



Gas Turbine Performance Enhancements

An Online Continuing Education Course for Engineers

Course Number: M-2017

Credit: 2 Hours / 2 PDH / 2 CPD

Gas Turbine Performance Enhancements (2 PDH)

Introduction

Power companies have long been thought of as bastions of conservatism, preferring evolutionary changes over radical departures from tried and proven technology and business strategies. The industry, however, has undergone, and is still undergoing changes that have been forced upon them by outside forces. Examples of some of these outside forces are the so-called deregulation, which among other things has separated power generation, transmission, and distribution, which used to be under single regional monopolies; instability of fuel costs; uncertain climatic changes; increasing awareness of the public on environmental consequences; corporate irresponsibilities within the industry; and the globalization of the economy.

What all this means is this:

1. Decisions on power plant configurations are based on a different set of economic factors than were previously used.
2. These decisions are being made largely by independent power producers and their financiers, rather than by the traditional government-regulated power companies.
3. Huge central station power plants are being displaced by smaller, more adaptable plants with a much shorter life cycle horizon.
4. Availability and reliability are just other economic factors.

O.K., enough politics! But what these newer criteria mean is that the trend has been to smaller power plants that are more adaptable to changing criteria, more flexible in their fuel needs, can burn mixtures of liquid and gaseous fuels, are adaptable to pollution abatement technology, can be economically operated over a wide range of power demands, and can be designed and constructed in months instead of years on limited amounts of real estate.

These new criterion have translated very well into combined cycle power blocks that consist of

CTGs, HRSGs, and steam turbine-generators that can be largely factory-assembled and hooked up to gas pipelines.

That is why we are looking at ways to make gas turbines even more adaptable and efficient.

Another course on PDHengineer.com goes more deeply into the thermodynamic theories that underlie cogeneration plants. For simplification, and to avoid the ambiguities of cogeneration efficiencies, this course assumes pure electric power producers, not cogeneration.

Much of the descriptive material in this course has been adapted from General Electric Company literature and brochures.

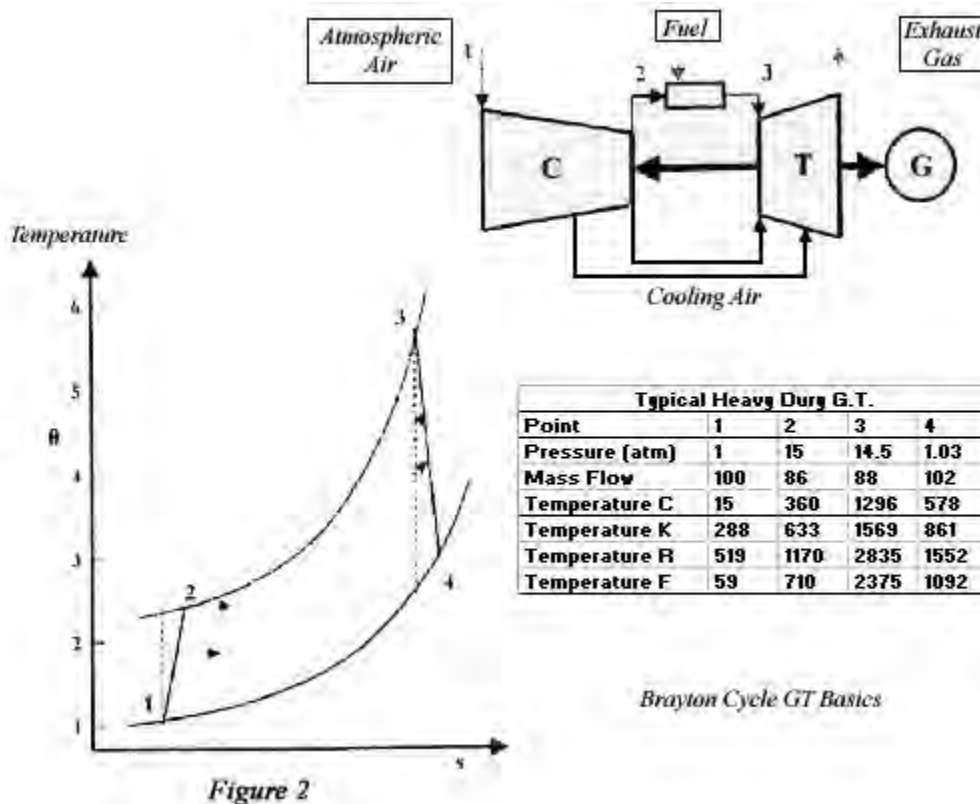
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The combined cycle power generating plant has proven its advantages over simple cycle (either steam or combustion turbine) generators in both commercial power generation and industrial cogeneration. Performance enhancements in the form of add-on features, primarily to the gas turbine part of the cycle, improve efficiency and increase power output. These enhancements can be included in new machines, or in some cases can be retrofitted to existing ones. Some are effective at all loads, while others are used for boosting power generation during periods of peak demand.

A separate course on PDHengineer.com, *Thermodynamics of Cogeneration*, describes the possible ambiguities that may be encountered in attempts to quantify the efficiencies of cogeneration plants that produce both electric and thermal energy. For that reason, the discussion in this course will assume that 100% of the useful output will be in the form of electric energy, rather than combinations of electric and thermal energy. Such a cycle consists of a combustion turbine-generator (CTG), a heat recovery steam generator (HRSG), and a steam turbine-generator (STG). (I personally prefer the term “heat recovery steam boiler” over HRSG, but I will defer to the industry standard terminology).

The Brayton Cycle

This course will concentrate on the CTG portion of the combined cycle. This may be represented by the Brayton cycle, illustrated by **figure 2**. The compressor draws air in through an inlet filter system. The air is compressed (1-2), and delivered to the combustor, where the fuel is injected and burned. A relatively small pressure drop and a large temperature increase take place in the combustor. The high temperature gas leaving the combustor has a much greater volume than the air entering the combustor, therefore the ability to do work is much greater. The hot gas expands through the turbine (3-4), producing more power than is consumed by the compressor. The turbine drives the compressor, and the excess work drives the load, an electric generator. The exhaust gas is at a pressure slightly higher than atmospheric, and still at a high temperature.



The power production in the turbine is approximately twice that consumed by the compressor, so the net power output is approximately half that produced by the whole engine. The cycle performance is higher at high turbine inlet temperatures, but there are temperature limits imposed by the metallurgy of the turbine blades. For this reason, a portion of the compressor air is bled back for turbine cooling.

Effect of Cycle Parameters

First, an idealized Brayton cycle will be assumed, where:

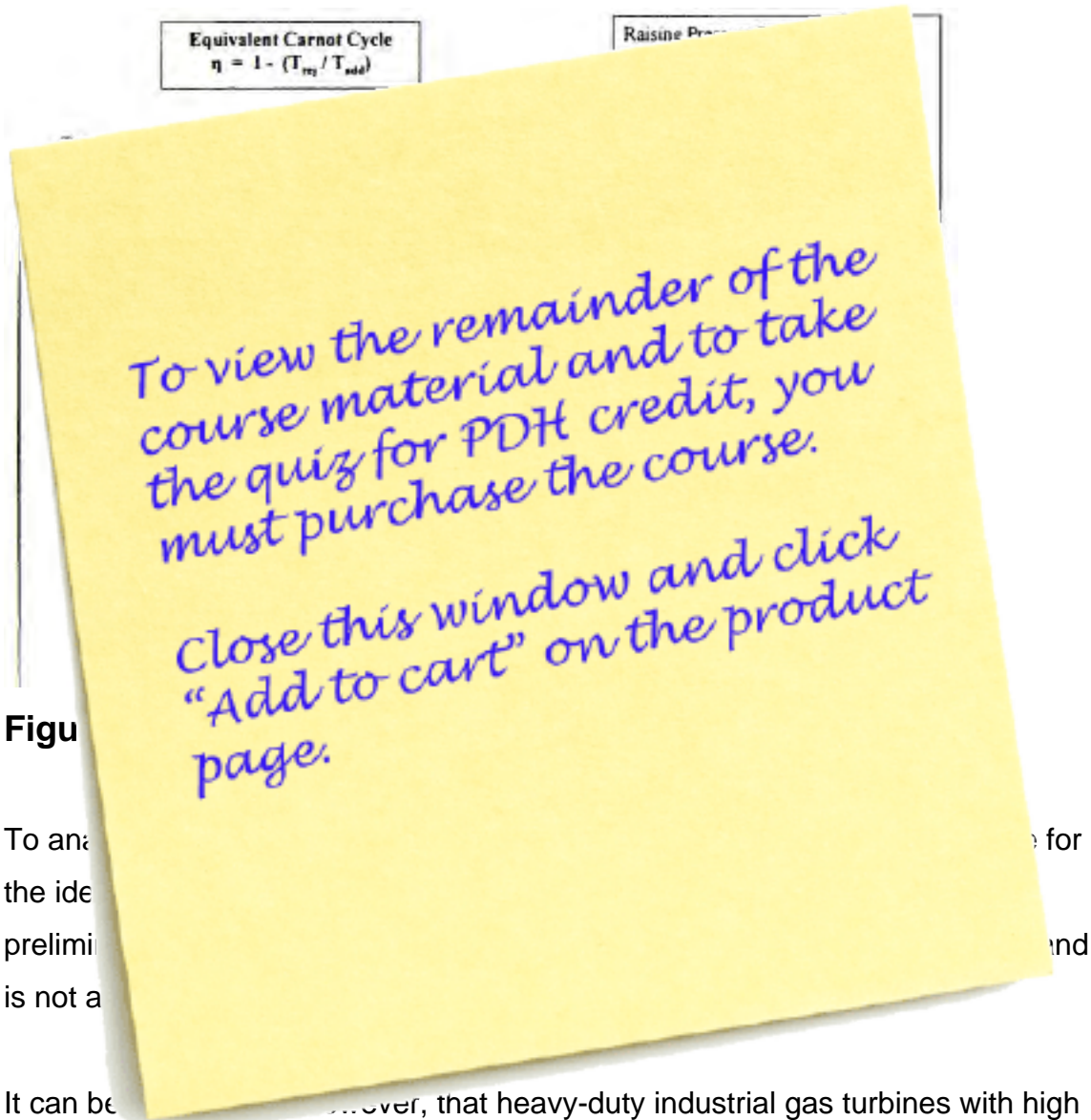
1. The working substance is air throughout.
2. Air is a perfect gas.
3. Fuel mass flow is negligible, and combustion is equivalent to the heat addition at constant temperature.
4. Compressor and turbine are isentropic (100% efficient)
5. Inlet, combustor, and exit pressure losses are zero.
6. Turbine is uncooled.

It can be shown that:

- A. The thermal efficiency of such a cycle is dependent on the pressure ratio only.
- B. The net work per unit air flow (specific power) depends on the pressure ratio as well as the dimensionless maximum temperature ($\dot{\epsilon}$), which is the ratio of turbine inlet temperature to ambient temperature

Figure 3 shows three ideal Brayton cycles with the same $\dot{\epsilon}$ and three different pressure ratios. In the low-pressure ratio case, both the turbine and compressor work are low, so the difference is low, which results in low specific power. The mean temperatures of heat addition and heat rejection are close to one another, resulting in poor efficiency. For the very high-pressure ratio, the turbine and compressor work are both large, but almost equal, so the net work or specific

power are small. The mean temperature of heat addition is much higher than that of heat rejection, resulting in a high efficiency. The intermediate pressure ratio case has the maximum specific power. (Just like in the story of the Three Bears).



Figure

To analyze the ideal cycle, the preliminary design is not a

It can be seen, however, that heavy-duty industrial gas turbines with high specific powers are less sensitive to the mechanical and thermal inefficiencies of the machinery. A typical high-pressure ratio aero-derivative gas turbine, on the other hand, will have a lower specific power and is more sensitive to turbo-machinery inefficiencies. Also, whereas the efficiency of the idealized cycle depends on pressure ratio only, the efficiency of the real cycle depends on the