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Externally fired gas turbine technology: A review

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HIGHLIGHTS

- High temperature heat exchanger technology is the key element to the EFGT success.
- Closed cycle EFGT plants were operated successfully for more than half a century.
- Closed cycle EFGT is expected to play a major role in HTR nuclear power plants.
- Biomass fueled EFGT-CHP is a promising candidate for distributed generation.
- Solar hybrid gas turbine is an upgrade for lower carbon-footprint gas turbine.

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ABSTRACT

Externally fired heat engines were used widely since helium the industrial revolution using dirty solid fuels for example coal, due to the lack of refined fuels. However, with the availability of clean fuels, external firing mode was abandoned, except for steam power plants. Lately, with the global trend moving towards green power production, the idea of the external fired system has captured the attention again especially externally fired gas turbine (EFGT) due to its wider range of power generation and the potential of using environment friendly renewable energy sources like biomass. In this paper, a wide range of thermal power sources utilizing EFGT such as concentrated solar power (CSP), fossil, nuclear and biomass fuels are reviewed. Gas turbine as the main component of EFGT is investigated from micro scale below 1 MW_e to the large scale central power generation. Moreover, the different high temperature heat exchanger (HTHE) materials and designs are reviewed. Finally, the methods of improving cycle efficiency such as the externally fired combined cycle (EFCC), humidified air turbine (HAT), EFGT with fuel cells and other cycles are reviewed thoroughly.

Contents

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1. Externally fired gas turbine (EFGT) technology

Externally or indirectly fired gas turbine means that the hot combustion gases are not in direct contact with the turbine blades. Since the turbine's working fluid is separated from the combustion gases, the thermal power of the combustion gases should be transferred to the working fluid via a high temperature heat exchanger (HTHE). Unlike the directly fired gas turbine (DFGT), EFGT can be an open cycle with air as the working fluid, or a closed cycle with air or other fluid having better thermodynamic properties. Thus, an additional gas cooler has to be added to the closed cycle to reduce the gas temperature before reentering the compressor, which also makes this configuration ideal for the combined heat and power (CHP) generation. Some of the common fluids used in the closed cycle EFGT are: helium, carbon dioxide, and nitrogen [1,2]. One of the advantages of the closed cycle is the possibility of operating at higher pressure levels while maintaining low pressure ratio similar to the open cycle. This can reduce the size of the system components considerably due to the lower gas specific volume at higher pressure leading to a higher power-to-volume ratio and lower system cost. On the other hand, system pressure can also be reduced below atmospheric to operate at a lower pressure level.

The externally and directly fired gas turbines are explained thermodynamically by the Brayton cycle, but, the latter can achieve higher specific output power mainly due to its higher turbine inlet temperature (TIT) [3]. However, it can deal only with clean fuels. It can also deal with solid fuels like coal and biomass only after a gasification process [4–8] but with an intensive gas cleaning process. EFGT can deal with a wide range of fuels even solid fuels without cleaning systems or fuel compression and injection equipments. It is very flexible and can use a wide range of thermal power sources such as combustors, furnaces, solar power concentrators and even nuclear reactors. Schematic drawings of the EFGT and DFGT are shown in Fig. 1.

2. EFGT thermal power sources

The EFGT has the advantage of utilizing any available thermal sources. Thus, a wide variety of fuels were tested on this cycle. Table 1 presents some of the EFGT plants/test facilities.

2.1. Fossil fuels with EFGT

During the early stages of gas turbine development, with the shortage in clean liquid and gaseous fuels supply, firing gas turbine directly with pulverized coal was elaborately investigated. Special combustor designs were developed with several ash separators installed between the combustor and turbine [9]. However, it was found that ash contact with turbine blades is inevitable and even with special alloy materials used for the turbine blades, the DFGT plants come short in reliability and plant life compared to the closed cycle EFGT plants.

Many small and medium closed cycle EFGTs have been successfully operated in Europe and the USA during the last century. The starting point for the closed cycle EFGT was in the late 1930s with the 2.3 MW_e Escher Wyss plant facility in Zurich [10,11]. The turbine operated with air as the working fluid and TIT was below 700 °C. Using pulverized coal and also oil, the plant delivered electrical and thermal power for small industries and buildings in Ravensburg with high reliability exceeding 110,000 h of operation [12]. In 1960, a helium closed cycle EFGT was developed to drive a cryogenic facility for gas liquefaction without any output power generation [10]. Also, in the early 1960s, three other CHP-EFGT air closed cycle power plant running mainly on pulverized coal were developed. The first power plant provided 6.6 MW_e and 16 MW_{th} of electrical and thermal power respectively for the city of Coburg [11–13]. Detailed description of the plant and the operation experience is presented by Bammert [14]. The second plant was in Oberhausen with electrical and thermal powers of 13.7 MW_e and 28 MW_{th} respectively [11–13]. Further studies using mathematical models were conducted on this plant and the results were compared with experimental results [15]. The third plant was in Haus Aden with electrical and thermal powers of 6.4 MW_e and 7.6 MW_{th} respectively [11–13]. New calculation methods by implementing Wohlenberg method with higher surface temperature and irradiation curves were proposed to improve heat transfer calculation in the coal fired furnaces and HTHE. Numerical results were verified against the experimental data obtained from this plant [16]. With the experience gained from these plants, scaling up of the output power was done to meet the increasing demand for power. In 1967, a larger CHP-EFGT was developed to provide 17.25 MW_e

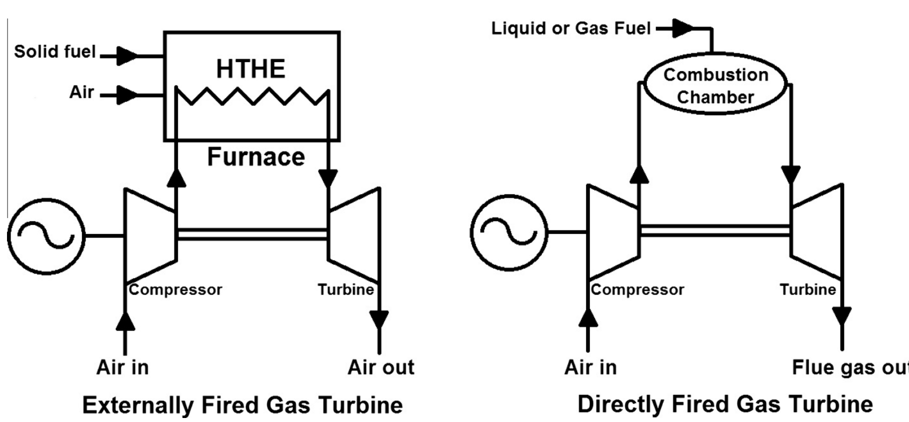

Fig. 1. Simple externally and directly fired gas turbine cycles.