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Research paper

Analysis of a high-temperature heat exchanger for an externally-fired micro gas turbine

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HIGHLIGHTS

- The performances of two heat exchangers for externally fired gas turbine-cycles were compared.
- The effectiveness of the corrugated plate heat exchanger is more influenced at larger thicknesses of deposit materials.
- The effect of the deposit materials is twofold for both heat exchangers.
- The effectiveness has a stronger influence in the power output than the pressure drop.

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ABSTRACT

The externally-fired gas turbine (EFGT) can convert fuels such as coal, biomass, biomass gasification gas and solar energy into electricity and heat. The combination of this technology with biomass gasification gas represents an interesting option for gasification, for which it has been difficult to find a conversion technology. In this system, the heat exchanger deals with the contaminants of biomass derived gas instead of the turbine itself. However, these contaminants can build a deposit layer in the heat exchanger that can affect its performance. The heat exchanger is important in externally fired gas turbines since the turbine inlet temperature is directly dependent on its performance. Several studies on heat exchangers for externally fired gas turbines have been carried out. However, very few detailed studies were found comparing the performance of heat exchangers for externally fired gas turbines considering the effect of deposit materials on the surfaces. In this regard, this work compares the performance of a corrugated plate heat exchanger and a two-tube-passes shell and tube heat exchanger considering the effect of thickness of deposit material with different thermal conductivities on pressure drop and effectiveness. The results show that the effectiveness of the corrugated plate heat exchanger is more influenced at larger thicknesses of deposit materials than the two-tube-passes shell and tube heat exchanger. There is an exponential increase in the pressure drop of the plate heat exchanger while a monotonic increase of pressure drop is seen for the shell and tube heat exchanger. The increase in the thickness of the deposit material has two effects. On one hand, it increases the resistance to heat transfer and on the other hand, it reduces the through flow area increasing the velocity and hence the heat transfer coefficient. Additionally, the effectiveness of the heat exchangers had a stronger influence on the power output than the pressure drop.

1. Introduction

Externally fired gas turbines (EFGT) are an interesting option for electricity and heat production due to their configuration. In externally fired gas turbines, combustion takes place outside the cycle at atmospheric pressure. Flue gas coming from the combustor heats the compressed air in a heat exchanger. The resulting hot, clean and compressed air is later expanded in a turbine. This

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Nomenclature

A	heat transfer area, m^2
b	plate distance, mm
C	heat capacity rate, W/K
c_p	heat capacity, kJ/kg K
d	diameter, m
d_e	equivalent diameter, m
d_h	hydraulic diameter, m
Ds	shell diameter, m
De	equivalent diameter for the shell side, m
f	friction factor, dimensionless
h	heat transfer coefficient, W/m^{2}K
k	thermal conductivity, W/m K
L	length, m
m	mass flow rate, kg/s
N_b	number of baffles, dimensionless
N_p	number of passes, dimensionless
NTU	number of transfer units, dimensionless
Nu	Nusselt number, dimensionless
Pr	Prandtl number, dimensionless
ΔP	pressure drop, Pa
Re	Reynolds number, dimensionless
R_f	fouling factor, m^{2}K/W
T	temperature, K
U	overall heat transfer coefficient, W/m^{2}K
v	actual velocity, m/s
V	volumetric flow, m^3/s
x_f	thickness of deposit material, m

Greek letters

β	chevron angle
ε	effectiveness
ρ	density, Kg/m^3
μ	viscosity, N s/m^2

Subscripts and superscripts

c	cold
h	hot
i	inlet
max	maximum
min	minimum
o	outlet
t	tubes
w	wall

configuration allows the use of a variety of fuels since the flue gas is not in direct contact with the turbine [1].

The configuration of externally fired gas turbines represents an option for utilizing biomass gasification gas. Biomass gasification gas has encountered difficulties in finding a conversion technology capable to deal with its contaminants [2]. These contaminants are particulates, alkali metals, tars, sulfur and chlorine. They can cause erosion, hot corrosion, clogging and depositions internally [3]. Cleaning steps are recommended prior to using gasified biomass in internal combustion engines and standard gas turbines, where combustion takes place as part of the cycle [4]. However, the addition of cleaning steps after gasification has made it a complex and costly system [2]. Instead, externally fired gas turbines offer an opportunity for biomass gasification gas reducing strict fuel quality requirements by switching the flue gases to the heat exchanger, and thus avoiding direct contact with the turbine [1,2].

The heat exchanger is the main component in externally fired gas turbines. The heat exchanger should be able to deal with the conditions of the flue gases from biomass gasification gas and operate at high temperatures for long periods of time. Additionally, the cold side outlet temperature from the heat exchanger corresponds to the turbine inlet temperature (TIT). Theoretically, a higher turbine inlet temperature increases the efficiency of the cycle. As a result, the selection of a heat exchanger type that can handle these conditions is important. The size, the temperatures, the fluids, the geometry, and other factors influence its performance.

There are various studies of different types of heat exchangers to be used in externally fired gas turbines. Zimmermann et al. [5] proposed a pebble heater when using combustion of solid biomass in an externally fired gas turbine system. The pebble heater was able to work up to 950 °C [5]. A bayonet tube heat exchanger with internal fins was suggested by Zeng et al. [6] for high temperature applications. Gaderer et al. [7] suggested a heat exchanger immersed in a fluidized bed combustor when using solid biomass. This concept was chosen in order to reduce fouling and increase heat transfer.

Chu et al. [8] studied the flow nonuniformity of a plate-fin heat exchanger for high temperature applications. The effect of inclined, helical, and segmented baffles added at the inlet were compared. The addition of helical baffles changing the pitch equidifferently reduced the flow nonunformity, increased the Nusselt number and pressure drop [8]. Ma et al. [9] investigated the thermo-hydraulic performance of a ribbed channel in a heat exchanger. It was found that the heat transfer was improved with increasing the rib height and pressure drop was higher when the inlet temperature increased [9]. Nagarajan et al. [10] developed a novel ceramic plate-fin heat exchanger using CFD simulations. The thermal and hydraulic performances of nine different fin designs were compared for high temperature applications [10]. Monteiro and Batista de Mello [11] studied a ceramic offset strip fin heat exchanger for high temperature applications using CFD simulations. Correlations for Colburn and friction factors were found for the heat exchanger studied [11]. Additionally, varying the geometrical dimensions of the heat exchanger suggested, the effect of pressure drop and effectiveness on the net electrical efficiency of an externally fired gas turbine cycle was analyzed. The results showed that the effectiveness of the heat exchanger had a stronger influence than the pressure drop on the efficiency of the cycle studied [12]. Ma et al. [13] analyzed the heat transfer and pressure drop performances of an offset-bubble primary surface channel. The study was focused on the surface structure and geometrical parameters [13]. Cordiner et al. [14] proposed a high-temperature flat plate fin heat exchanger coupled to a furnace for a prototype power plant based on an externally fired gas turbine. The objective was to take advantage of radiative and convective heat transfer. The prototype was modeled with the proposed heat exchanger. The power output and efficiency were evaluated with different characteristics of the fuel. A control of the biomass characteristics in terms of higher heating value was found to be very important to reduce its impact on the performance of the prototype studied [14].

Al-attab and Zainal [15] suggested a shell and tube heat exchanger as more suitable for externally fired gas turbines when using biomass gasification gas due to fouling and maintenance