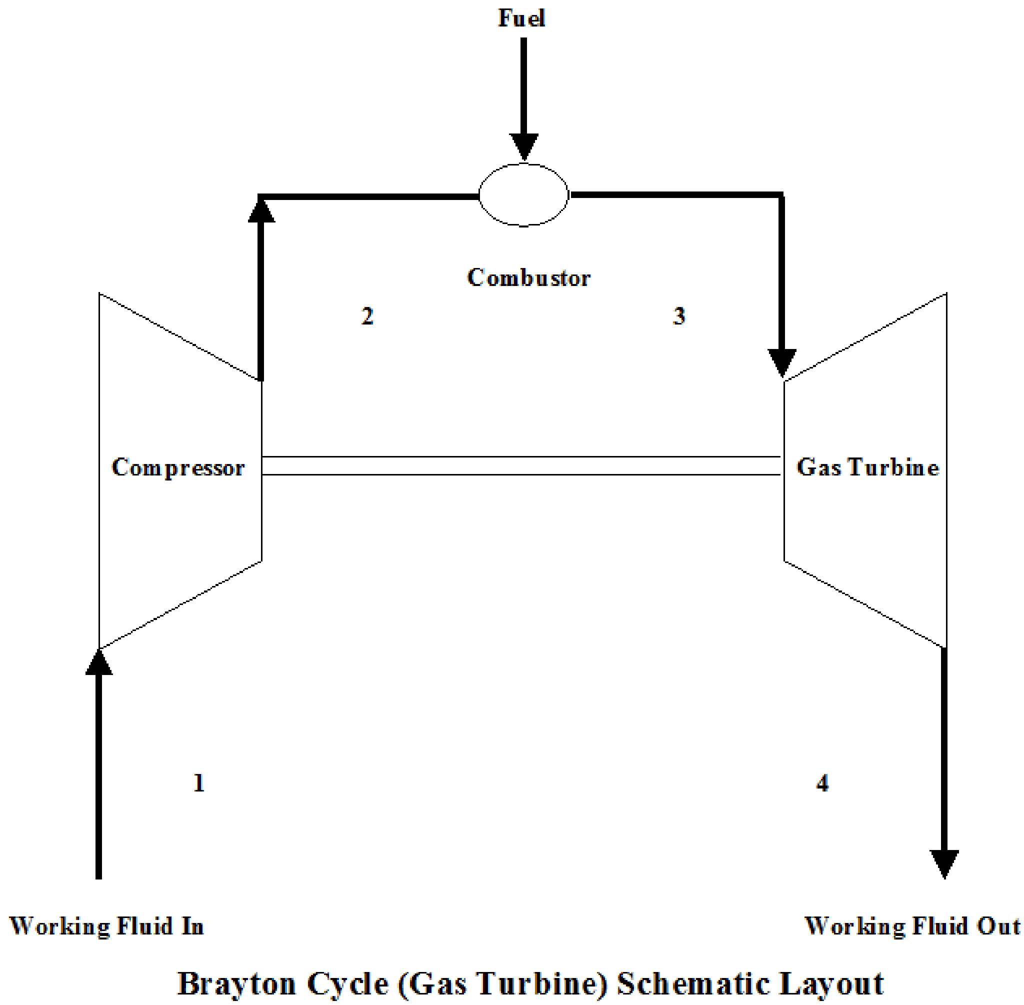


Figure 1 - Brayton Cycle Schematic Layout

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

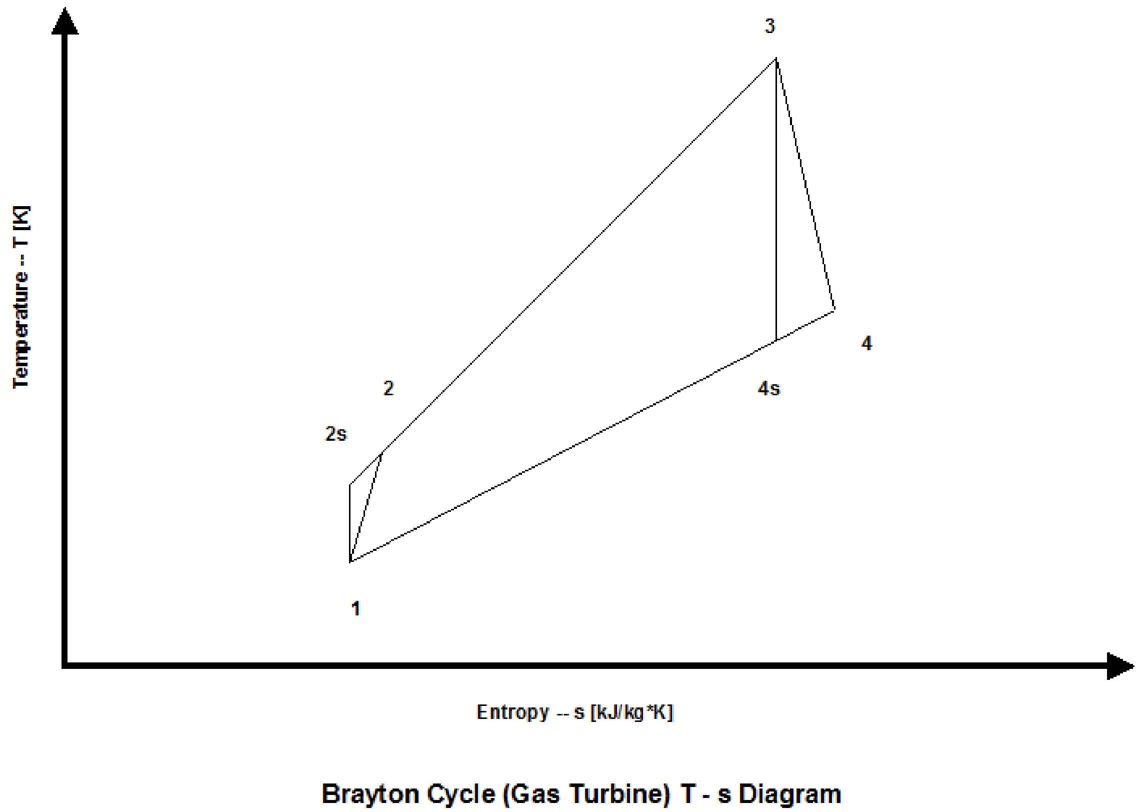


Figure 2 - Brayton Cycle Temperature vs. Entropy Diagram

It should be pointed out that this material deals with the open Brayton Cycle. The way how the T - s diagram is presented, it describes a closed Brayton Cycle -- this would require a heat exchanger after point 4 where the working fluid would be cooled down to point 1 and the cycle repeats. Therefore, the T - s diagram is presented as a closed Brayton Cycle to allow easier understanding and derivation of the Brayton Cycle thermal efficiency -- heat addition and heat rejection.

The gas turbine and compressor are connected by shaft so the considerable amount of work done on the gas turbine is used to power the compressor.

It can be noticed from the T - s diagram that the work done on the gas turbine is greater than the work necessary to power the compressor -- constant pressure lines in the T - s diagram diverge by going to the right side (entropy wise).

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:

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

or

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

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_t - expansion specific power output [kJ/kg]

w_c - compression specific power input [kJ/kg]

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

W_t - 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]

r_p - compression ratio [/]

For isentropic compression and expansion:

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

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

Knowing that

$p_3/p_4 = p_2/p_1$

$r_p = p_2/p_1$

where

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

p_1, p_2, p_3, p_4 - pressure values at points 1, 2, ...

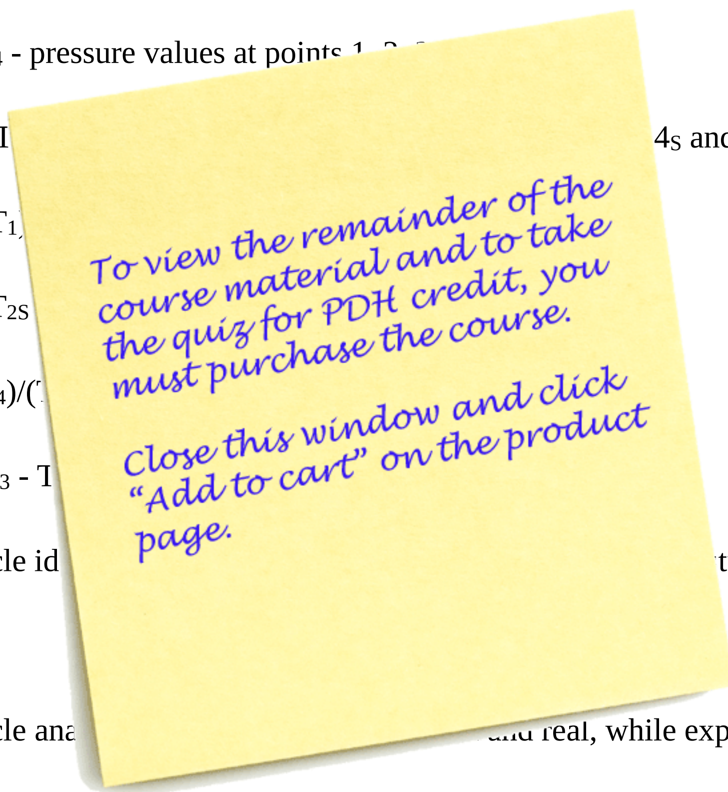
T_1, $T_{2S,}$ T_2, T ... 4_S and 4 [K]

$\eta_c = (T_{2S} - T_1$ ...

$T_2 = T_1 + (T_{2S}$ ...

$\eta_e = (T_3 - T_4)/($ ...

$T_4 = T_3 - (T_3 - T$ ...



In this Brayton Cycle id ... tudies are presented - A, B and C.

Case Study A

In this Brayton Cycle ana ... real, while expansion is only ideal.