FRI-9.3-1-THPE-14

TECHNICAL - ECONOMICAL ANALYSE OF THE AIR HEATER WHEN SWITCHING COAL FROM NATURAL GAS

Prof. Iliya Iliev, PhD
Department of Heat, Hydraulics and Environmental Engineering,
"Angel Kanchev" Univesity of Ruse
Phone: +359 887306898
E-mail: iki@uni-ruse.bg

Assoc. Prof. Angel Terziev, PhD
Technical University of Sofia
Phone:
E-mail:

Engineer Milen Venev, PhD
Department of Heat, Hydraulics and Environmental Engineering,
"Angel Kanchev" Univesity of Ruse
Phone: +359883333425
E-mail: mvenev@uni-ruse.bg

Engineer Emilian Velkov, PhD Student
Department of Heat, Hydraulics and Environmental Engineering,
"Angel Kanchev" Univesity of Ruse
Phone: +359887208403
E-mail: evelkov@uni-ruse.bg

Abstract: *This work consists of an analysis of the economical feasibility of introducing air heaters to energy steam generators, which is extremely important and is usually directly related to the saving of combustion resources in the process of waste heat utilization.*

A project for the introduction of an additional AH-TS steam heater for steam generators No 1 and 2 in the „Pernik" Ltd heating plant was described for the purpose of lowering the exhaust gas temperature from 220 °C to about 180 °C, The efficiency of the steam generator by about 2-2.5%.

It has been found that the use of an air heater with thermosyphons as a waste heat exchanger leads to significant fuel savings and increases boiler efficiency. The air heater with thermosyphons has shown steady performance over a long period of time. The use of an air heater with gas-fired thermosyphons leads to significantly higher savings and, respectively, to a shorter payback period than to solid fuel. A more significant reduction of CO2 emissions is observed in the realization of an air heater with thermosyphons for solid fuel boilers.

Keywords: *Thermosyphon; Utilization; Specific speed, fuel saving.*

INTRODUCTION

The analysis of the economic feasibility of introducing air heaters to energy-producing steam generators is extremely important and is usually directly related to the saving of combustion resources in the process of waste heat utilization. Continuous operation of these facilities can provide insights into metal resistance, as well as the causes of abrasive exports or corrosion processes that have led to a reduction in the lifetime of the air heaters.

EXPOSITION

The steam generators № 1 and № 2 were designed and built at the end of the 1940s in the Central Bohemian city of Dukla (former Czechoslovakia) and put into operation in 1951 and 1952 with the design fuel respectively. The energy mix of the Pernik Central Power Plant has the following fuel-technical characteristics:

Indicator	Humidity	Ashes content	Volatile content	Lower combustion heat
	W^r, %	A^r, %	V, %	Q^r_i, kJ/kg
	16	43	51.5	10500

The quality of the working fuel for the period 1951-2001 is constantly deteriorating, with its calorific value decreasing from Q^r_i = 10500 to 8150 kJ/kg.

During the planned reconstruction of the steam generators №1 and №2, two thermosiphonic type air heaters were manufactured under Patent № 745 / 01.06.2005 Heat exchanger with heat pipes, [Marinov H., I., Iliev Patent No. 745 / 31.01.2002, Heat exchanger with heat pipes, 2005, Patent Office Bulgaria].

Under the terms of reference of "Toplofikatsiya - Pernik" EAD in 2000, a project for the installation of an additional air heater with thermosyphons (AH-TS) for steam generators No 1 and 2 was developed and implemented. The aim of the project was to increase the energy efficiency of the steam generator by lowering the outlet gas temperature from 2200 °C to about 1800 °C, resulting in an increase in efficiency. of the steam generator by about 2-2.5%.

Fig.1 is a schematic diagram of an air heater with thermosyphons. The air heater includes 1710 tubes (second-hand economiser tubes) with a diameter d = 32/4 mm, located in 9 rows along the gas path. The arrangement of the pipes is corridor and the total length is 7 m, the evaporation zone is 3 m long and is situated at an angle of 300, the adiabatic zone is 2 m long and is at an angle of 300 to the evaporation zone, the condensation zone is of length 2 m and is located at an angle of 300 to the adiabatic zone. Separation of the gas from the air part of the tubular air heater is realized by a 10 cm perlite-concrete layer.

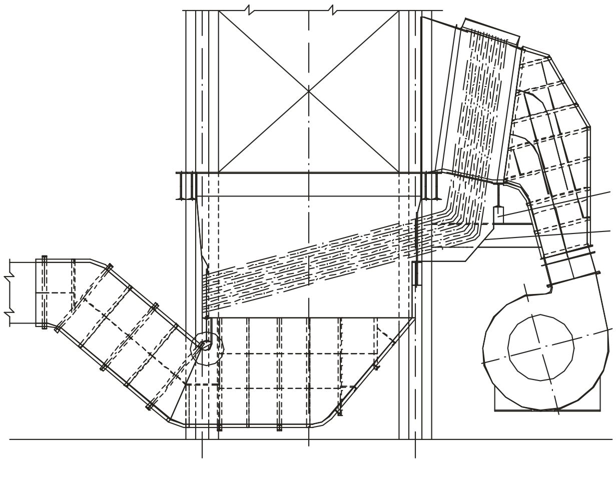

Fig. 1. Scheme of a heat-pipe air heater, realized in TPP "Republic"

Chemical desalted water filled to about 25 ÷ 30% of the volume of the pipe at a pressure lower than atmospheric pressure (999 mbar; 1015 - 950 = 65 mbar) is used for working fluid.

One of the steam generators was in operation by 2009, and due to the failure to meet the environmental standards of EC Directive 2001/80 to limit emissions of dust, nitrogen and tar oxides, carbon dioxide from large combustion plants is decommissioned. steam generator No. 2 changed the coal-fired combustion base of natural gas without any reconstruction to change the heating surfaces. The reason for this is that the steam generator was used only in emergency situations and the investments in new reconstruction were not economically justified.

Table 1 presents the characteristics of the working fuels for the steam generators and the technical parameters of the two air heaters respectively in the mode of use of coal and natural gas.

Table 1.

№	Name	Nom	dim	Options, Custom sizing of AH-TS				
1	Elementary composition of the design coal for a work mass for AH-TS	-	%	C^r	H^r	S^r	O^r	N^r
				21,4	2,1	1,3	7,0	0,5
2	Moisture and ash content of the design fuel of AH-TS	W^r, A^{dry}	until 2000 year		after 2000 year			
			15,1	59	14,5	53,2		
3	LHV by operational data	Q^r_i	until 2000 year		after 2000 year			
			kJ/kg	8540	8164			
4	Combustion air per kg fuel	V^0_{ca}	Nm^3/kg	2,269				
5	Fuel gas volume per kg fuel	V_g	Nm^3/kg	3,508				
6	Excess of air coefficient in the combustion chamber	α_c	-	1,2				
7	Volume ratio of air per kg fuel to AH-1	V^o	Nm^3/kg	2,831				
8	Dew point temperature of the flue gases	t^{dp}	^0C	80	51			
9	Elementary composition of the natural gas for AH-TS	-	%	CH_4	C_2H_6	C_3H_8	CO_2	N_2
				97,96	0,81	0,26	0,15	0,71
10	LHV by certificate	Q^r_i	kJ/nm^3	33587				
11	Nominal operating parameters of steam generator (SG) № 1							
11.1	Nominal load of the steam generator	D_{st}	t/h	125				
11.2	Pressure of preheated steam	P_{ps}	MPa	7,7				
11.3	Temperature of preheated steam	t_{ps}	^0C	500				
11.4	Pressure of feed water	P_{fw}	MPa	13,2				
11.5	Temperature of feed water	t_{fw}	^0C	130				
11.6	Enthalpy of preheated steam	I_{ps}	kJ/kg	2403,8				
11.7	Enthalpy of feed water	I_{fw}	kJ/kg	554,8				
12	Heat loses		%	Accepted values are the average performance				
				Coal	Natural gas			
12.1	Heat loss due to flue gas	q_2	%	10,48	8,53			
12.2	Heat loss due to unburn carbon	q_3	%	0	0			
12.3	Heat loss due to unburnt fuel in residual	q_4	%	1,5	0			
12.4	Heat loss due to radiation	q_5	%	0,67	0,67			
12.5	Heat loss due to fly ash and slag	q_6	%	0,18	-			
12.6	Steam boiler efficiency	η	%	84,8	88,6			
13	Enthalpy of outgoing gases for the designed fuel of AH-TS	I''_{fgas}	kJ/kg (kJ/nm^3)	$q_2 = \left[\frac{\left(I''_{fgas} - \alpha'' I^0_{air}\right)}{Q^r_i}\right] \cdot \left(\frac{100 - q_4}{100}\right)$				
14	Flue gases temperature at nominal load	t'_{fgas}	^0C	220	220			
15	Flue gases temperature after reconstruction	t''_{fgas}	^0C	184	180			
16	Air temperature at the inlet to the AH-TS	$t'^{AHTS}_{äir}$	^0C	25	25			
17	Air temperature at the outlet of AH-TS	$t''^{AHTS}_{äir}$	^0C	84,8	83,3			
18	Enthalpy of outgoing gases at the inlet to the AH-TS	I''_{fgas}	kJ/kg (kJ/nm^3)	1156,3	4003,3			
19	Enthalpy of outgoing gases at the outlet to the AH-TS	I'''_{fgas}	kJ/kg (kJ/nm^3)	975,2	3259,9			
20	Enthalpy of cold air at the entrance of the AH-TS	I'_{air}	kJ/kg (kJ/nm^3)	74,9	315,5			
21	Excess of air in the flue gases	α''_{fgas}	-	1,37	1,25			
22	Flue gas losses at inlet temperature to the AH-TS	q_2'	-	10,48	8,53			
23	Flue gas losses at outlet temperature to the AH-TS	q_2''	-	12,86	10,75			
24	Boiler efficiency at inlet temperature to the AH-TS	η'	-	84,8	88,6			

25	Boiler efficiency at outlet temperature to the AH-TS	η''	-	87,2	90,8
26	Difference in boiler efficiency	$\Delta\eta$	-	$\Delta\eta = (\eta'' - \eta')/\eta''$	
				2,72	2,43
27	Amendment in losses q_2 at change of t'_{fgas} by 10^0C	Δq_2	-	0,755	0,595
28	Determination of fuel consumption at inlet temperature to the AH-TS	B'	t/h (nm^3/h)	50,343	11969
29	Determination of fuel consumption at outlet temperature to the AH-TS	B''	t/h (nm^3/h)	48,972	11678
30	Fuel savings at nominal load	ΔB	t/h (nm^3/h)	1,371	291
31	Annual usage of the boiler #1	τ	h/year	4800	
32	Annual fuel savings	B	t/year (10^3nm^3/year)	6580	1397
33	Fuel price	P_f	EUR/t (EUR/10^3nm^3)	12,59	254,85
34	Price of electrical energy	P_{el}	EUR/kWh	0,08	
35	Annual cash savings	L_{an}	EUR/year	82842	356025
36	Electrical energy consumption for coal milling	E	kWh/t	25	-
37	Annual savings of electrical energy	L_{el-s}	kWh/year	164500	-
38	Annual cash savings of electrical energy	L_{an-el}	EUR/year	13160	-
39	Total annual cash savings	$L_{an}+L_{an-el}$	EUR/year	96002	356025
40	Total heating surface of AH-TS	A_{total}	m^2	860	
41	Total mass of AH-TS	G	kg	26144	
42	Total costs of implementation of AH-TS	L_{total}	EUR	185000	
43	Payback period	PB	year	1,93	0,52
44	CO_2 emission factor	EF_{CO2}	t CO_2/t (t $CO_2/10^3nm^3$)	0,789	1.996
45	CO_2 emission reduction	CO_2	t/year	5192	2788

The data presented in Table 1 shows a higher efficiency of steam generator 2 when operating with natural gas, due to the possibility of deeper cooling of the exhaust gases. However, the final effect, expressed in the relative decrease of Δη, in the use of a heater with thermosyphons on fuel coal is higher $\Delta\eta$ = 2.72 against $\Delta\eta$ = 2.43 for gaseous fuel. This is explained by the fact that in the case of solid fuel boilers, kW (η'= 84.8%) without the presence of an air heater is considerably lower than that of a combustion gas boiler (η' = 88.6%) at the same conditions.

Regarding the economic feasibility, the use of an air heater with a thermosyphon for gas fuel leads to significantly higher savings and, respectively, to a shorter payback period than to solid fuel due to the significantly higher gas price compared to this of local coal.

An assessment of the reduction of CO2 emissions as a result of the fuel savings for solid and gaseous fuels has also been made. From the results presented in Table 1, it is seen that a more significant reduction in CO2 emissions was observed in the realization of an air heater with thermosyphons for solid fuel boilers.

The visual observations on the thermal surfaces of the thermosyphons show little wear as a result of the abrasive action of the coal dust resulting from the 9-year operation of the high-ash coal-fired steam coal steam generator. It should be noted, however, that thermosyphons have not compromised their tightness because they are made of re-used thick-walled economiser tubes.

EXPERIMENTAL RESEARCH

The purpose of the experimental studies is to determine whether the 18-year operation of the steam generator No. 2 (9 years, of which the steam generator worked on coal and the remaining 9 on natural gas) influenced the efficiency of the steam generator and the step in the operation data Table 2) correspond to the calculations presented in Table 1.

Numerous experimental studies regarding the efficiency of the suggested two-phase thermosyphons have been carried out at different regimes of steam boiler operation.

The measurements of the air heater were carried out in 2008 and 2015 when the boiler burned solid fuel (2008) and subsequently natural gas (2015) and its characteristics are presented in Table 1. During the experiments, the following is measured at multiple points along the flue gases and the air paths: the air temperature before AH-TS; the temperature of the flue gases before AH-TS; the temperature of the flue gases after AH-TS; the steam generator's nominal load (table 2) (figure 1). The average temperatures of the parameters measured are given in the last column of table 2.

The heat transfer coefficients in the evaporation and condensation zones have been determined analytically by means of the normative method used in [8] with corrections made in accordance with the angles of inclination of the thermosyphons. Using the aforementioned methodology we obtain the heat transfer coefficients of the evaporation and condensation zones respectively α_{fgas}=104.9 и α_{air}=84.9 (W/m^2.K) for coal and respectively α_{fgas}=99,7 и α_{air}=84.7 (W/m^2.K) за газово гориво. Lower values of convective heat exchange coefficients are overshadowed by lower gas flow rates in the inter-tubular space of natural gas as a result of the lower excess air ratio compared to solid fuel.

Table 2.

Parameter	**Label**		**Trial**				
			1	**2..**	**..23**	**24**	**Average**
Air temperature before AH-TS, ^{0}C	t'^{AH-TS}_{air}	coal	25	23.6	24.8	26.2	**25.0**
		natural gas	22.6	24.2	24.8	25.1	**24.2**
Air temperature after AH-TS, ^{0}C	t''^{AH-TS}_{air}	coal	84.8	81.7	73.0	80.2	**81.2**
		natural gas	84,6	83,7	83,9	86,3	**84,6**
Flue gas temperature before AH-TS, ^{0}C	t'_{fgas}	coal	219.5	214	218	217.5	**218.4**
		natural gas	222.5	218.8	216.4	220.5	**219.6**
Flue gas temperature after AH-TS, ^{0}C	t''_{fgas}	coal	184.3	179	189	185	**184.9**
		natural gas	180.2	178.1	177.1	178.5	**178,5**
Steam generator load, t/h	D_s	coal	122.5	118	121	123	**121**
		natural gas	120	122.4	118.9	114.6	**119**

The experimental results presented in Table 2 show that the measured temperatures (Table 2) are very close to the computational (Table 1).

CONCLUSIONS

1. The use of an air heater with a thermosiphon as a waste heat exchanger leads to significant fuel savings and increases the boiler efficiency from 2.4 to 2.7% depending on the fuel used.
2. The air heater with thermosyphons has shown steady performance for 18 years, 9 of which worked with high abrasive hard coal.
3. Economically advantageous is a gas heater gas heater. The payback period is significantly lower and the heater's resource may be significantly higher.

REFERENCES

Marinov, H. I., Iliev, Patent № 745/31.01.2002, *Heat exchanger with heat pipes*.

Iliev, I. (2013). *Methods and Tools for Effective Utilization of Waste Heat from Low Potential Paragon Flows*. Publishing House of RU, ISBN 978-619-90013-9-4.

Stamov, S. (2000). *Heating, heat and gas supply*. Technika Publishing House, Sofia.

M. R. Sarmasti Emami. *Mathematical Modeling of Thermosyphon Heat Exchanger for Energy Saving*.

Manteli, M. (2013). *Thermosyphon Technology for Industrial Applications in Heat Pipes and Solid Sorption Transformations edited by L. Vasiliev and S. Kakac*. CRC Press, ISBN 9781466564145.

Thermal calculation of boilers (Standard Method), third edition, pre-processed and augmented, Leningrad, 1973.

Thermal calculation of boilers (Standard method), second edition, pre-processed and augmented, Leningrad, 1973.

Bezrodny, M. K., Pioro, I. L., Kostyuk, T. O. (2005). *Transfer processes in two-phase thermosiphon systems. Theory and Practice*, 2nd ed., Ext. and pererabat. - Kiev: Fact, 704 p., ISBN 966-359-045-9.