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Research paper

A novel method for inlet duct geometry improvement of heat recovery steam generators

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HIGHLIGHTS

- To suggest geometry improvement of inlet duct of heat recovery steam generators in power plants.
- To conduct numerical simulation of fluid flow in inlet duct of heat recovery and its 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 geometry of inlet duct of HRSGs strongly affects flow uniformity and plays an important role in an increase in the efficiency of combined cycle power plants (CCPPs) where HRSG is the main component. Therefore, using some remedies to create a uniform flow distribution in HRSG inlet duct seems to be required in order to avoid reducing the effective surface temperature. In this research paper, part elimination and lattice search (PELS) method is presented to improve the inlet duct geometry. This is an innovative method which improves the inlet duct shape due to the amelioration of the flow quality. Uniformity of the velocity profile is considered at the exit section by quantifiable performance parameters of Root Mean Square (RMS). The RMS difference of local velocity from average velocity is used to evaluate the uniformity of the flow. To apply this method, a standard inlet duct of a 5 MW HRSG is considered and improvements for this case are addressed. The terms of uniform velocity and temperature distribution along the HRSG is numerically solved and explained. Finally, the results are reported in order to compare the standard inlet duct and the improved one. The comparison shows that the flow uniformity at the duct exit section in the modified model has been enhanced.

1. Introduction

Heat recovery steam generator (HRSG) is a heat exchanger that facilitates the heat exchange between two fluids at two different temperatures. The hot fluid, which can be the exhaust of a gas turbine, passes through inlet duct and enters a HRSG casing as shown in Fig. 1. The exhaust heat is then utilized and transferred to the cold fluid, working fluid of the Rankine vapor cycle, in individual parts such as superheater, evaporator and economizer. Fig. 1 also shows a schematic of all the components of a typical HRSG. HRSGs play a significant role in combined cycle power plants as they recover exhaust energy from gas turbines and utilize the heat in order to produce steam in the bottoming cycle to drive a steam turbine to generate electricity. This is hence really important to have and optimized and cost effective HRSG which has the ability to recover more energy to increase the power plant efficiency. The higher the energy recovered, the higher the thermal efficiency of the power plant.

In addition to the heat exchanger element along the HRSG, flue gas temperature entering the HRSG, pinch point temperature difference, inlet HRSG duct shape is another major parameter which leads to better performance of the system [1]. In designing an HRSG, having an inlet duct in a way that can create a uniform flow is

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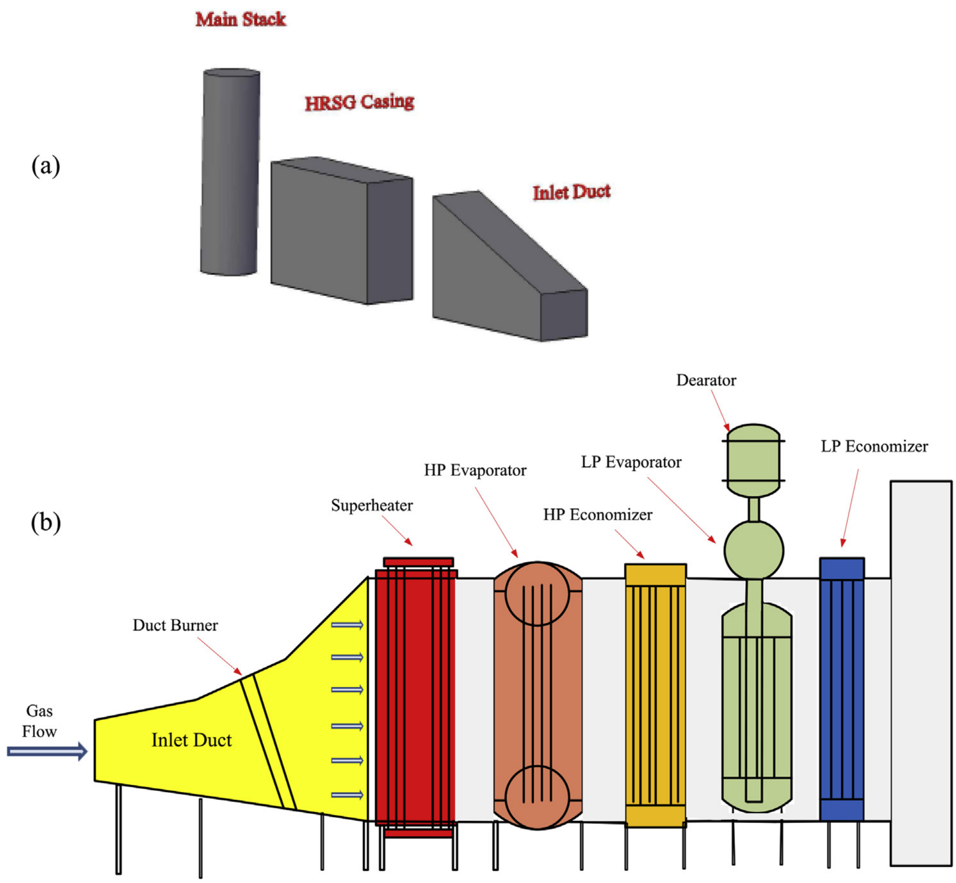

Fig. 1. HRSG main sections; (a) 3D view, (b) 2D view of components.

of the greatest importance on superheater and evaporator tube bundles for heat recovery steam generator manufacturers [8]. Optimizing the HRSG design parameters are referred by several researchers. Casarosa et al. [5] performed a thermodynamic optimization based on the minimization of exergy losses and provided a thermoeconomic optimization based on the minimization of the total HRSG cost. Mohagheghi and Shayegan [15] introduced a new method for modeling a steam cycle in advanced combined cycles by organizing non-linear equations and their simultaneous solutions by use of the hybrid Newton methods. Hajabdollahi et al. [10] modeled a 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. Tajik Mansouri et al. [20] investigated the effect of HRSG pressure levels on exergy efficiency of combined cycle power plants and showed how an increase in the number of pressure levels of the HRSG affect the exergy losses due to heat transfer in the HRSG and the exhaust of flue gas to the stack. Ameri et al. [3] conducted the exergy analysis of a combined cycle power plant equippted with supplemnetray 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 Ref. [4] they studied the effect of ambient temperature on exergy losses of a heat recovery steam generator and concluded that ambinet temperature will affect the HRSG performance. Ghazi et al. [9] 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.

Ahmadi et al. [1] conducted exergy, exergoeconomic and environmental impact assessment of a combined cycle power plant equipped with supplementary firing and they applied an evolutionary based optimization to determine the optimal design parameters. The concluded that optimization of HRSG can lead to an increase in system efficiency. In another study [25] they performed a sensitivity analysis of changing fuel cost and other parameters to optimize a CCPP with dual pressure HRSG.

The flow pattern can affect the heat transfer efficiency. The non-uniformity in the gas flow pattern may cause an irregular heat transfer, which leads to heterogeneous thermal absorption in different positions of the superheater or evaporator tubes. So the flow quality is an effective factor on the overall amount of heat transfer. Velocity profile and flow pattern passing through 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 do not have equal values.

Because of the non-uniformity of flow, the amount of receiving hot gas in the lower half of the tubes is more than the upper half. So that upper and lower half of the tube bundles have different temperatures in such a way that the lower half temperature increases, while the upper half has a lower temperature. These temperature and velocity non-uniformities lead to some major problems, including high exergy destruction along the heat transfer elements in the HRSG. Upper parts of the superheater and evaporator would quit the heat exchange process due to the same reasons. Moreover, temperature difference increases heat stress and causes damage and failure in the HRSG. The combination of these effects will lead