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A methodology for the geometric design of heat recovery steam generators applying genetic algorithms

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HIGHLIGHTS

► The paper shows a methodology for the geometric design of heat recovery steam generators.
► Calculates product of the overall heat transfer coefficient by heat exchange area as a function of certain HRSG thermodynamic design parameters.
► It is a complement for the thermoeconomic optimization method.
► Genetic algorithms are used for solving the optimization problem.

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ABSTRACT

This paper shows how the geometric design of heat recovery steam generators (HRSG) can be achieved. The method calculates the product of the overall heat transfer coefficient (*U*) by the area of the heat exchange surface (*A*) as a function of certain thermodynamic design parameters of the HRSG. A genetic algorithm is then applied to determine the best set of geometric parameters which comply with the desired UA product and, at the same time, result in a small heat exchange area and low pressure losses in the HRSG.

In order to test this method, the design was applied to the HRSG of an existing plant and the results obtained were compared with the real exchange area of the steam generator. The findings show that the methodology is sound and offers reliable results even for complex HRSG designs.

1. Introduction

The Combined Cycle Gas Turbine (CCGT) power plant efficiency is affected by the design of all its components. Among them, the Heat Recovery Steam Generator (HRSG) is one of the most important, since there the union of the gas and steam cycles takes place. The power generated by the steam cycle is strongly dependent on the HRSG thermal efficiency. The power generated by the steam cycle is highly dependent on the HRSG thermal efficiency. Therefore the thermodynamic HRSG design parameters must be carefully selected in order to achieve the optimum performances in the combined cycle.

Many authors have directed their researches to the optimization of CCGT power plants and HRSG [1,4,5,14].

Certain works are specifically concerned with the design of the HRSG, for instance, that of Franco and Giannini [6] show a method, based on hierarchical strategy, for the optimal design of the HRSG, considering the maximization of the compactness index and the minimization of the pressure losses. On the same topic, Manassaldi et al. [10] proposed a methodology for the HRSG design. This methodology applies a mixed nonlinear program model to optimize the design according to three criteria: net power maximization, the ratio between net power and material weight maximization, and net heat transfer maximization. The results of this paper are accurate but the economic optimization problem is not discussed.

On the other hand, Rovira et al. [11], Duran [5] and Valdés et al. [15] (the latter is the preceding work to this most recent one) made a thermoeconomic optimization which minimizes the generating cost or maximizes the annual cash flow of the plant, considering as independent design parameters of the HRSG the thermodynamic design variables: namely, drum pressure, pinch points, approach

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Nomenclature

A	HRSG area (m^2)
ap	approach point (K)
b	HRSG width (m)
d_0	outer tube diameter (mm)
d_2	fin diameter (mm)
e_t	thickness of tube (mm)
e	thickness of fin (mm)
f	function
h	enthalpy (kJ/kg)
k	thermal conductivity (W/mK)
K	penalization constant
L	tube length (m)
l_{perp}	tubes separation
l_{par}	row separation
η	thermal efficiency
N_t	Number of tubes per row
N_{prof}	number of tubes per column
pp	pinch point (K)
Pen	penalization
r_i	inner radius
r_o	outer radius
t	temperature (K)
v	velocity (m/s)
U	overall heat transfer coefficient (W/m^2K)
W_{cc}	combined cycle total power (kW)
x	general variable
x_i	restriction value of a general variable
z	number of fins per unit length
ΔT	gas to steam temperature difference at the superheater (K)
Δp	pressure loss (Pa)
ρ	density (kg/m^3)

Subscripts

e	error
Ec	economizer
Ev	evaporator
f	fitness
HP	high pressure
HRSG	heat recovery steam generator
i	inside conditions
IP	intermediate pressure
g	gas
Geom	obtained with the geometric parameters
Lim	limit
LP	low pressure
o	outside conditions
obj	objective
sh	superheater
Therm	obtained with the thermodynamic parameters
v	vapor

points and temperature differences at the superheater exit. In this work, the selection of a given set of these thermodynamic parameters led to the determination of the products (UA) of the overall heat transfer coefficient (U) by the area (A) of the HRSG heat exchange surfaces. Nevertheless, various pairs of U and A might lead to the same UA product. Thus, as the same thermal CCGT performances could be obtained with different HRSG geometric designs, the HRSG geometric design was undetermined and there is still room for improvement of the optimization process.

This more recent work applied the results obtained with the thermoeconomic optimization proposed by Valdés et al. [15] and Durán and Galindo [5] and presents a method that solves the uncertainty in the determination of the HRSG geometric design parameters. The method proposed here uses a genetic algorithm in order to find the geometric design of the HRSG which fulfills the desired UA product while, at the same time, obtaining a small heat exchange area and low pressure losses.

2. HRSG description

2.1. Geometric parameters of the HRSG

A single pressure level HRSG has three different sections: economizer, evaporator and superheater (see Fig. 1).[1] The flow conditions and the manufacturing materials differ from section to section, so the pressure losses and the convective heat transfer coefficient are different too.

Each HRSG section could be considered a crossflow heat exchanger. Its corresponding arrangement and some of the geometric design parameters are shown in Fig. 2. Most of the geometric design parameters for each section are different, but in this paper it will be considered that the length of the tubes (L) and the width of each section (b) (economizer, evaporator, superheater) have the same value, in order to have an HRSG with uniform transverse section.

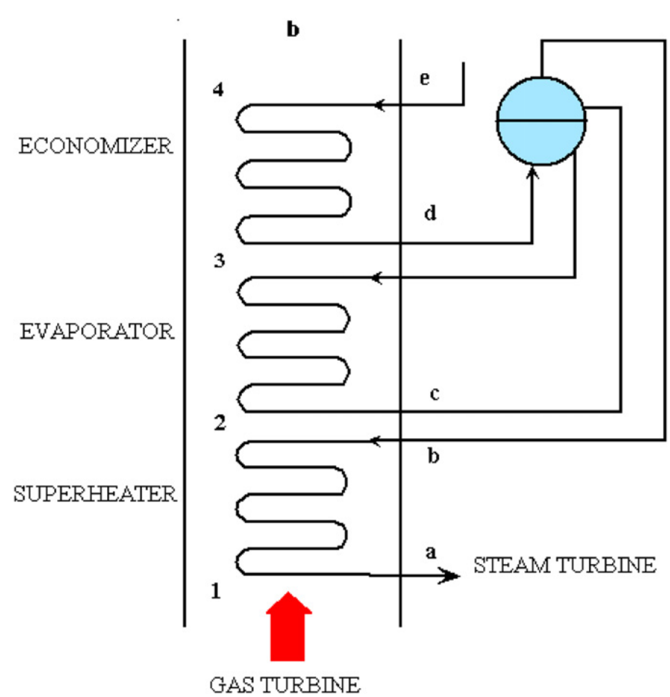

Fig. 1. Schema of the one pressure level heat recovery steam generator.

[1] When the HRSG has more pressure levels the sections are the same but corresponding to each pressure level.