ТЕРМОТЕХНИКА, 2009, XXXV, 3-4, 221–230

Dragan Tucaković[1], Titoslav Živanović[1], Milan Petrović[1], Vladan Ivanović[2], Sava Lazić[3]

[1] Faculty of Mechanical Engineering, University of Belgrade, Belgrade, Serbia
[2] Faculty of Mechanical Engineering, University of Podgorica, Montenegro
[3] Methanol & Acetic acid Complex (MSK) in Kikinda, Serbia

Technical Solution for Use of Gas Turbine Exhaust Gases in the Existing Steam Boilers in MSK Kikinda

Original scientific paper
UDC: 621.438:621.18

Within the energy system in Methanol & Acetic acid Complex (MSK) in Kikinda, beside process boiler and auxiliary equipment, there are three identical steam boilers made by "Minel Kotlogradnja", provided for combustion of natural gas, fuel oil, and process gases. To increase capacity of the power plant in MSK Kikinda, installation of one 14 MW gas turbine is planed. Since the exhaust gases are at the relatively high temperature and contain large quantity of oxygen, it is specified to split exhaust gas into two equal streams and introduce them into two existing steam boilers, each having production of 16,67 kg/s (60 t/h).

In order to use heat as well as oxygen from the exhaust gases in the existing boilers, it is necessary to replace the existing burners and to reconstruct heat exchangers in the vertical convective gas channel. Besides, it is necessary to verify if the existing flue gases fan can comply with the new operating regime, during which a half of the turbine exhaust gas is introduced into the steam boiler.

Key words: *gas turbine, exhaust gas, steam boiler*

Introduction

Within the energy system in Methanol & Acetic acid Complex (MSK) in Kikinda, beside process boiler and auxiliary equipment, there are three identical steam boilers made by "Minel Kotlogradnja", powered by natural gas, fuel oil, and process gases. Aiming to increase the MSK Kikinda power plant capacity, the installation of one 14 MW gas turbine is planed. To utilize the heat of hot exhaust gases coming from the gas turbine (temperature around 500 °C), it is necessary to make reconstruction of two existing one-drum vertical tube steam boilers having nominal production of 16.67 kg/s (60 t/h) each. The exhaust gases, which contain large quantity of air (surplus of air is 3.3), should be distributed in two equal flows and inducted into these two steam boilers. An additional combustion of natural gas is foreseen to obtain higher production of boilers with guaranteed temperature of the superheated steam.

To enable utilization of oxygen from the exhaust gases, it is necessary to replace the existing burners with new ones with open door design. The connection between gas turbines and steam boiler through which the exhaust gases are introduced via burner into the furnace (solution by firm "SAACKE"[1]) is shown in the fig. 1.

Fresh air fan (fig. 1) is applied in case of higher steam production in boiler when the quantity of exhaust gases, namely oxygen within them, is insufficient. Beside that, it is necessary to complete a reconstruction of heating surfaces in the vertical convective gas channel of the steam boiler. Mixing of turbine exhaust gases with products of additional combustion of natural gas in burners happens in the furnace. It causes the maximum temperature reduction. Because of that, the heat exchanged in the furnace of the steam boiler is insufficient for complete vaporization in radiant evaporator. Therefore it is necessary to install supplement convective evaporating heating surface in the form of inclined evaporator. The disassembling of existing air heater and installation extra water heaters tube bank in its place is also necessary.

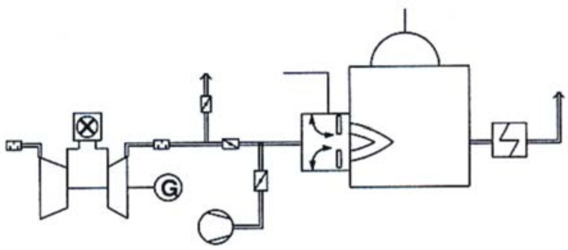

Figure 1. Connection of gas turbine and steam boiler

Considering the required reconstructions of steam boiler and new operating regime at which one boiler takes one half of turbine exhaust gases, it is necessary to check if the existing flue gas fan fits to new operating conditions.

Technical description of steam boiler

One-drum vertical and corner-tube steam boiler, with maximum steam production of 16.67 kg/s (D = 16.67 kg/s) is shown in fig. 2. Two SAACKE burners (1) for combined combustion of natural gas, heavy fuel oil, and process gases are located on the front wall of furnace, one above other. The heat produced by burning of fuel in the steam boiler furnace (2) is transferred by heating surfaces, situated in steam boiler gas tract. The produced superheated steam of following parameters t_s = 455 °C and p_s = 77 bar meets the requirement of steam turbine.

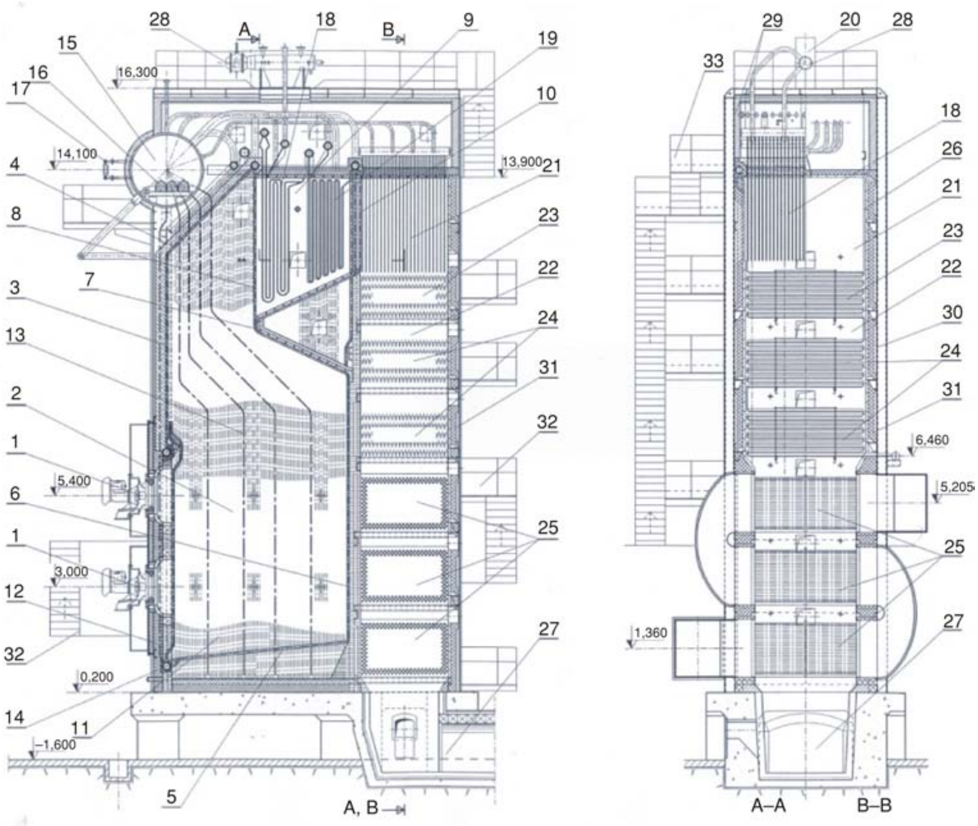

Figure 2. Disposition of steam boiler with angle tubes
(1) – combined burner, (2) – furnace, (3) – furnace front wall, (4) – furnace ceiling, (5) – furnace floor, (6) – furnace rear wall, (7) – ridge for the stream of flue gases, (8) – first tube screen, (9) – horizontal gas channel, (10) – second tube screen, (11) – furnace lateral walls, (12) – downcomer tubes for furnace front and rear wall, (13) – downcomer tubes for furnace lateral walls, (14) – corner tubes, (15) – steam drum, (16) – surface steam cooler, (17) – boiler drum fittings, (18) – secondary superheater, (19) – primary superheater, (20) – boiler fittings, (21) – guide chamber, (22) – vertical convection flue gases channel, (23) – third water heater bank, (24) – first and second water heater bank, (25) – air heater, (26) – connecting tubes of third water heater bank, (27) – flue gases duct, (28) – main steam header, (29) – light bricking, (30) – plate casing, (31) – vertical convection channel bricking, (32) – galleries, (33) – staircase

The first gas channel represents furnace (2) on which walls, ceiling and floor are densely positioned tubes. Every third tube on furnace rear wall (6), after reef, forms the first tube screen (8) which consists of one row of tubes, whereas two remaining tubes located on the floor of horizontal gas channel, in which superheaters are situated, form the second tube screen (10) with 2 rows in chess setup.

A transversal steam drum (15), which is included in natural circulation circuit, is situated on the top of steam boiler. In his water part a surface steam cooler (16) is positioned. The secondary superheaters (18) and the primary (19) superheaters are located in horizontal (second) gas channel (9) between two tube screens. Vertical tube coils of the secondary superheater are realized as double in a corridor setup.

After second tube screen, flue gases are getting into vertical convection flue gas channel (22), going through guide chamber in the process (21). Vertical convection flue gases channel represents third gas channel and gases within are streaming downwards.

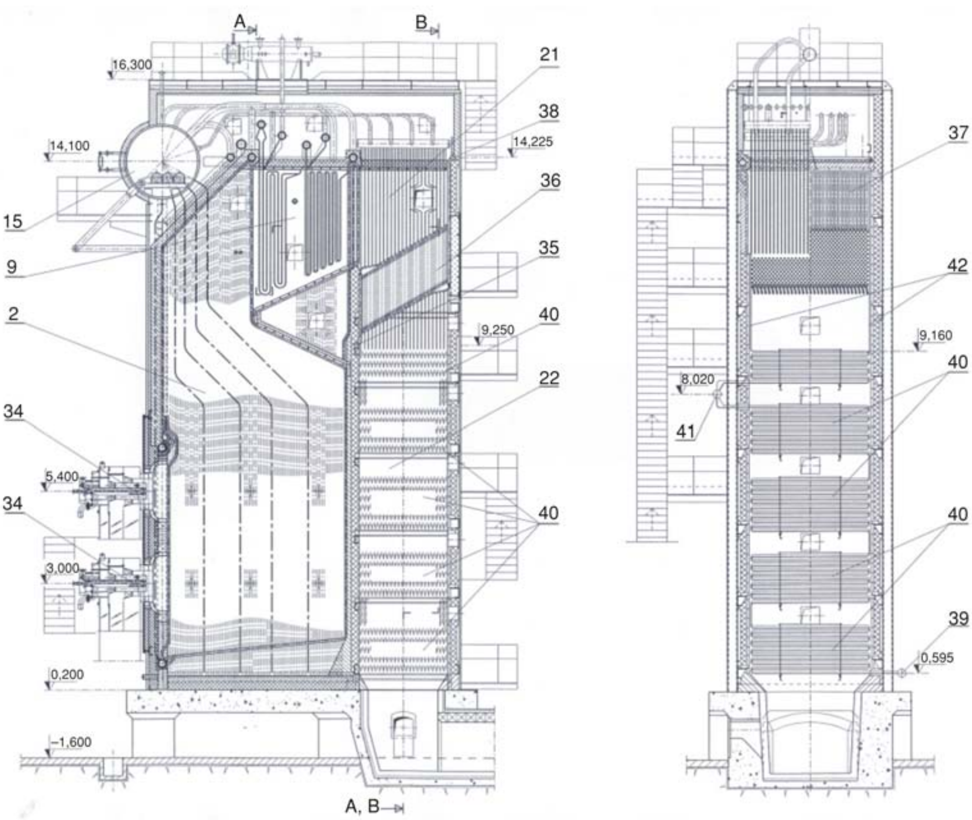

Figure 3. Disposition of the reconstructed steam boiler
(2) – furnace, (9) – horizontal gas channel, (15) – steam drum, (21) – guide chamber, (22) – vertical convection flue gases channel, (34) – new gas burner, (35) – convective evaporator lower header, (36) – inclined evaporator, (37) – tubes of inclined convective evaporator, (38) – convective evaporator upper header, (39) – feed header, (40) – water heater, (41) – water heater upper header, (42) – boiler bricking

The water heater (23 and 24) built of three banks and tube air heater (25) are positioned in this gas channel. Three pass air heater is made from horizontal staggered tubes, around which the flue gas streams, heating air. Warm air, suppressed by air fan, comes to burners (1) via channels, in which it is mixed with fuel to achieve a full combustion.

Flue gases are transported by adequate fan, which than blows them through a stack into the atmosphere.

Technical description of the reconstruction

Figure 3 shows the disposition of the reconstructed steam boiler aimed for utilization of hot exhaust gases coming from a 14 MW gas turbine.

On the furnace front wall (3), which should be adjusted to new burners, two burners (34) are located. Burners are used for combustion of natural gas, with presence of gas turbine exhaust gases. Since the oxygen from these gases is used for combustion of the natural gas in steam boiler furnace, the mass flow of gases, that stream through steam boiler and that is exhaust into atmosphere through the stack by the existing fan, is reduced.

The first gas channel (furnace 2), horizontal gas channel (9), and guide chamber (21), should not be reconstructed at all. After second tube screen, the mixture of flue gases and exhaust gases passes through guide chamber and enters the vertical convection flue gas channel (22). At the inlet of this channel there is an inclined evaporator (36) connected to the steam drum (15) by falling and connecting tubes. Boiling water from steam drum gets to the lower header (35) of inclined evaporator (36), through falling tubes, where it evaporates. Steam and water mixture gets to upper header (38) through tubes of larger diameter (37) which are located on the rear wall of the guide chamber. From the upper header the mixture is brought to steam drum by connecting tubes for phase separation.

The water heater of the existing boiler is being reconstructed, while the air heater is being dismantled and removed.

Several of water heater banks (40) should be placed into the vertical convection flue gases channel (22) of the reconstructed steam boiler. With regard to that, the part of steam boiler steel structure in which the air heater was located should be reconstructed to enable installation of last three banks of new water heater on the same place. All manholes for entrance into vertical convection flue gas channel (22) remain functional.

Since the place of the air heater is occupied by tubes of the larger water heater, the air channel also needs to be reconstructed, starting from the entrance to the boiler house, all the way, to the burner. In case of operation of the new boiler without exhaust gases, approximately same amount of fresh air is necessary, so, the air channel has the same cross-section as before the reconstruction. However, if gas turbine is operational, for combustion of natural gas, the hot exhausted gases, enriched by oxygen, and cold air are used. Therefore, the existing air fan has to provide extra amount of cold air, which would be lead to new burner.

Analysis of the calculation results

Steam boiler heat balance

Steam boiler heat balance is made to calculate the boiler efficiency, *i.e.* fuel consumption [2]. For the existing boiler, the amount of the introduced heat is calculated at first. In the given case, it consists of lower heating value of natural gas and his physical heat. Beside that, the air mass balance for boiler has to be defined. It has to assume the coefficient of surplus air at the furnace outlet, the increase of air surplus in the furnace and along the boiler, as well as, the ratio between the amount of air that leaks from the heater and the theoretical air quantity.

For the reconstructed boiler operating with hot exhaust gases and air, the amount of heat introduced in the boiler has to be defined at first. It consists of natural gas lower heating value, his physical heat and the heat coming with exhaust gases. For combustion of natural gas in these conditions, the ratio between the real quantity and theoretically necessary quantity of the air is assumed to be for 0.1 higher than standard. Excess air in the end of furnace is defined as ratio between the unused oxygen from exhaust gases and theoretical air quantity. Flow rate, excess air ratio and temperature of exhaust gases for normal gas turbine operation at output of 14 MW are shown in tab. 1.

Heat balance of steam boiler (tab. 2) is calculated for maximum production (100%) for both the existing and the reconstructed steam boiler. The reconstructed steam boiler is able to operate with and without turbine exhaust gases, so the heat balance for maximal production (100%) and for production of 50% when boiler operates with a half of the gases introduced into the burners of one steam boiler.

Table 1. Parameters of nominal gas turbine work regime

Parametars name	Unit	Value
Volume air flow rate at the compressor inlet	m^3s^{-1}	38.101
Air quantity at the compressor inlet	m^3m^{-3}	31.672
Theoretical air quantity	m^3m^{-3}	9.534
Excess air	–	3.32
Temperature	°C	485

Thermal calculation of steam boiler

The thermal calculations based on the boiler heat balance (tab. 2) and geometric parameters of the existing and the reconstructed boiler [1] for operation at different steam productions was performed [2, 3].

The temperatures of flue gases at exit of individual heating surfaces received as results of the thermal calculation are shown in tab. 3.

In case of operation of the reconstructed steam boiler at 50% load (a half of exhaust gas mass flow from the gas turbine), the calculated temperature of the flue gases at the boiler outlet was 181 °C, the excess air was 2.13 and the boiler efficiency was

Table 2. Heat balance of steam boiler

No.	Parameters name	Mark	Unit	Exhaust gases of gas turbine			
				Without	Without	With	With
				Existing boiler	Reconstructed boiler		
				Steam boiler load [%]			
				100	100	100	50
1.	Natural gas lower heat value	H_d	$kJm^{-3}{}_G$	34065.0	34065.0	34065.0	34065.0
2.	Exhaust gases heat quantity	Q_{tur}	$kJm^{-3}{}_T$	–	–	22153.7	22153.7
3.	Excess air in exhaust gases	α_{tur}	–	–	–	3.32	3.32
4.	Ratio of real and theoretical air quantity	β_G	–	1.15	1.15	1.25	1.25
5.	Furnace excess air	α_1	–	1.15	1.15	1.16	1.88
6.	Fuel temperature	t_G	°C	20	20	20	20
7.	Physical natural gas heat	Q_G	$kJm^{-3}{}_G$	31.91	31.91	31.91	31.91
8.	Disposed heat quantity	Q_r^r	$kJm^{-3}{}_U$	34096.9	34096.9	30017.1	27320.4
9.	Excess air at the boiler outlet	a_{tz}	–	1.35	1.35	1.36	2.13
10.	Temperature of outlet gases	t_{iz}	°C	145	162	173	181
11.	Outlet gases enthalpy	I_{iz}	$kJm^{-3}{}_U$	2794.7	3133.2	3376.4	5296.8
12.	Loss due to incomplete mechanical combustion	q_4	%	0	0	0	0
13.	Waste gas loss	q_2	%	6.70	7.69	9.53	16.43
14.	Loss due to unburned gases	q_3	%	0.50	0.50	0.5	0.50
15.	Radiation loss	q_5	%	0.85	0.85	0.85	1.70
16.	Boiler efficiency	η_k	%	91.95	90.96	89.12	81.37
17.	Superheated steam production	D	kgs^{-1}	16.667	16.667	16.667	8.333
18.	Superheated steam production	D	th^{-1}	60	60	60	30
19.	Superheated steam temperature	t_s	°C	455	455	455	455
20.	Superheated steam presure	p_s	bar	77	77	77	77
21.	Superheated steam enthalpy	i_s	$kJkg^{-1}$	3291.3	3291.3	3291.3	3291.3
22.	Feed water temperature	t_{nv}	°C	110	110	110	110
23.	Feed water pressure	p_{nv}	bar	92	92	92	80.8
24.	Feed water enthalpy	i_{nv}	$kJkg^{-1}$	467.9	467.9	467.9	467.9
25.	Heat quantity used in steam boiler	Q_{pk}	kW	47057.1	47057.1	47057.1	23535.5
26.	Natural gas consumption	B_G	$m^3{}_G s^{-1}$				
27.	Turbine fuel consumption by half of the exhaust gases brought into the boiler	B_T	$m^3{}_T s^{-1}$				
28.	Total fuel consumption	B	$m^3{}_U s^{-1}$				

Table 3. Temperature of flue gases

Parametars name	Mark	Unit	Exhaust gases of gas turbine			
			Without	Without	With	With
			Existing boiler	Reconstructed boiler		
			Steam boiler load [%]			
			100	100	100	50
Flue gas temperature						
Furnace outlet	t_l	°C	1147	1122	1082	790
First tube screen outlet	t_{cr1}	°C	1114	1091	1056	776
Secondary superheater outlet	t_{spp}	°C	902	889	879	689
Primary superheater outlet	t_{ppp}	°C	630	625	636	550
Second tube screen	t_{cr2}	°C	618	613	624	542
Guide chamber outlet	t_{gz}	°C	614	609	620	540
Convective evaporator outlet	t_{ki}	°C	–	418	430	396
Water heater outlet	t_{nv}	°C	249	162	173	181
Air heater outlet	t_{zv}	°C	145	–	–	–
Steam boiler outlet	t_{iz}	°C	145	162	173	181
Cooler balance (cooler maximum capacity is 4561 kW)						
Cooler heat quantity	Q_H	kW	4314,9	3898,7	4451,5	1779,2

81.37%. In case of operation at 100% load, the temperature of flue gases at the boiler outlet was 173 °C, the excess air 1.36 and efficiency was 89.12%.

At lower loads, the excess air through boiler increases, since the whole amount of oxygen from turbine exhaust gases can not be used. This reduces the boiler efficiency substantially. At the highest loads, the complete amount of the oxygen from turbine exhaust gases is used. Because of that, it is necessary to introduce additional fresh air (about 5% of theoretical air quantity) using an appropriate fan.

The performed thermal calculations showed that the capacity of the surface cooler is lower than its maximum value (4561 kW) for all cases considered here.

Aerodynamic calculation of the gas tract

To check if the existing flue gas fan satisfies new boiler operating conditions, the aerodynamic calculation of the gas tract [4] was conducted. The most difficult conditions for considered steam boiler, *i. e*. operation at maximal steam boiler production with one half of turbine exhaust gases is chosen for the calculation. The calculated flow rate of flue gases is 46.56 m^3/s and the corrected calculated head is 3145 Pa. These values are brought in the fan aerodynamic operation diagram [1] and, according to position of the operating point in the diagram we have concluded that the existing fan is able to meet demand at considered conditions. The inlet vane guide angle should be set at φ 20°. Under these conditions the fan will work with somewhat reduced efficiency (around 78% comparing to 79.5% under design condtions).

Conclusions

In order to enable utilization of exhaust gases from a new 14 MW gas turbine in MSK Kikinda the following changes at existing steam boilers should be conducted:

– replacement of the existing burners with special burners,
– installation of an inclined evaporator of adequate surface at the inlet of the vertical convection gas channel and inclusion of the evaporater into steam boiler natural circulation cycle,
– dismantling of the existing air heater and water heater and installation of a new water heater with significantly larger heating surface in their place,
– building an exhaust gas channel between gas turbine and boilers number 1 and 2 and connect it with new burners, so that one half of these gases is led to the boiler number 1 and the other half in the boiler number 2, and
– reconstruction of the fresh air channels from the fans to new burner to enable operation in cases when steam boiler works without the turbine exhaust gases.

Checking the aerodynamic characteristics of gas tract confirmed that the existing fan is able to operate under the most difficult conditions when the half of the turbine exhaust gases is being led into one boiler.

The investment costs for reconstruction of both steam boilers with turbine exhaust gases channel are etimated to be 1.215.000 € [1]. On the other hand, a new waste-heat boiler costs 3.532.000 € [1]. To make the final decesion whether the reconstruction of boilers is technically feasible, considering significantly lower price, the estimation of the remaining operating lifetime of boilers has to be made.

References

[1] Petrović, M., Živanović, T., Tucaković, D., *et. al*., Predesign of Combined Production of Electric and Thermal Energy with gas Turbine in MSK Kikinda, Faculty of Mechanical Engineering, University of Belgrade, Belgrade, 2006
[2] Brkić, Lj., Živanović, T., Tucaković, D., Steam Boilers Thermal Calculation, Faculty of Mechanical Engineering, University of Belgrade, Belgrade, 2006
[3] Brkić, Lj., Živanović, T., Tucaković, D., Steam Boilers, Faculty of Mechanical Engineering, University of Belgrade, Belgrade, 2007
[4] Brkić, Lj., Živanović, T., Tucaković, D., Galić, R., Gas Tract Aerodynamic Calculation, Art Engineering, Belgrade, 2007

Апстракт

Драган ТУЦАКОВИЋ*[1]*, Титослав ЖИВАНОВИЋ*[1]*,
***Милан ПЕТРОВИЋ*[1]*, Владан ИВАНОВИЋ*[2]*, Сава ЛАЗИЋ*[3]**

[1] Машински факултет, Универаитет у Београду, Београд, Србија
[2] Машински факултет, Универзитет у Подгорици, Подгорица, Црна Гора
[3] Акционарско друштво Метанолско сирћетни комплекс (МСК), Кикинда, Србија

Техничко решење коришћења топлоте издувних гасова из гасне турбине у постојећим парним котловима у МСК Кикинда

У оквиру енергетике Метанолско сирћетног комплекса у Кикинди налазе се, поред процесног котла и остале пратеће опреме, три једнака парна котла производње „Минел-Котлоградња” који су предвиђени за сагоревање природног гаса, мазута и процесних гасова.

У циљу повећања енергетског капацитета енергане МСК Кикинда предвиђена је уградња једне гасне турбине снаге 14 MW. С обзиром да издувни гасови из гасне турбине имају релативно високу температуру и велику количину неискоришћеног кисеоника из ваздуха, предвиђено је да се они поделе на две једнаке струје и да се уведу у два постојећа парна котла продукције од по 16,67 kg/s (60 t/h).

Да би се искористила ова топлота издувних гасова, као и кисеоник садржан у њима, неопходно је прво заменити постојеће горионике и извршити неопходне реконструкције грејних површина у вертикалном конвективном гасном каналу парног котла. Осим тога потребно је проверити да ли постојећи вентилатор за димне гасове може да задовољи нови режим рада при коме се у један котао уводи половина издувних гасова турбине.

Кључне речи: *гасна турбина, издувни гас, парни котао*

Одговорни аутор / Corresponding author (D. Tucaković)
E-mail: dtucakovic@mas.bg.ac.rs