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Research Paper

Experimental and numerical investigation of optimum design of semi industrial heat recovery steam generator inlet duct

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HIGHLIGHTS

- To suggest geometry improvement of inlet duct of heat recovery steam generators in power plants.
- To gain optimum distribution of inlet duct of pilot model.
- To use both numerical and experimental methods for inlet duct geometry optimization.
- To apply the proposed method in a standard inlet duct of a 5 MW HRSG in power plant.

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ABSTRACT

The optimization of Heat Recovery Steam Generators (HRSGs) is one of the key parameters to optimize the efficiency of combined cycle power plants. One of the major characteristics in the field of HRSG design and optimization is the investigation of flow within the body from the hydrodynamics point of view. Making uniform flow with minimal pressure loss over time has been an interesting issue for HRSG designers and manufacturers. In this research study, a comprehensive analysis and assessment of flow patterns in the tradition zone of inlet duct of horizontal HRSG is conducted using both experimental and numerical methods. The HRSG is modeled in 1/10 scale-down and velocities are measured by an anemometer device (KM 909 model) at diverse points in its selected sections. Numerical simulation is performed to compare with different results of experimental study in order to ensure the validity. In this study, the difference rages of inlet duct angle are analyzed and finally the optimum model in terms of flow was compared with initial model by using smoke test. The results shown that inlet duct with 23° angle and movable plate with 200 mm length is better than others based on hydrodynamics with minimum velocity deviation and pressure loss between the outlet of fan and transition zone.

1. Introduction

Combined cycle power plants (CCPPs) have attracted ample interests during the last decades as they can recover exhaust energy from a gas turbine to generate electricity in a Rankine cycle. These systems can increase the efficiency while reducing greenhouse gas emissions. In CCPPs energy is recovered in a heat exchanger called a heat recovery steam generator which works as a connector between the topping cycle (i.e., Bryton cycle) and the bottoming cycle (i.e. Rankine cycle). Therefore, the better design of an HRSG will result in a better performance of the power plant [1,2]. Besides the thermodynamic optimization of the HRSG, the fluid flow in HRSG is another important factor affecting the system performance. The inlet side of HRSG is connected to the exit side of gas turbine by an interconnecting duct. There are many aspects to design HRSG channel, in which the flow correction at inlet duct to provide the uniform distribution of velocity is an important one. The non-uniformity in the gas flow pattern may cause a male heat transfer, which leads to heterogeneous thermal absorption in different positions of tubes. This is hence the flow quality is an effective factor on the overall amount of heat transfer. Velocity profile and flow pattern while passing the inlet duct determine the quality of the flow field in the HRSG casing. In the ideal state, flow should enter the HRSG casing uniformly but in real cases, velocity and temperature profiles vary in the casing entrance section and are not equal in all points. Due to the difference in the amount of receiving gas, upper and lower half of the tube bundles have different temperatures. Therefore, while the lower half temperature rises, upper half will have less temperature. These

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Nomenclature

A_1	first area [m^2]
A_2	transition zone [m^2]
F_B	body force
N	number of data
Q	flow rate [m^3/min]
Re	Reynolds number
u	local normal velocity [m/s]
u_{rms}	RMS velocity [m/s]
U	mean velocity [m/s]
V	velocity [m/s]
θ	angle [°]
ρ	density $\left[\frac{kg}{m^3}\right]$

temperature and velocity non-uniformities lead to some problems. To assure a desirable velocity distribution an experimental test on the model HRSG duct should be conducted. Therefore, flow patterns have to be analyzed and transition zone should be carefully designed for better uniformity.

The optimum design of HRSG has a particular interest to enhance the performance of heat recovery to raise the effectiveness of the combined cycle. There are several studies on thermodynamic optimization of HRSGs [3–5].

Mohagheghi and Shayegan [6] introduced a new method for modeling a steam cycle in advanced combined cycle by organizing non-linear equations and their simultaneous solutions by use of the hybrid Newton methods. Hajabdollahi et al. [7] modeled an HRSG with a typical geometry and a number of pressure levels used at combined cycle power plants. They also applied a fast and elitist non-dominated sorting genetic algorithm with continuous and discrete variables to obtain maximum exergy efficiency with minimum total annual cost per produced steam exergy as a two objective functions. Ameri et al. [8] conducted the exergy analysis of a combined cycle power plant equipped with supplementary firing (SF) in the HRSG inlet. The results showed that using SF results in an increase in output power while reducing the exergy efficiency of the cycle. In another study Ameri and Ahmadi [9] studied the effect of ambient temperature on exergy losses of a heat recovery steam generator and concluded that ambient temperature will affect the HRSG performance. Ghazi et al. [10] performed a comprehensive thermodynamic modeling of a dual pressure combined cycle power plant and carried out an optimization study to find the best design parameters. Sindareh et al. [11] studied the thermodynamic modeling based optimization for thermal systems in heat recovery steam generator during cold start-up operation. Duran et al. [12] performed a methodology for the geometric design of heat recovery steam generators applying genetic algorithms.

Several researches have also been conducted on the flow pattern inside the HRSG. Yoo et al. [13] considered the change of inlet duct shape for the improved uniform flow and showed its possibility. Ameri and Jazini [14] considered the CFD modeling of heat recovery steam generator inlet duct. In their study the abilities of computational fluid dynamics have been assessed to obtain the crucial profiles without the experimental difficulties. Regarding the special characteristics of flow and geometry, numerical solution may not be performed without taking some techniques into the CFD modeling. Hegde et al. [15] made a modification in the internal configuration of the HRSG. They investigated the influence of a flow correction device (FCD) on the profile of the gas flow entering a high pressure superheater. They modeled the FCD by a perforated plate of a given open area. They also attained a further

Table 1
Characteristic of system according to flow.

Tests numbers	$Q\ \left(\frac{m^3}{min}\right)$	A_1	A_2
		$V_{av}\ \left(\frac{m}{s}\right)$	$V_{av}\ \left(\frac{m}{s}\right)$
Test 1	2.2	3.86	0.75
Test 2	3.5	6.14	1.19
Test 3	5	8.77	1.71
Test 4	6.5	11.4	2.23

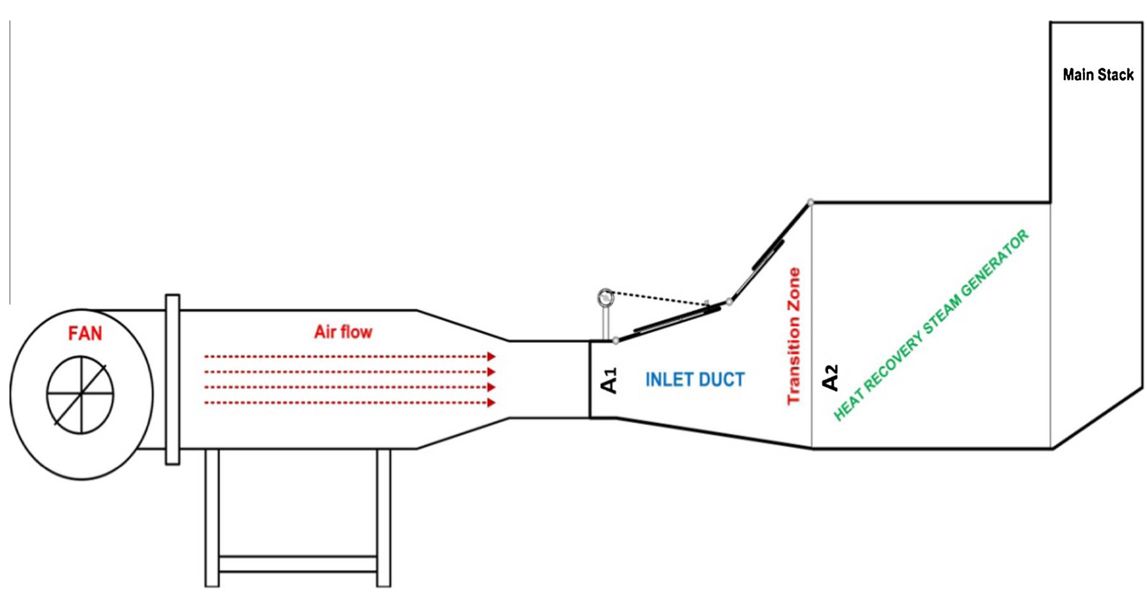

Fig. 1. Schematic of horizontal HRSG and fan.