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Usage of thermosyphon for avoiding of low grade corrosion on the surfaces of air heaters and increasing of thermal efficiency of steam generators PK-38-4

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Abstract

The paper presents and analyzes new type air heater, which uses the thermosyphon's technology, aims to replace the existing horizontal tubular air heater of first-degree for steam generators Nos. 5,6,7 and 8 at TPP Maritsa East-2 in Bulgaria. The main advantage of the air heater with heat pipes is the ability to lower the temperature of exhaust gases to levels that are impossible for the conventional tubular air heaters, thus increasing the efficiency of the steam generator. Along with the increased energy efficiency, reductions in CO_2, SO_x and NO_x emissions into the atmosphere are achieved. The preheating of the air, used for air combustion by recirculation relieving the operation and improving the combustion in the steam generator, is also reduced.

Keywords: Heat pipes; Thermosyphon; Waste heat recovery; Air heater.

Nomenclature

AH-TS	–	air heater thermosyphon's type
AH-1	–	air heater first degree
AH-2	–	air heater second degree
SAH	–	separate air heater
D_n	–	nominal load of the boiler (steam production), t/h
D	–	range of thermal load of the boiler, %
t_w	–	surface temperature on the pipe wall in the gas part, °C

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t_w^{min}	–	the minimum temperature on the pipe wall of the tubular air heater, °C
t'_{fg}	–	inlet flue gas temperature (before AH-TS), °C
t''_{fg}	–	flue gas temperature in the middle of AH-TS, °C
t'''_{fg}	–	outlet flue gas temperature (after AH-TS), °C
t'_{ia}	–	income air temperature, °C
t'_{beams}	–	air temperature before beams, °C
t'^{air}_{AH-TS}	–	air temperature before AH-TS, °C
t^{air}_{mix}	–	air temperature in mixer chamber, °C
$t^{dp}_{H_2SO_4}$	–	sulphuric acid dew point temperature, °C
V^{air}	–	air flow, nm^3/h.

Greek symbols

α	–	excess air coefficient
η_{th}	–	efficiency

1 Introduction

One of the main factors which determine the efficiency of the steam generators at 'Maritsa East-2' is the temperature of exhaust gases that is directly related to the reliable operation of the air heater of first degree (AH-1). Until the installation of the new air heaters with heat pipes (AH-TS – air heater thermosyphon's), the temperature has been maintained within the range t'_{fg} = 185–190 °C provided that the loads weigh less than the nominal. The efficiency of the steam generators has ranged from η_{th} = 81–82%.

2 Current state of the problem

The steam generators are equipped with tubular air heaters of horizontal type. According to the latest legal method [10] the decrease of the load of the steam generators in the range D = 100–50% is associated with the need to raise the temperature of the incoming in AH-1 air, to ensure the minimum allowable temperature of the AH-1 pipe wall. The same source claims the incoming air temperature in a horizontal pipe – AH-1 should be higher than $t_{ia} > 800$ °C [7, 10]. However, the average incoming air temperature in the existing AH-1 is about $t_{ia} \approx 50$ °C, achieved by methods that decrease the efficiency of combustion by recirculation of hot air in the combustion chamber.

The minimum temperature of the pipe wall of the tubular AH-1 is calculated at t_w^{min} = 121 °C, based on the data from TPP Maritsa East-2. Taking into account, however, that the most 'dangerous' section of the horizontal pipe AH, is the area at the beginning (where cold air enters) with a length of 150 mm, where heat exchange is intensified at the expense of the thin laminar air layer, the coefficient of convective heat transfer to air side is about 2 times higher than the other area [1, 7]. Intensification of heat transfer on air side leads to a more intensive cooling of this part of the pipe and to the increased danger of sulphuric acid low-temperature corrosion and contamination. According to some acknowledged scientific sources, this temperature is t_w^{min}= 104 °C at nominal work regime of the boiler. The measured values of the sulphuric acid dew point temperature range in $t^{dp}_{H_2SO_4}$ = 138–145 °C, which shows that the existing horizontal tubular air heater works in a corrosive regime. As a result are observed damaged areas and a lot of infiltrations from diffused air, and low-temperature contamination, leading to reduced heat transfer efficiency and lower efficiency of the boiler.

Increasing the energy efficiency of PK-38-4 steam generator and prevention of the end heating surfaces of the air heaters is associated with lowering the temperature of effluent gases and the subsequent use of the low-potential heat for preheating of the incoming air in AH-2.

Under the project of Exergia Max Ltd. [5, 8] and Promishlena Energetika Jsc, Yambol (project executor) are implemented four air heaters with heat pipes to replace the existing horizontal-pipe air heaters of first degree. In this paper are presented the experimental results from tests of steam generator No. 8 at TPP Maritsa East-2.

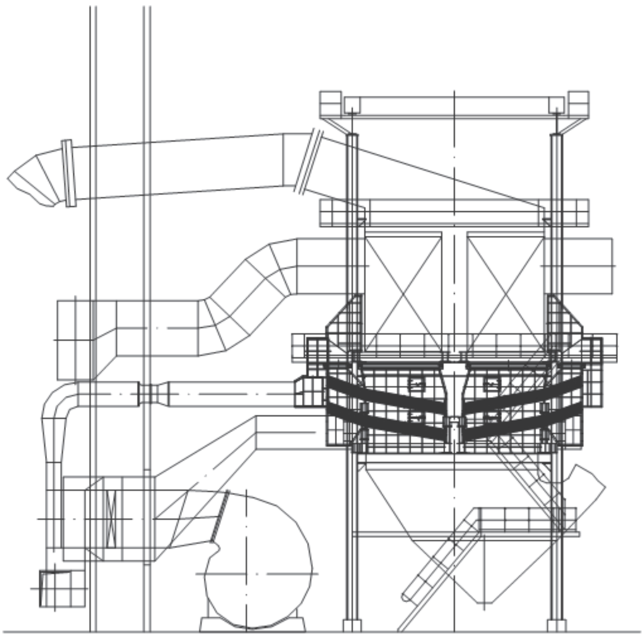

Figure 1. Overview of the separate air heater and the new air heater with heat pipes.

Measurements of the following parameters have been made: air temperature before and after (in the blender) AH-TS; gas temperature before and after AH-TS; airflow entering in AH-TS; generator load. Table 1 presents the results from 24-

hour tests of the air heater with heat pipes. The tests were held on June 5 and June 6, 2011.

Figure 2. Overview of the heat pipes bundles before installation.

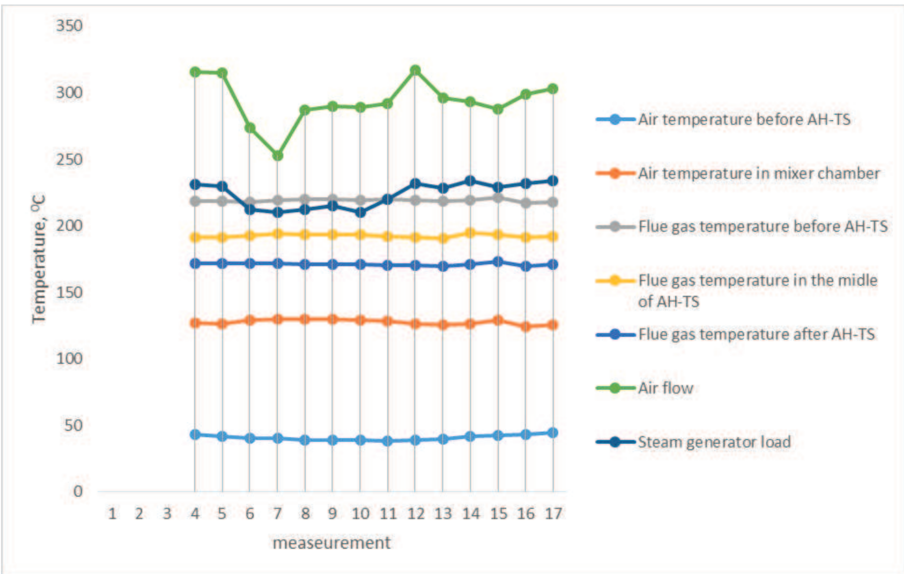

Figure 3. Graphical representation of the test results of air heaters with heat pipes.

Table 1. Test results of an air heater with heat pipes of boiler No. 8 at TPP Maritsa East-2, held on 7 May 2011 and 7 June 2011

Parameters		dimension	Time of measurement							
			12:00	13:00	14:00	15:00	16:00	17:00	18:00	Average
Air temperature before beams	t'_{beams}	°C	27.1	26.3	25.2	24.2	22.9	22.7	22.2	**26.6**
Air temperature before AH-TS	t'^{air}_{AH-TS}	°C	42.9	41.9	40.4	40.0	39.0	38.8	38.5	**43**
Air temperature in mixer chamber	t^{air}_{mix}	°C	127.0	126.5	129.0	130.0	129.5	129.5	129	**128**
Flue gas temperature before AH-TS	t'_{fg}	°C	218.7	218.7	217.7	219.3	219.7	219.7	219	**219**
Flue gas temperature in the middle of AH-TS	t''_{fg}	°C	191.5	191.5	192.5	194.0	193.0	193.0	193.0	**193**
Flue gas temperature after AH-TS	t'''_{fg}	°C	172.0	172.0	171.5	171.5	171.0	171.0	171.0	**172**
Air flow value	V_{air}	$10^3 nm^3/h$	316	315	274	253	287	290	289	**297**
Steam generator load	D_n	t/h	231	230	212	210	212	215	210	**226**

Parameters		dimension	Time of measurement							
			19:00	20:00	21:00	22:00	23:00	00:00	01:00	Average
Air temperature before beams	t'_{beams}	°C	22.2	22.9	23.9	24.2	26.5	27.2	27.9	**26.6**
Air temperature before AH-TS	t'^{air}_{AH-TS}	°C	38.3	39.1	39.8	41.5	42.5	42.7	44.7	**43**
Air temperature in mixer chamber	t^{air}_{mix}	°C	128.5	126.0	125.5	126.5	129.0	124.0	125.5	**128**
Flue gas temperature before AH-TS	t'_{fg}	°C	219.7	219.3	218.7	219.0	221.3	217.3	217.7	**219**
Flue gas temperature in the middle of AH-TS	t''_{fg}	°C	192	191.5	190.5	194.5	193.0	191.5	192.0	**193**
Flue gas temperature after AH-TS	t'''_{fg}	°C	170.5	170.5	169.5	171.0	173.0	169.5	171.0	**172**
Air flow value	V_{air}	$10^3 nm^3/h$	292	317	296	293	288	299	303	**297**
Steam generator load	D_n	t/h	220	232	228	234	229	232	234	**226**

The test results of the air heaters with heat pipes in Tab. 1 and Fig. 2 show that at nominal load of the boiler D_n = 230–240 t/h, the temperature of the exhaust gases is maintained within 170–172 °C. Taking into consideration the maintained temperature of exhaust gases when the loads in the boiler are below the nominal t'_{fg} = 180–185 °C, it could be concluded that the increased efficiency of the boiler is $\Delta\eta_{th}$ = 1.7%. The maintenance of these parameters is realized in summer mode, when the temperature of the incoming in the AH-TS air is the highest (t_{ia} = 40–48 °C)[4]. At temperatures lower than the above-mentioned, the useful temperature difference between the gases and the air will rise. This will result in increased thermal capacity of AH-HP and decreased temperature of the exhaust gases. The expected increase in efficiency of the steam generator in winter mode is $\Delta\eta_{th}$ = 2.3% and annually the average is about $\Delta\eta_{th}$ = 2%. The AH-TS is estimated to cool the effluent gases to t''_{fg} = 165 °C, as this temperature is related to working requirements of the electrical filter [6].

3 Expected benefits from the implementation of the project

The proposed installation of the replacing air heater of the 'heat pipe type enables deeper cooling of effluent gases from t'_{fg} = 185 °C to t''_{fg} = 170–165 °C. This leads to increased energy efficiency of the boiler with $\Delta\eta_{th} >$ 1.7–2.3% and annual fuel savings of about 16000 t. Another important advantage of the air heater with heat pipes (unlike the existing horizontal tubular AH-1) is that on the surface of the pipes, in the gas section, the temperature is maintained above the condensation point, which eliminates the possibility of corrosion processes. The outcome of warm air after AH-TS is being led to the mixers, not needing to use hot recirculation (except for some extreme modes of steam generators). This results in significant additional savings of operating costs and maintenance of the proper technical state of AH-1 for a longer period without crashing and corrosion problems in the starting area of the horizontal pipes.

As a result of the installation of the air heaters with heat pipes of steam generator No. 8 at Maritsa East-2, the consumption of lignite will be reduced by 16000 t annually compared to the present situation. At current prices of lignite the expected annual savings due to the energy saving measure (replacement of the existing AH-1 with an air heater with heat pipes); amount to 135 thousands EUR. Table 2 shows the sources of cash flow for the project for the warranty period in terms of physical quantities and monetary values.

The main reason for global warming is the increased amount of greenhouse gases in the atmosphere, the major share of which belongs to carbon dioxide (CO_2). One of the main effects of this project is the reduction of greenhouse gases in the environment. Therefore, one of the major objectives of the project is to reduce the emissions of carbon dioxide in the atmosphere.

In determining the reduction of carbon dioxide and other harmful gas components is used the Commission Decision of 21.01.2004 establishing guidelines for the monitoring and reporting of Greenhouse gas emissions pursuant to Directive 2003/87/EC of the European Parliament and of the Council [2]. For the assessment of CO_2 are used emission factors, provided by the Ministry of Environment and Water (Methodology for calculating using the liability methods for the emissions of harmful substances (pollutants) into the air [9] as well as stoichiometric calculations of the combustion process [3, 5].

As a result of the annual savings of 16025 t of lignite coal, CO_2 emissions was reduced by 10207 t in 2006. For the period from 2005 to 2012 the reduction in CO_2 emissions resulting from the project was 81653 t. Table 3 presents the reduction of carbon dioxide emissions for the period from 2005 to 2012.

As a result of the studies, the following was found: The annual savings of lignite as a result of the introduction of air heaters with heat pipes of steam generator No. 8 amounted to 16025 t, thus CO_2 emissions was reduced by 10729 t annually. For the period from 2005 to 2012, the reduction of CO_2 emissions as a result of the coal economies was 79572 t.

4 Major conclusions

1. The implementation of AH-TS minimizes the use of recirculation in the pre heating of the cold air.

2. The tests show that the air heater with heat pipes (AH-TS) has a sufficiently high surface temperature in the gas part ($t_w > 150\,^\circ$C) which makes its operation safe in terms of corrosion activity. Surface temperatures are significantly higher than the dew point, and which conforms to the anticorrosion mode [10]. Only in exceptional cases will be used recirculation with hot air, the visual observations show that there is no dirt on heating surfaces and the ensuing crash of the tube bundles.

3. The heater with heat pipes (AH-TS) will provide heating of the outside air from $t_{ia} = 25$–$35\,^\circ$C to 110–140 °C, with guaranteed anticorrosion mode for AH-1 and AH-2.

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Table 2. Sources of cash flow.

	Unit	Period								
Installation of AH-TS		2005	2006	2007	2008	2009	2010	2011	2012	2020
Lignite coal	(t/y)	6677	16025	16025	16025	16025	16025	16025	16025	16025
Lignite coal	EUR/t	8.44	8.44	8.44	8.44	8.44	8.44	8.44	8.44	8.44
Lignite coal	EUR	28801	69123	69123	69123	69123	69123	69123	69123	69123
Total savings	EUR	**28801**	**69123**	**69123**	**69123**	**69123**	**69123**	**69123**	**69123**	**69123**

Table 3. Reduction of carbon dioxide emissions

Emission characteristics	Unit	2005	2006	2007	2008	2009	2010	2011	2012	Total
Coal savings	t/y	6677	16025	16025	16025	16025	16025	16025	16025	118852
Heat energy savings	GJ/yr	42	100	100	100	100	100	100	100	742
CO_2 emission factor for lignite coal	kg CO_2/GJ	107	107	107	107	107	107	107	107	
CO_2 emission reduction	t CO_2/yr	4470	10729	10729	10729	10729	10729	10729	10729	79572
Total CO_2 emission reduction	t CO_2/yr	**4470**	**10179**	**10179**	**10179**	**10179**	**10179**	**10179**	**10179**	**79572**

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