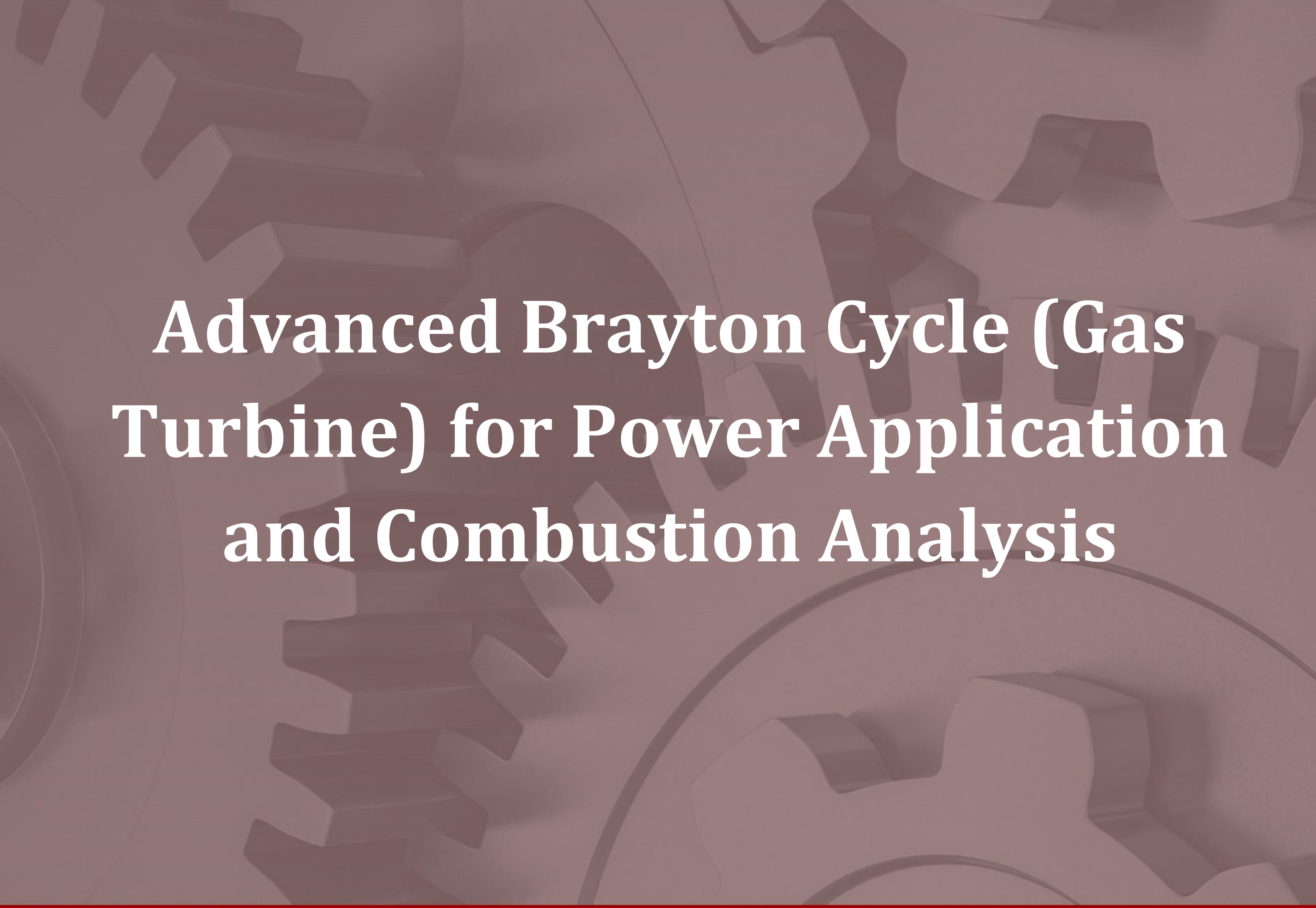

Advanced Brayton Cycle (Gas Turbine) for Power Application and Combustion Analysis

An Online Continuing Education Course for Engineers

Course Number: M-3037

Credit: 3 Hours / 3 PDH / 3 CPD

Advanced Brayton Cycle (Gas Turbine) for Power Application and Combustion Analysis

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Course Description

The ideal cycle for a simple gas turbine is the Brayton Cycle, also called the Joule Cycle. In this three hour course, the open, simple Brayton Cycle used for stationary power generation and combustion are presented.

When dealing with Brayton Cycle, air, argon, helium and nitrogen are considered as the working fluid.

When dealing with combustion, six different fuels (carbon, hydrogen, sulfur, coal, oil and gas) react with air and oxygen enriched air as the oxidant at different stoichiometry values (stoichiometry => 1) and oxidant inlet temperature values.

For Brayton Cycle, thermal efficiency derivation is presented with a simple mathematical approach. Also, a T - s diagram and power cycle major performance trends (thermal efficiency, specific power output, power output, combustion products composition on weight and mole basis, specific fuel consumption and stoichiometry) are plotted in a few figures as a function of compression ratio, turbine inlet temperature and/or final combustion temperature and working fluid mass flow rate. It should be noted that this online course does not deal with costs (capital, operational or maintenance).

The combustion technical performance at stoichiometry => 1 conditions is presented knowing the specific enthalpy values for combustion reactants and products, given as a function of temperature. Combustion products composition on both weight and mole basis is given in tabular form and plotted in a few figures. Also, flame temperature, oxidant to fuel ratio and fuel higher heating value (HHV) are presented in tabular form and plotted in a few figures. The provided output data and plots allow one to determine the major combustion performance laws and trends.

In this course, the student gets familiar with the ideal Brayton Cycle and combustion and their T - s and h - T diagrams, 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 elements of Brayton Cycle and combustion and their T - s and h - T diagrams
- Be familiar with Brayton Cycle and combustion operation
- Understand general Brayton Cycle and combustion 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.

Combustion is a process of active oxidation of combustible compounds such as: carbon, hydrogen and sulfur. High amount of heat released during the combustion process is used to provide work and/or power.

In addition to knowing the reactants and combustion products physical properties, for any kind of combustion analysis and calculations, it is important to know both oxidant and fuel compositions. As a result, one can calculate and analyze combustion products composition on both weight and mole basis, flame temperature, stoichiometric oxidant to fuel ratio and fuel higher heating value (HHV).

Today, global warming is becoming more evident and it is being said that it is primarily caused by CO_2 emissions. A detailed combustion analysis can be very useful in determining different fuel and technology scenarios that would result in the reduction of current CO_2 emissions.

Brayton Cycle (Gas Turbine) for Power Application

This section provides a Brayton Cycle analysis when air, argon, helium and nitrogen are considered as the working fluid.

Analysis

In the presented Brayton Cycle analysis, air, argon, helium and nitrogen are 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.

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

Figure 1 presents a Brayton Cycle schematic layout.

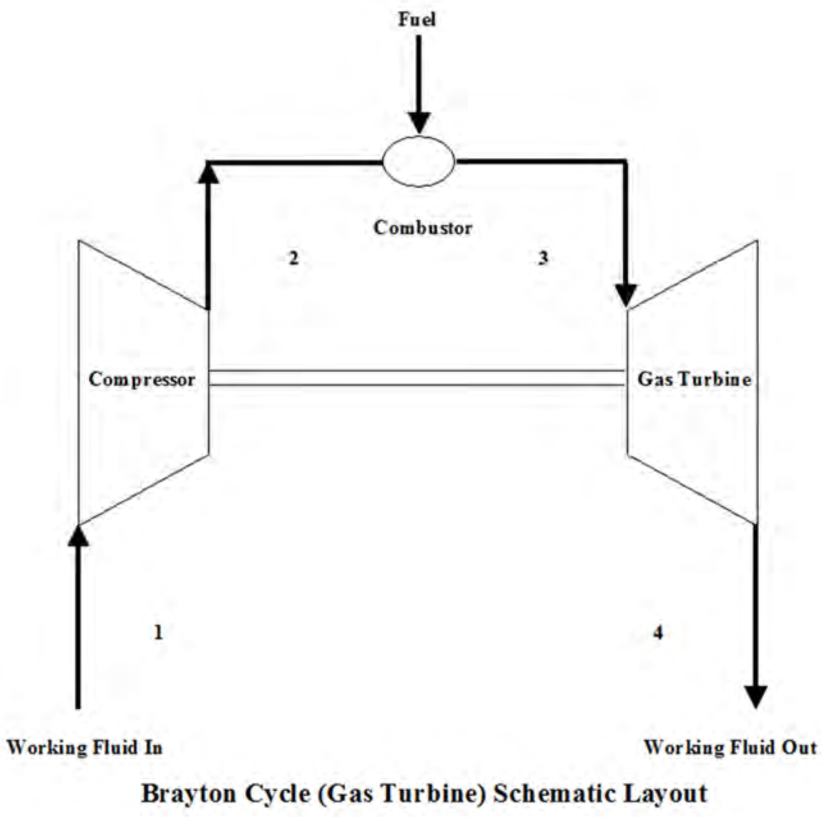

Figure 1 - Brayton Cycle Schematic Layout

Figure 2 presents a Brayton Cycle temperature vs entropy diagram.

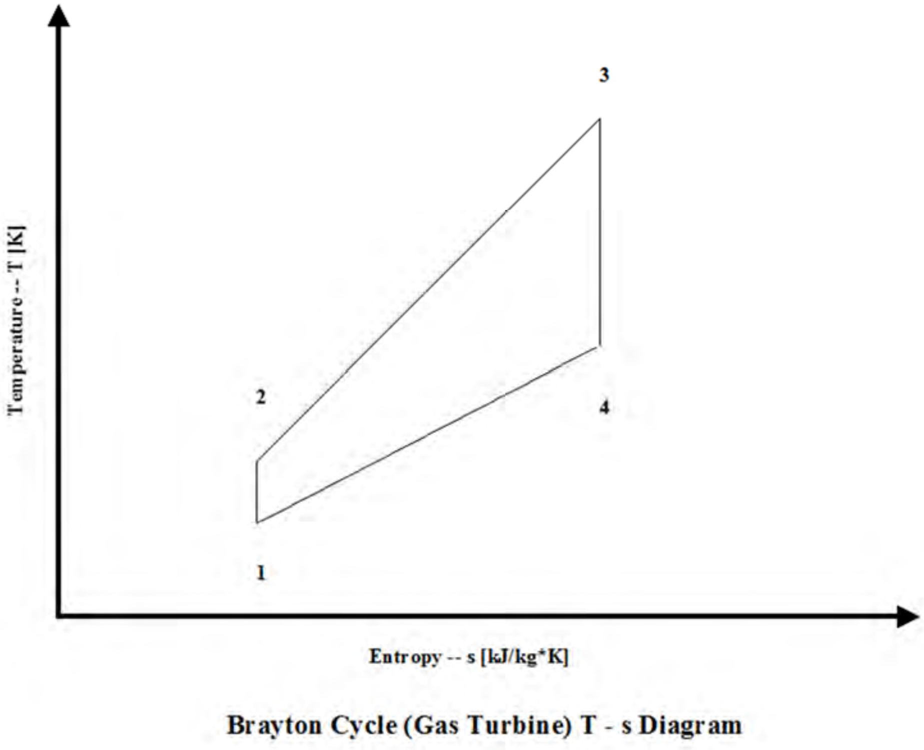

Figure 2 - Brayton Cycle Temperature vs Entropy Diagram

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

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

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]

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

W_t - expansion power output [kW]

W_c - compression power input [kW]

q_h - heat added t

q_l - heat rejected

c_p - specific heat a

c_v - specific heat at

m - working fluid m

r_p - compression rat

For isentropic compr

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

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

Knowing that

$p_3/p_4 = p_2/p_1$

where

$\varkappa = c_p/c_v$

p_1, p_2, p_3, p_4 - pressure v ts 1, 2, 3 and 4 [atm]

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

It follows that

$T_3/T_4 = T_2/T_1$