Energy 66 (2014) 907–918

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Efficiency and power upgrade by an additional high pressure economizer installation at an aged 620 MWe lignite-fired power plant

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A R T I C L E I N F O

Article history:
Received 22 July 2013
Received in revised form
10 December 2013
Accepted 1 January 2014
Available online 27 January 2014

Keywords:
Waste heat
Flue gas
Economizer
Boiler

A B S T R A C T

An additional high pressure economizer was installed at Unit B1 of the 620 MWe lignite-fired Power Plant "Nikola Tesla B" after 30 years of its operation. An innovative connection of the new additional economizer was applied. It is in parallel connection to the first section of the originally built economizer and it is directly fed with the feedwater from the outlet of the feedwater pump. The analysis of Unit B1 operation with such an economizer arrangement is performed and it is supported by measured data. It is shown that more than 30 MWth of the flue gas waste heat is recovered. The Unit gross efficiency is increased by 0.53 percentage points, which leads to 9.4 MWe of the electric power production. The parallel connection of the additional economizer also leads to the partial feedwater bypass of the high pressure heaters, which enables an increase of the plant electric power by up to 24.5 MWe. The accompanying effects are the reduction of the pressure drop in the feedwater line and the economizers, which leads to the decrease of the energy consumption for the main feedwater pump operation. The applied solution is presented together with measured and calculated energy and economic benefits.

1. Introduction

Electricity is indispensable for modern societies. For example, many industrial machines and devices, household appliances and information technologies are powered by electricity. Its consumption is related to the Human Development Index, which is a composite measure of health, education and income or a measure for human well-being [1]. In 2011 the share of electricity in the final energy consumption in the world was 17.7%, while this share in the economically developed part of the world represented by the OECD (the Organisation for Economic Co-operation and Development) countries is even higher 22% [2]. Hence, a lot of attention is applied to the efficiency of electricity final consumption, for instance in residential and industrial sectors [3]. At the same time, a substantial increase of the overall efficiency of energy systems can be achieved by measures on the electricity supply side, especially in countries where electricity is produced in thermal power plants by coal combustion. Coal is still the main energy source for electricity production in the world, according to [2] its share was 41.3% in 2011. Recent commercial developments of the technology of thermal power plants that operate under steam Rankine cycles have risen their efficiency, but the majority of thermal power plants are built decades ago and their efficiency is still below 40% [4]. Therefore, the increase of efficiency of aged thermal power plants leads to the reduction in coal consumption and the increase of overall energy efficiency, especially in countries that are dependent on coal consumption. Examples of other important benefits are the reduction of carbon-dioxide emission and increase of electricity generation economy.

The utilization of waste heat of flue gases at thermal power plants leads to an important increase of efficiency in electricity production. In Ref. [5] it is indicated that a reduction of the exit flue gas temperature from 130 °C to 120 °C at a pulverized coal-fired thermal power plant increases the net plant efficiency by about 0.3 percentage points. Although this is only a fraction of one percent it leads to substantial fuel conservation, especially at the large thermal power plants that operate with the electric power of several hundred megawatts or even in the range of 1 GW throughout the year. The utilization of waste heat and the cooling of

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0360-5442/$ – see front matter
http://dx.doi.org/10.1016/j.energy.2014.01.001

flue gases to temperatures below 130 °C is a common procedure at thermal power plants equipped with the flue gas desulphurization systems. Besides the waste heat utilization, the cooling of the flue gas provides benefits for the desulphurization process, such as a reduction of energy and water consumption and an increase of desulphurization efficiency. At the 900 MWe lignite-fired thermal power plants Schwarze Pumpe, Lippendorf and Boxberg in Germany, specially designed heat exchangers were installed behind the electrostatic precipitator and in front of the flue gas desulphurization plant with the aim of waste heat utilization from the exhaust flue gas, as shown in Fig. 1 [6]. The heat recovered from the flue gas is transferred by a water circulation system and through intermediate heat exchangers into the condensate line in the steam turbine plant. This solution provides the flue gas cooling from 170 °C to 130 °C and an increase of the power plant efficiency by approximately 0.5%. A similar design solution was analyzed in Ref. [7] for a 600 MWe coal-fired power plant. It was assumed that the heat recovered in a heat exchanger from the flue gas is transferred to water directly taken from the condensate line in the steam turbine plant, without application of the intermediate heat exchangers. The application of finned tubes was considered in the flue gas-water heat exchanger. Cases analyzed in Ref. [7] show the flue gas cooling from 123 °C to temperatures below 100 °C. Comprehensive design solutions for the utilization of waste heat from the flue gas were applied at the 1000 MWe lignite-fired power plant Niederaussem Unit K [8]. The heat recovered by cooling the flue gas in a gas-water heat exchanger, from approximately 160 °C–100 °C or even lower, in front of the desulphurization plant, is transported by a closed water circuit to a water–air heat exchanger that preheats the combustion air (Fig. 2). In addition, high pressure and low pressure economizers are installed in a bypass flue gas channel behind the main economizer bank at the top of the steam generator. The high pressure bypass economizer provides heat directly to the high pressure feedwater in parallel with the high pressure heaters 1 to 3. The low pressure bypass economizer provides heat to a naturally recirculating system incorporating a steam drum that transfers heat to the condensate line through a heat exchanger, which is in parallel connection with the low pressure heater 5. The installation of the low pressure economizer for the flue gas heat recovery was analyzed in Ref. [9] based on the data from an existing 1000 MW typical power generation unit in China. Four possible arrangements for water taking from the condensate line, heating in the economizer and returning to the condensate line were investigated. It was found that a delivery of the recovered heat to a higher temperature section of the condensate line with regenerative heaters provides higher energy-saving effects than a delivery to a colder part. The example of low pressure economizer installation in the Shanghai Waigaoqiao No. 3 power plant is reported in Ref. [9] based on the original paper published in Chinese in Ref. [10]. In this case the condensed water is used from the inlet of the 7th low-pressure regenerative heater to retrieve the waste heat of flue gas. This solution reduces the design temperature of the flue gas

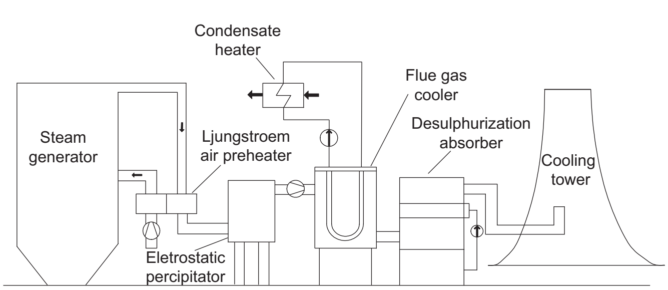

Fig. 1. Flue gas cooling in front of the desulphurization plant [6].

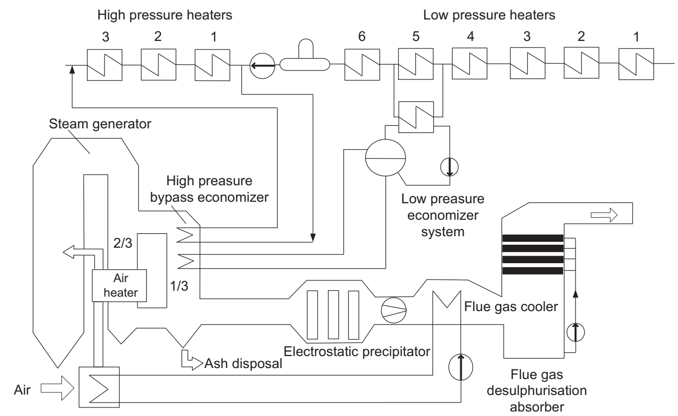

Fig. 2. Multiple solutions for the recovery of waste heat from the flue gas at the power plant Niederaussem Unit K [8].

from 125 °C to 85 °C, which improves boiler efficiency by 2% points and overall unit efficiency by 0.8–0.9% points.

It should be mentioned that there are numerous methods for the utilization of the flue gas waste heat. In Ref. [11] the usage of the heat pumps is analyzed, in Ref. [12] various solution methods applicable to waste-to-energy process plants are presented, and a development of systems based on the Organic Rankine Cycles for the waste heat utilization from low-temperature flue gases is presented in Refs. [13], to mention a few.

In this paper an innovative and applied solution for the waste heat utilization from the steam boiler exit flue gas is presented. It was applied at an aged, 30 year old unit of the lignite-fired Thermal Power Plant “Nikola Tesla B” in Serbia. It consists of an additional economizer that was installed parallel to the first section of the originally built economizer. The additional economizer is fed with the feedwater by a newly installed separate feedwater line that is connected to the main feedwater pump discharge line. In Section 2 the motivation for the retrofit of Unit B1 at the Thermal Power Plant “Nikola Tesla B” is presented together with the solution of the additional economizer installation. The applied approach to the energy analysis of the retrofitted power plant is presented in Section 3. In Section 4 presented and discussed are the results of the energy efficiency and electric power upgrade at the power plant, which are achieved by the additional economizer installation. The economic evaluation of the project is also performed. The achieved energy and economic benefits are outlined in the last section under Conclusions.

2. Upgrade of the lignite-fired thermal power plant by the installation of the additional economizer

The Thermal Power Plant “Nikola Tesla B” consists of two identical Units B1 and B2 with designed electric power 620 MWe per each unit. The fuel is pulverized lignite with the lower heating value in the range from approximately 5800 to 8000 kJ/kg. Unit B1 started operation in 1983 and Unit B2 in 1985, and their accumulated operating time is respectively more than 210,000 and 196,000 h. Due to the long operating period, projects of revitalization and modernization have been conducted, together with a project for the power increase. A substantial potential for the increase of the plant’s efficiency and power was observed in the recovery of waste heat from the steam boilers’ exit flue gas. Namely, the temperature of the exit flue gas after the regenerative air preheaters of the Ljungstrom type is in the range from 180 °C to 190 °C, while the design temperature for the clean heat transfer surfaces in the boiler is 151 °C (the minimum temperature that does not lead to