Combustion Turbine Power Plants

An Online Continuing Education Course for Engineers

Course Number: M-3046

Credit: 3 Hours / 3 PDH / 3 CPD

Combustion Turbine Power Plants

Lee Layton, P.E.

Cover Photograph: Broad River CT Plant, South Carolina. The plant consists of 5 x 170 MW units. Photo is courtesy of Calpine.

Introduction

Combustion turbines (CT) are one of the primary workhorses of the power industry. Because of the abundance of natural gas, new central station power plants will likely be combined cycle plants that use combustion turbines as the first stage as well as used individually as "peakers". Smaller CTs have characteristics favorable for use in distributed energy resource (DER) applications.

Small combustion turbines are found in a broad array of applications including mechanical drives, base load grid-connected power generation, peaking power, and remote off-grid applications. CTs can also be used in cogeneration applications usually with the addition of a heat recovery steam generator. Combustion turbines are also available in transportable configurations allowing the plant to be moved from one location to another.

The concept of a turbine engine has been around for hundreds of years. As early as 150 AD the concept of a steam turbine was presented. In the early 1900's the first gas turbines were produced that could actually generate more power than needed to run the turbine itself. In 1930, Sir Frank Whittle patented the design for a gas turbine for jet propulsion and this unit was the basis of the first utility power generation gas turbine, which was placed in service by Brown, Boveri, & Cie (BBC) in 1939 in Switzerland.

Combustion turbines used for power generation range in size from units starting at about 1 MW to over a 400 MW. Units from 1-15 MW are generally referred to as industrial turbines, a term which differentiates them from larger utility grade turbines and smaller microturbines.

Gas turbines are relatively inexpensive with capital costs ranging from $300-$1000/kW and the costs tend to increase with decreasing power output. Compared with reciprocating engines, combustion turbines tend to cost more for smaller sizes and less at the larger sizes.

The construction process for gas turbines can take as little as several weeks to a few months, compared to years for base load power plants. Their other main advantage is the ability to be turned on and off within minutes, supplying power during peak demand. Since single cycle (gas turbine only) power plants are less efficient than combined cycle plants, they are usually used as peaking power plants, which operate anywhere from several hours per day to a few dozen hours per year, depending on the electricity demand and the generating capacity of the region. In areas with a shortage of base load and load following power plant capacity or low fuel costs, a gas turbine power plant may regularly operate during most hours of the day. A large single cycle gas turbine power plant typically produces 100 to 400 megawatts of power and has 35–45% thermal efficiency.

Combustion turbines have relatively low installation costs, low emissions, high heat recovery, infrequent maintenance requirements, but low energy efficiency. See Table 1 for an overview of the advantages and disadvantages of combustion turbines.

Table 1
Combustion Turbines

Advantages	Disadvantages
Low capital cost	Reduced efficiencies at part load
Readily available over a wide range of power outputs (1MW to over 400MW)	Sensitivity to ambient conditions
Capability of producing high-temperature steam using exhaust heat	Small system cost and efficiency not as good as larger systems
Low operating pressure	High operating costs
High power-to-weight ratio	
Proven reliability and availability	

Gas turbine technology has steadily advanced since its inception and continues to evolve; research is active in producing ever smaller gas turbines. Computer design, along with material advances, has allowed higher compression ratios and temperatures, more efficient combustion and better cooling of engine parts. On the emissions side, the challenge in technology is increasing turbine inlet temperature while reducing peak flame temperature to achieve lower NOx emissions to cope with the latest regulations.

In this course, we will take a detailed look at the natural gas industry including where the current and expected gas reserves are located. Then we will go into the details of how a combustion - or gas - turbine power plant works. Finally, we will discuss some of the environmental impacts of combustion turbines. But first, let's look at the natural gas industry.

Chapter 1

Natural Gas as a Fuel Source

Natural gas is a gas consisting primarily of methane. It is found associated with other fossil fuels, in coal beds, and is created by organisms in marshes, bogs, and landfills. It is an important fuel source and a major feedstock for fertilizers.

Before natural gas can be used as a fuel, it must undergo extensive processing to remove almost all materials other than methane. The by-products of that processing include ethane, propane, butanes, pentanes, and higher molecular weight hydrocarbons, elemental sulfur, carbon dioxide, water vapor, and sometimes helium and nitrogen.

History

Before there was an understanding of what natural gas was, it posed somewhat of a mystery to man. Sometimes, such things as lightning strikes would ignite natural gas that was escaping from under the earth's crust. This would create a fire coming from the earth, burning the natural gas as it seeped out from underground. These fires puzzled most early civilizations, and were the root of much myth and superstition. One of the most famous of these types of flames was found in ancient Greece around 1000 B.C. The Greeks, believing it to be of divine origin, built a temple on the flame. This temple housed a priestess who was known as the Oracle of Delphi, giving out prophecies she claimed were inspired by the flame.

In the 1800s, natural gas was usually produced as a byproduct of producing oil, since the small, light gas carbon chains come out of solution as it undergoes pressure reduction from the reservoir to the surface. Unwanted natural gas can be a disposal problem at the well site. If there is not a market for natural gas near the wellhead it was virtually useless since it must be piped to the end user. In the 1800s and early 1900s, such unwanted gas was usually burned off at the well site. Often, unwanted gas was pumped back into the reservoir with an 'injection' well for disposal or re-pressurizing the producing formation. In locations with a high natural gas demand, pipelines were constructed to take the gas from the well site to the end consumer.

An early commercial form of natural gas was known as “town gas”. *Town gas* is a mixture of methane and other gases, mainly the highly toxic carbon monoxide that can be used in a similar way to natural gas and can be produced by treating coal chemically. Most town "gashouses" located in the eastern United States in the late nineteenth and early twentieth century’s were simple by-product coke ovens which heated bituminous coal in air-tight chambers. The gas driven off from the coal was collected and distributed through town-wide networks of pipes to residences and other buildings where it was used for cooking and lighting purposes. The coal tar that collected in the bottoms of the gashouse ovens was often used for roofing and other water-proofing purposes, and also, when mixed with sand and gravel, was used for creating bitumen for the surfacing of local streets.

Manufactured natural gas of this type was first brought to the United States in 1816, when it was used to light the streets of Baltimore, Maryland. However, this manufactured gas was much less efficient, and less environmentally friendly, than modern natural gas that comes from underground.

Chemical Composition

Natural gas is colorless, shapeless, and odorless in its pure form. It is abundant in the United States and when burned it gives off a great deal of energy and few emissions. Unlike other fossil fuels, natural gas is clean burning and emits lower levels of potentially harmful byproducts into the air.

Natural gas is a combustible mixture of hydrocarbon gases. While natural gas is formed primarily of methane, it can also include ethane, propane, butane and pentane. Table 2 shows the "typical" make-up of natural gas. The make-up varies based on the source of the gas.

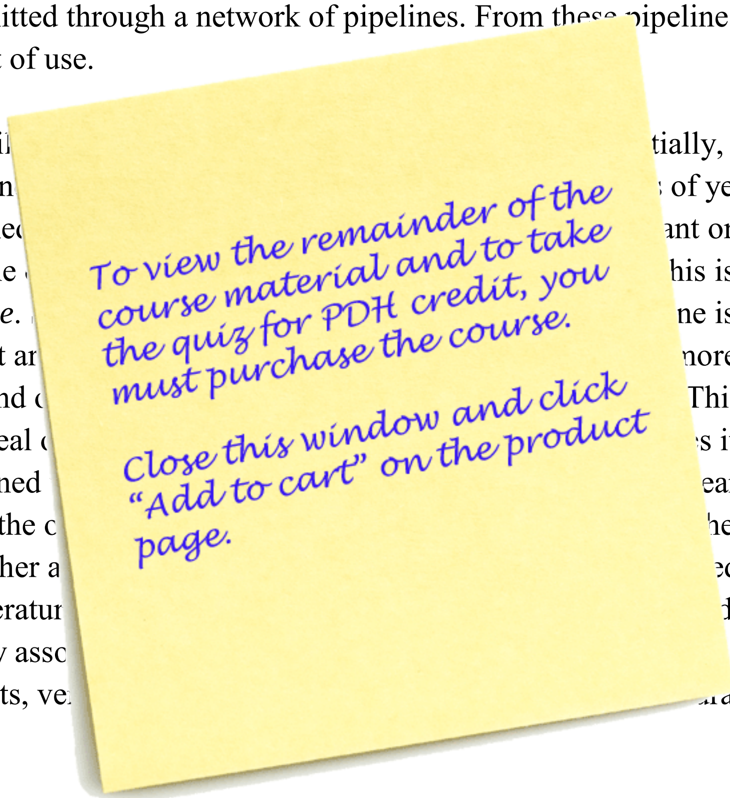
Table 2 Composition of Natural Gas		
Component	**Symbol**	**Percentage**
Methane	CH_4	70-90%
Ethane	C_2H_6	0-20%
Propane	C_3H_8	
Butane	C_4H_{10}	
Carbon Dioxide	CO_2	0-8%
Oxygen	O_2	0-0,2%
Nitrogen	N_2	0-5%
Hydrogen Sulphide	H_2S	0-5%
Rare Gases	A, He, Ne, Xe	Trace amounts

As you can see from Table 2, natural gas is almost pure methane.

Natural gas is considered *dry* when it is almost pure methane, having had most of the other commonly associated hydrocarbons removed. When other hydrocarbons are present, the natural gas is considered *wet*.

Found in reservoirs underneath the earth, natural gas is often associated with oil deposits. Once brought from underground, the natural gas is refined to remove impurities such as water, other gases, sand, and other compounds. Some hydrocarbons are removed and sold separately, including propane and butane. Other impurities are also removed, such as hydrogen sulfide (the refining of which can produce sulfur, which is then also sold separately). After refining, the clean natural gas is transmitted through a network of pipelines. From these pipelines, natural gas is delivered to its point of use.

Natural gas is a fossil … tially, the remains of
plants and animals an… of years ago.
Fossil fuels are forme… ant or animal) is
compressed under the … his is referred to as
thermogenic methane. … ne is formed from
organic particles that ar… nore and more
sediment and mud and … This sediment and
debris puts a great deal … s it. This
compression, combined … earth, breaks down
the carbon bonds in the … he earth's crust, the
temperature gets higher a… ed relative to natural
gas. At higher temperatur… d to oil. That is why
natural gas is usually assc… below the earth's
crust. Deeper deposits, ve… ral gas, and in many
cases, pure methane.



Natural gas can also be formed through the transformation of organic matter by tiny micro-organisms. This type of methane is referred to as *biogenic methane*. Methanogens, tiny methane-producing micro-organisms, chemically break down organic matter to produce methane. These micro-organisms are commonly found in areas near the surface of the earth that are void of oxygen. These micro-organisms also live in the intestines of most animals, including humans. Formation of methane in this manner usually takes place close to the surface of the earth, and the methane produced is usually lost into the atmosphere. In certain circumstances, however, this methane can be trapped underground, recoverable as natural gas. An example of biogenic methane is landfill gas. Waste-containing landfills produce a relatively large amount of natural gas from the decomposition of the waste materials that they contain.