Detection of Cause of Pipe Burst in Economizer of Process co Steam Boiler

OGNJEN S. STAMENKOVIĆ, University of Belgrade,
Faculty of Mechanical Engineering, Belgrade
GORAN M. STUPAR, University of Belgrade,
Faculty of Mechanical Engineering, Belgrade
*DRAGAN R. TUCAKOVIĆ***,** University of Belgrade
Faculty of Mechanical Engineering, Belgrade
BOJAN M. BOŠKOVIĆ, Petroleum Industry of Serbia Head of Thermoenergetics
Department Oil Refinery Pančevo, Pančevo

Professional paper
UDC: 658.1:665.6/.7(497.113)
621.184.2:539.4
DOI: 10.5937/tehnika2201055S

*In this paper results of analysis of process steam boiler operation with maximum continuous steam production of 75 t/h, steam pressure and temperature of 45,5 bar and 412 °C are presented. Steam boiler is predicted to operate within steam production facility of oil and gas refinery in Pančevo, Serbia. On the demand of purchaser steam boiler is enabled to operate with various fuels as well as with two or three fuels simultaneously. By fuels intake facilities it is enabled to introduce refinery gas, fuel oil and high-temperature waste gas to the boilers furnace. Waste gas is guided from FCC (**F**uel **c**atalyst **c**racking) facility and presents two-component fluid with polydisperse solid phase composed of particles of diameter smaller than 40 µm. Recent changes in steam consumption in refinery resulted in modifications in boiler`s operating regime and, further on, in significant changes in its operational parameters. At present, in new conditions, boiler operates with frequent pipe bursts on pipe bundles of boiler economizer which requires forced interruption in steam production as well as time and cost consuming operations for resuming boiler work. In this paper results of thermal calculations for design and new operational conditions are presented for the purpose of identification of cause of frequent unscheduled steam production interruptions. After analysis of presented results, recommendations on how to modify certain boiler operational parameters in order to eliminate or reduce possibility of such unfavourable occurance has been provided.*

Key Words: *process steam boiler, waste gas, thermal calculation, economizer, pipe burst*

1. INTRODUCTION

Process steam boiler located in oil and gas refinery in Pančevo, Serbia, produces overheated steam utilized for domestic electricity production as well as for the needs of technological processes within refinery. Steam boiler operates since 1980. Recent changes in steam consumption in entire facility occurred which led to significant reduction of fresh steam flow rate in process steam boiler, even below minimum level. In such operational conditions pipe burst on economizer pipe bundles are frequent which requires immediate shutdown of steam boiler and unscheduled interruption in steam production. Such occurrence led to the reduction in boiler operational effectiveness, reliability and cost-effectiveness which requires conduction of analysis of boiler operational parameters in new working conditions in order to detect cause of such time and cost-consuming outages. In order to detect most influential parameters of boiler operation thermal calculation for boiler design parameters and new working conditions has been performed. By comparing the results of thermal calculations for various operational conditions cause of frequent pipe burst has been identified. Additionally, in order to verify fouling factors of all heat exchangers visual inspection of interior of flue gas tract has been conducted.

Author's address: Ognjen Stamenković, University of Belgrade, Faculty of Mechanical Engineering, Belgrade, Kraljice Marije 16

e-mail: ostamenkovic@mas.bg.ac.rs

Paper received: 26.01.2022.

Paper accepted: 07.02.2022.

2. TECHNICAL OVERVIEW OF BOILER

Process steam boiler is single-drum type with vertically aligned pipes in furnace, natural circulation in evaporator, three passes of heat emitter and force draught in flue gas tract. Boiler is able to operate with various fuels – refinery gas, fuel oil, and combination of waste gas with refinery gas or fuel oil.

Due to the application of valid ecological norms operation of boiler with fuel oil has been avoiding for a while. Thus, in this paper operation of boiler with refinery gas only (RG regime) and simultaneous work with refinery and waste gas (RG+WG regime) has been considered. Design operational parameters for maximum continuous production when boiler utilizes two fuels - refinery and waste gas and refinery gas only are given in tab. 1.

1.2. Overview of heat emitter and heat receiver streams

1.2.1. Heat emitter – flue gas stream

In fig. 1 from [1] longitudinal section of process steam boiler with positions of all heat exchangers in flue gas tract is given.

High temperature flue gas (heat emitter) generated in combustion process in furnace (1) exchange heat with wall pipes mounted on upper (2b), bottom (2c), front (2a), rear (2e) and back wall (2d) of furnace. Flue gas, at the end of furnace, turns and enters the horizontal convective flue gas channel formed of pipes on back and rear walls guided from furnace.

First stage (3) and second (4) stage convective superheaters are located in horizontal flue gas duct. After superheaters convective heat exchanger (5) consisted of evaporator pipes extended from furnace back wall is positioned. At the end of horizontal duct flue gas turns downward and crosses through second pass vertical convective duct (7).

In second pass convective duct convective evaporation bank tubes (6) are located. In this part of duct flue gas is guided by routing metal sheets for the purpose of intesifying heat transfer between heat emitter and heat receiver.

At the end of second pass vertical duct convective heat exchanger (8) composed of convective evaporation bank tubes is located. Afterwards, heat emitter turns upward into third pass vertical convective duct (9). On the bottom of turning section two funnels (10) for separation of solid phase of combustion products are placed. In third pass convective duct flue gas crosses last heat exchanger in process boiler - two stages economozier (11).

Outlet flue gas at the end of third pass convective duct turns into short horizontal duct (12) that guides flue gas to the long hoirzontal flue gas duct (14) via verticaly aligned interconnecting element (13). Through duct (14) flue gas is introduced into concrete-made stack and, further on, released to the atmosphere.

As air fan (15) is located upstream of the process steam boiler entire flue gas duct operates in pressurized draft regime (so called forced draft).

Table 1. Design parameters of process steam boiler.

No	Parameter	Notation	Unit	Value	
				RG	RG+WG
1.	Max. continous fresh steam mass flow rate	D	t/h	75	75
2.	Outlet steam pressure	p_s	bar	44,62	44,62
3.	Outlet steam temp.	t_s	ºC	412	412
4.	Feedwater temperature	t_{nv}	ºC	105	105
5.	Minimum steam mass flow rate	D_{min}	kg/s	52 %	40 %
6.	Flue gas outlet temp.	t_{iz}	ºC	~220	~220
7.	Excess air coefficient in furnace	α_l	-	1,10	1,22
8.	Mass flow rate of refinery gas	M_{RG}	kg/h	5071	2104
9.	Mass flow rate of waste gas	M_{OG}	kg/h	0	90000
10.	Waste gas temperature	t_{OG}	ºC	/	700
11.	Boiler efficiency rate	η_K	%	92,8	85,0
REFINERY GAS (RG)					
12.	Lower heating value of refinery gas	$H_{d,RG}$	kJ/kg	44817.4 (19268 Btu/lb)	
WASTE GAS (WG)					
13.	Concentration of H_2O	r_{H2O}	%v/v	12,0 – 14,5	
14.	Concentration of CO_2	r_{CO2}	%v/v	7,5 – 13,8	
15.	Concentration of CO	r_{CO}	%v/v	≤ 9,0	
16.	Concentration of N_2	r_{N2}	%v/v	67,8 – 72,6	
17.	Concentration of O_2	r_{O2}	%v/v	0,5 – 1,0	
18.	Concentration of SO_2	r_{SO2}	%v/v	0,6 – 0,7	
19.	Mass flow rate of solid phase in waste gas	m_p	kg/h	41	
20.	Finesses of solid phase in waste gas	D_{20}	%	70	
		D_{40}	%	100	

1.2.2. Heat receiver - water/steam stream

Feedwater is introduced to the pipe bundles of economizer (11) from boiler inlet header. Heat receiver (water) leaves economizer with higher temperature and is guided by interconnecting pipes to the waterpart of boiler drum (16a). If it is required to introduce water into economizer with higher temperature it is predicted to guide part of feedwater flow toward water preheater (17) located in waterpart of boiler drum (16a). Part of water from water preheater is then mixed with the rest of waterflow from bypass line and then, with higher temperature, introduced to the economizer.

Part of saturated water from waterpart of boiler drum is then guided through downcoming pipes to the bottom headers of radiant evaporator (2a-2e). Within this hydraulic circulation loop convective heat exchanger (5) at the end of the horizontal flue gas is positioned. The rest of saturated water is guided to the bottom header (20) of convective evaporation bank tubes (6) in second pass of flue gas duct. This hydraulic circulation loop also includes convective heat exchanger(8) at the end of the second pass vertical flue gas duct which guides heat receiver through pipes placed on back wall (19) of second pass convective flue gas duct and, afterwards, to the upper header (21) of convective evaporation bank tubes.

Saturated vapor from steampart of boiler drum (16b) is guided to the first stage superheater (3). Pipe bundles of this heat exchanger area ligned in horizontal plane. Part of superheated steam is then guided to the surface-type desuperheater (22) for the propose of regulation of fresh steam outlet temperature. Afterwards, superheated steam from surface-type desuperheater is mixed with second part of superheated steam from bypass line and, further on, guided toward second stage superheater (4).

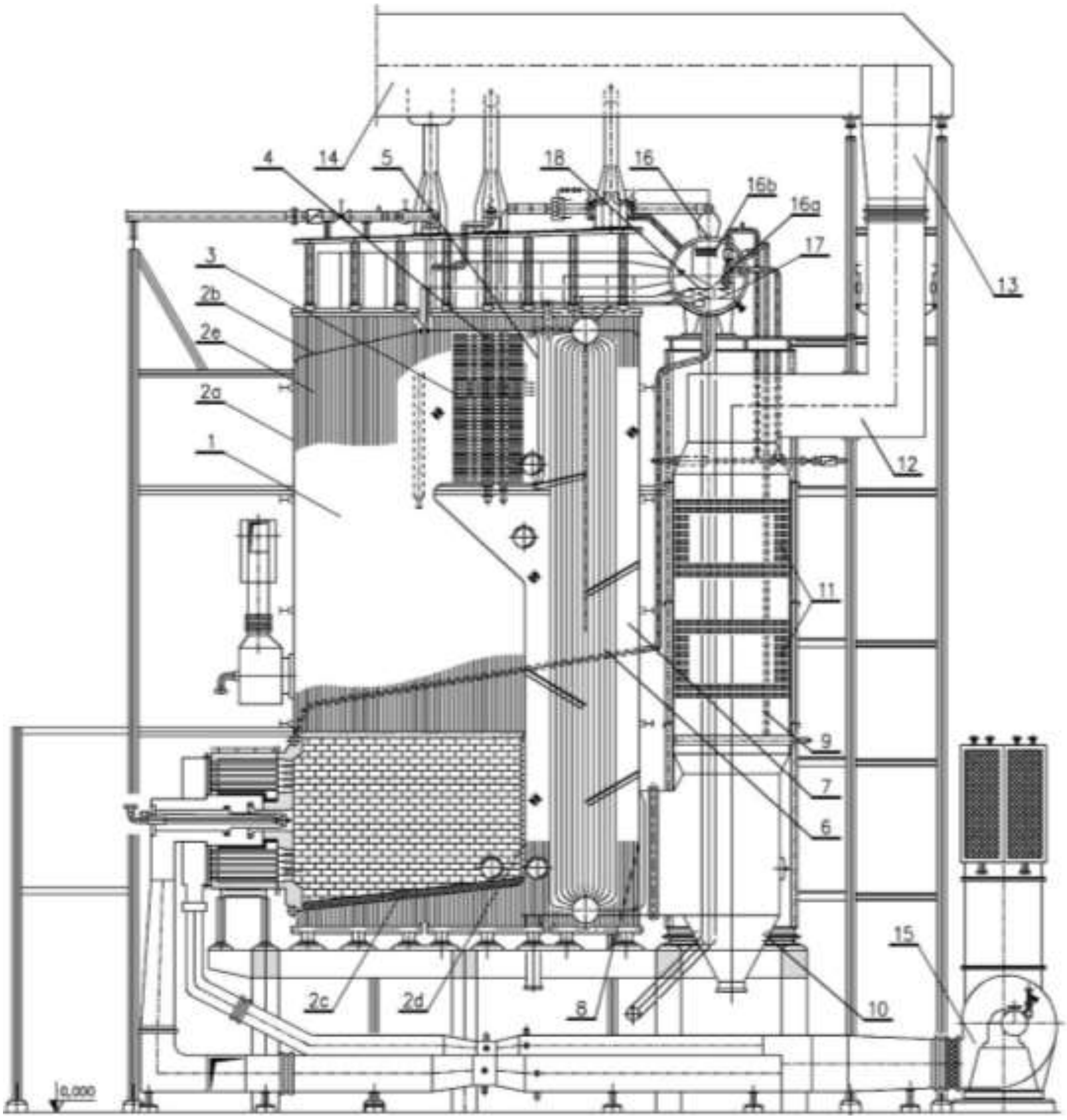

Figure 1 - Longitudinal section of process CO steam boiler

Pipe bundles of second stage superheater (4) are also placed in horizontal planes along duct height alternately to pipe bundles of first stage superheater. After second stage superheater fresh superheated steam is guided toward main boiler header and afterwards to the steam consumers.

1.3. Overview of new operational conditions

After decades of operation needs for superheated steam in entire facility have been reduced. In order to adjust operation of steam boiler in new conditions its production has been also reduced and, nowdays, according to the permanent needs of various consumers, is in range from 15 up to 25 t/h. According to the boiler producer technical documentation (tab. 1, line 5) such massflow rate of superheated steam is below minimum level. Consequently, operated in such regime, steam boiler, is not able to produce fresh steam with design outlet temperature and in new conditions this parameter equals 402ºC. While temperature of feedwater and waste gas at boiler inlet in new operational conditions remained, massflow of waste gas is reduced form 90 to 60 t/h. Composition of this fuel is also changed and in new conditions it is composed of nitrogen, oxygen and carbon-dioxide. Nitrogen is main component with volume share larger then 80%. While share of nitrogen is mostly constant value, share of oxygen is in range from 5,5 to 11%, and changes alternately to the share of carbon-dioxide.

As massflow of waste gas is constant in time, adjusting of fresh steam mass flow rate is performed by changing the massflow of refinery gas introduced to the furnace. LHV of refinery gas in new operational conditions is close to the design value (tab. 1, line 12). In new operational conditions flue gas outlet temperature overcomes 300 ºC at any fresh steam mass flow rate.

Table 2. Steam boiler parameters for operation in new conditions.

No.	Parameter	Notation	Unit	Value
1.	Fresh steam mass flow rate	D	t/h	15 - 25
2.	Fresh steam pressure	p_s	bar	44,62
3.	Fresh steam temperature	t_s	ºC	402
4.	Feedwater temperature	t_{nv}	ºC	105
6.	Flue gas outlet temp.	t_{iz}	ºC	≥ 300*
7.	Concentration of oxygen in outlet flue gas	O_2	%	1,1 – 1,6
8.	Refinery gas massflow	M_{RG}	kg/h	- *
9.	Waste gas massflow	M_{OG}	kg/h	60000
10.	Waste gas inlet temp.	t_{OG}	ºC	677
11.	Boiler efficiency rate	η_K	%	- *

* Value depends on instant fresh steam mass flow rate.

Summarized overview of main boiler parameters of new operational conditions is given in tab. 2. Measurements taken on site during stationary operation of boiler used for calibration of certain parameters in control calculations are given in [5].

In new operational conditions frequent pipe burst in economizer occurs. The aim of conducted calculations of process steam boiler operation is to detect cause of such occurrence and to propose adequate measures which would reduce number and frequency of unplanned interruptions in boiler work.

2. ANALYSIS OF STEAM BOILER OPERATION FOR DESIGN CONDITIONS

For the purpose of assessing influence of particular parameters on overall heat exchange in steam boiler control calculations has been conducted for maximum continual fresh steam massflow rate (75 t/h) and designed parameters of feedwater and fresh steam in case when boiler works in RG and RG+WG regimes. Composition of refinery and waste gas used in calculations corresponds to the measured values in new operational conditions. Additionally, when boiler operates in RG+WG regime, control calculations has been performed for different feedwater preheating rates. Results of calculations for these regimes are presented in tab. 3. It is to be noted that heat balance and thermal calculations are performed in total according to [2, 3].

When comparing results of calculations for regimes RG and RG+WG in tab. 3 and same feedwater preheating rate (tab. 3, columns 5 - 6) it is to be noted that 20% less refinery gas massflow is required for the regime RG+WG. Thus it can be concluded that heat power introduced by WG substitutes 20% of heat power released in combustion of RG when boiler operates with RG only for the same fresh steam mass flow rate (tab. 3, columns 5 - 6, line 1.1.).

By comparing of flue gas outlet temperatures (tab. 3, columns 5 - 6, line 1.9) it can be stated that temperature is higher for approximately 50 ºC when boiler operates in RG+WG regimes which contributes to the higher values of heat loss in outlet flue gas (tab. 3, columns 5 - 6, line 1.10) and lower values of boiler efficiency rate (tab. 3, columns 5 - 6, line 1.11). Although introducing of WG in furnace reveals such negative trends, its utilization reduces massflow rate of refinery gas which makes boiler operation more cost-effective.

By comparing regimes RG+WG with different feedwater preheating rates it can be concluded that increase of water temperature at the economizer inlet gives higher temperatures of outlet flue gas (tab. 3, line 1.9, columns 6 - 8) as well as heat loss in oultet flue gases (tab. 3, lines 1.10, columns 6 - 8). Finally, such change at economizer inlet leads to the reduction of boiler efficency rate (tab. 3, lines 1.11, columns 6 - 8) which, further on, requires higher massflow of refinery gas for the same fresh steam massflow rate. Results of this analyse are graphically presented in fig. 2.

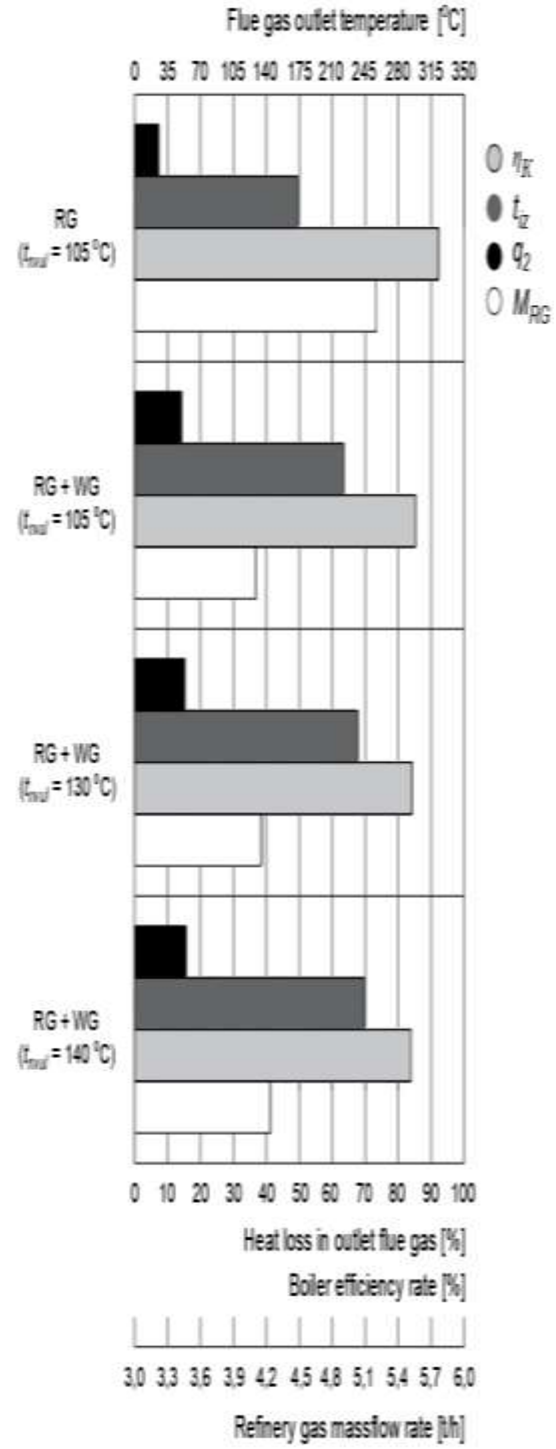

Figure 2 - Change of flue gas outlet temperature, heat loss in outlet flue gas, boiler efficiency rate and refinery gas mass flow rate for various boiler operation regimes and fresh steam mass flow rate of 75 t/h.

Control thermal calculations has been performed according to the heat balance calculations for the previously described regimes. Heat exchanger efficiency rate are adopted according to the recommendations given in [2] for case of combustion of gaseous fuel. Results of thermal calculations for boiler designed operational parameters are in accordance with data given in technical specification of boiler [4].

By comparing flue gas velocity (tab. 3, lines 2.9 – 2.11, columns 5-8) it can be stated that significantly higher values (for almost 80 %) occurs for the regimes RG+WG. Graphical presentation of flue gas velocities in superheaters and economizer is given in fig. 3.

By analyzing temperatures of heat emitter along flue gas tract (tab. 3, lines 2.1 – 2.7, columns 5 – 8) it is to be noted that temperatures are higher for regimes RG+WG in comparison with RG regime from superheaters to the boiler outlet.

Due to the higher massflow rate of flue gas in RG+WG regimes velocities of heat emitter are higher in area of any convenctive heat exchanger (as it is shown in fig. 3) which gives higher values of heat transfer coefficients, that is, more intense process of convection heat transfer.

Accordingly, due to the higher values of convective heat transfer coefficient lower heat emitter temperature drop on any convective heat exchanger is required for the same total amount of heat transferred to the heat receiver in boiler.

Consequently, higher temperatures of heat emitter occurs in entire convective flue gas tract when boiler operates with higher massflow of heat emitter, that is, in any of the analyzed RG+WG regimes.

Following this trend it can be seen that temperature of flue gas at the economizer inlet are higher for approximately 75ºC for the RG+WG regimes in comparison to the RG regime. Such higher temperature along with higher velocity of heat emitter for the same massflow of heat receiver results in higher value of heat exchanged in economizer which gives significantly higher temperature of water at the economizer outlet (tab. 3, line 3.4., column 5 – 8).

Nevertheless, for any of the considered RG+WG regimes, this temperature is sufficiently lower from saturation temperature at the boiler drum pressure (fig. 4) which leads to the conclusion that initial boiling of heat receiver in economizer pipe bundles will not occur.

Finally, according to the previuos conclusions, it can be stated that when boiler operates in design conditions economizer pipes are adequately cooled which ensures safe operation of this heat exchanger and entire boiler facility.

Table 3. Heat balance and thermal calcualtions results for design operation conditions

No.	Parameter		Mark	Unit	RG	RG + WG (D_{WG} = 90000 kg/h)		
					Economizer inlet heat receiver temperature			
					105 °C	105 °C	130 °C	140 °C
1	*2*		*3*	*4*	*5*	*6*	*7*	*8*
1.	**Heat balance**							
1.1.	Refinery gas massflow		M_{RG}	kg/h	5176,3	4124,1	4188,4	4214,5
1.2.	Waste gas massflow		M_{OG}	kg/h	0	90000,0	90000,0	90000,0
1.3.	Waste gas inlet temperature		t_{OG}	°C	0	677	677	677
1.4.	Intake air massflow		M_{VAZ}	kg/h	82296,5	54159,9	55319,6	55797,5
1.5.	Flue gas massflow		M_{DG}	kg/h	87472,8	148284,0	149508,0	150012,0
1.6.	Ambient air temperature		t_{hv}	°C	12	12	12	12
1.7.	Preheated air temperature		t_{zv}	°C	35	35	35	35
1.8.	Excess air coefficient		α	-	1,10	1,22	1,22	1,22
1.9.	Flue gas outlet temperature		t_{iz}	°C	173	222	237	244
1.10.	Heat loss in outlet flue gas		q_2	%	6,95	13,92	14,89	15,28
1.11.	Boiler efficiency rate		η_k	%	92,3	85,3	84,3	83,9
1.12.	Steam production rate		D	kg/s	20,833	20,833	20,833	20,833
1.13.	Thermal power of boiler		Q_{PK}	kW	58376,2	58376,2	58376,2	58376,2
2.	**Heat emitter – flue gas**							
2.1.	Flue gas adiabatic temperature		t_a	°C	1968	1382	1386	1387
2.2.	Temperature of flue gas at furnace outlet		t_l	°C	1145	1067	1071	1072
2.3.	Temp. of flue gas at superheaters outlet		t_2	°C	804	840	843	844
2.4.	Temperature of flue gas at convective evaporator inlet		t_3	°C	772	816	819	820
2.5.	Temperature of flue gas at convective evaporator outlet		t_4	°C	350	413	414	415
2.6.	Temperature of flue gas at 2. stage economizer inlet		t_5	°C	348	410	411	412
2.7.	Temperature of flue gas at 2. stage economizer outlet		t_6	°C	243	309	318	322
2.8.	Flue gas velocity in 1. stage economizer		w_{gnv1}	m/s	7,13	13,02	13,43	13,60
2.9.	Flue gas velocity in 2. stage economizer		w_{gnv2}	m/s	8,43	15,29	15,55	15,65
2.10.	Flue gas velocity in superheaters		w_{gs}	m/s	11,99	19,21	19,43	19,51
3.	**Heat receiver – water and steam**							
3.1.	Feedwater temperature		t_{nv}	°C	105	105	105	105
3.2.	Heat receiver temp. at economizer inlet		t_{nvul}	°C	105	105	130	140
3.3.	Heat receiver temperature at 1. stage economizer outlet		t_{nv12}	°C	126	149	170	179
3.4.	State of water at economizer outlet	Temperature	t_{nviz}	°C	159	198	216	223
		Drying rate	x_{nviz}	%	0	0	0	0
3.5.	Temperature of saturated steam		t_{szp}	°C	264	264	264	264
3.6.	Heat receiver temperature at 1. stage superheater outlet		t_{s1iz}	°C	409	416	418	419
3.7.	Heat receiver temperature at 2. stage superheater inlet		t_{s2ul}	°C	369	366	366	365

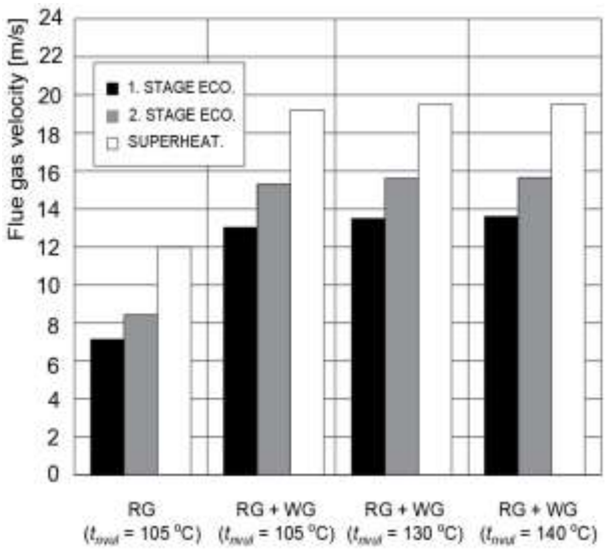

Figure 3 - Comparative overview of flue gas velocities in superheaters and economizer for the regimes given in tab. 3.

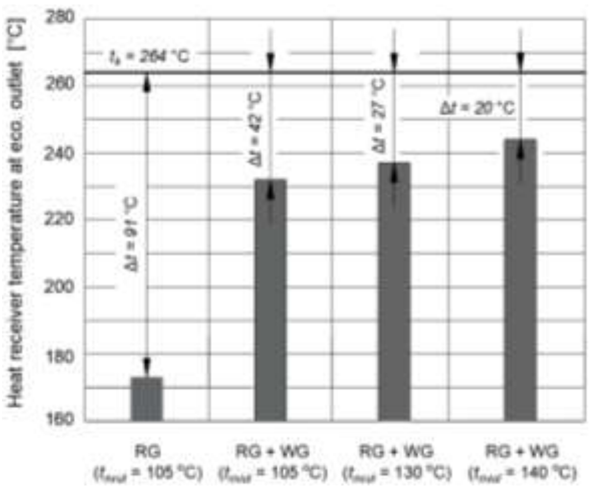

Figure 4 - Subcooling rate of water at economizer outlet for regimes given in tab. 3.

Additionally, temperature drop in steam line is to be noted between two stages of superheaters (tab. 3, lines 3.6. - 3.7., columns 5 – 8) which means that part of overall steam flow at outlet of first stage superheater is guided toward desuperheater located in waterpart of drum.

Thus, it can be stated that boiler operates within regulation area of superheated steam outlet temperature.

3. ANALYSIS OF BOILER OPERATIONAL PERFORMANCE IN NEW CONDITIONS

After assesing the influence of particular parameters on boilers operational performances for the design conditions control calcualtions has been performed for new working conditions by use of same mathematical model presented in [2, 3].

Figure 5 - Interior of flue gas duct. a) Fouling layer on pipes aligned vertically on furnace rear wall; b) Pipe bundles of 1. stage economizer

In order to identify cause of pipe burst on pipes of economizer visual inspection of interior of flue gas tract has been performed. Inspection has been conducted during one of several unscheduled interuption of boiler operation.

Photos taken during inspectiona are given in fig. 5a and 5b. Special attention has been dedicated to the assesing of fouling rates of every heat exchanger in boiler flue gas duct.

During inpsection very high fouling rates of all heat exchangers have been detected. All walls of furnace consisted of evaporators pipes are entirelly covered with white layer consisted of deposited solid phase of waste gas. Thickness of this layer varied from 2 to 5 mm (fig. 5a). Pipes of economizer are also covered with white layer although the layer thickness was smaller than thicknesses of layers on any other heat exchanger in flue gas duct.

According to the noted state of outer surfaces of heat exchangers in boiler, fouling factors used in thermal calculations have been adjusted in order to provide appropriate mathematical model able to predict performances of boiler in new operational conditions. Adjusting of fouling factors has been performed on the basis of measurements [5] taken on site for the regime in which boiler operated most of the time in new conditions (RG+WG with fresh steam massflow rate of 25 t/h). For the purpose of considering boiler operational performances calculations has been performed for regime of 40 t/h fresh steam massflow rate, that is, for the regime slighty above minimum steam production level. Control calculations has been also provided for the regimes in which boiler operated significant amount of time (20 t/h and 15 t/h). Results of heat balance and thermal calculations are given in tab. 4. Graphical presentation of the results is given in fig. 6.

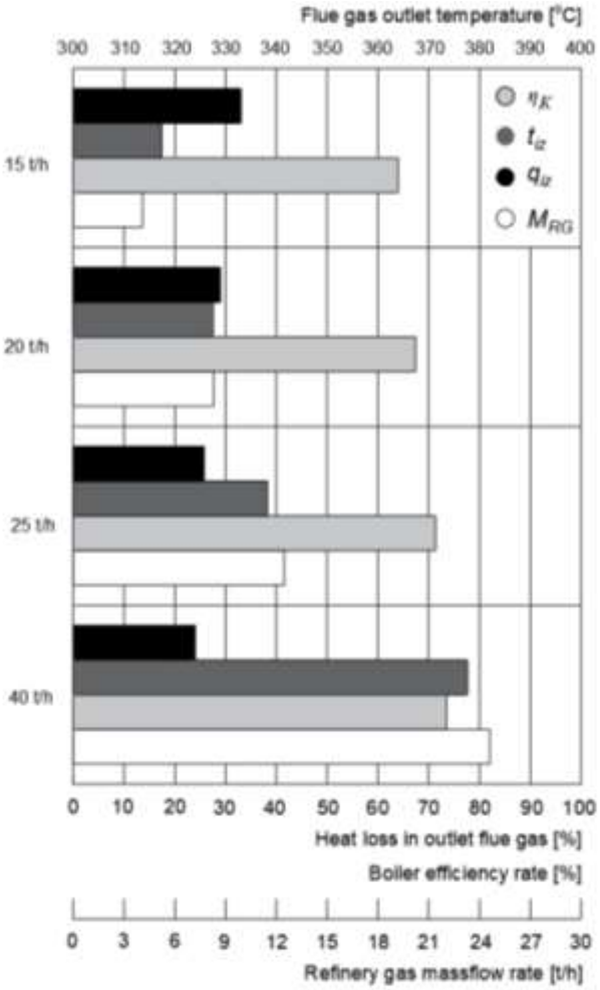

Figure 6 - Change of flue gas outlet temperature, heat loss in outlet flue gas, boiler efficiency rate and refinery gas consumption for the regimes in new operational conditions

Operation of boiler with lower fresh steam massflow rate requires lower consumption of refinery gas (tab. 4, line 1.1) in comparison with regime with maximum boiler capacity (tab. 3, line 1.1) although massflow rate of waste gas is reduced for 33% in comparison to the design conditions. As consequence of larger fouling rates in new operational conditions flue gas temperatures along flue gas duct are significantly higher. For instance, flue gas outlet temperature for steam massflow rate of 15 t/h is higher then 300 ºC and goes up to the value of 378ºC for the massflow of 40 t/h (tab. 4, line 1.7.).

Differences in flue gas outlet temperatures in comparison to the design conditions are even more pronounnced bearing in mind that design conditions reffer to the fresh steam massflow rate of 75 t/h - much larger then those in new operational conditions. Consequentlly, heat loss in outlet flue gas for new conditions is notably higher (tab. 4, line 1.8.) which gives significantly lower values of boiler efficiency rate (tab. 4, line 1.9) in comparison to the design conditions. Finally, consumption of refinery gas in new conditions is higher than it would be if boiler would operate with designed values of heat exchangers fouling factors.

When boiler operates with fresh steam massflow rate lower then 25 t/h outlet steam temperature is below level of 402ºC. Steam temperature at first superheater outlet is equal to steam temperature at the second stage inlet which means that boiler operates outside of the regulation area. In these regimes fresh steam outlet temperature depends on refinery gas massflow introduced to the boiler furnace.

Although temperatures of flue gas are higher along flue gas duct in new operational conditions velocities of heat emitter are lower (tab. 4, lines 2.9 – 2.11) as to design operational conditions (tab. 3, column 2.9. – 2.11.) which, in long-term operation, leads to the increased fouling rates of radiative and convective heat exchangers.

Also, following previuosly described trend, it is to be noted that economizer inlet flue gas temperature is significantly higher (tab. 4, line 2.6) in comparison to the design conditions (tab. 3) line 2.6) and it is in range between 450 and 550ºC. Higher temperature of flue gas along with lower massflow rate of heat receiver provides conditions under which of inital evaporation of water within economizer pipes occurs. As it is previously shown, counterflow emitter-receiver scheme in this heat exchanger is applied where heat receiver flows downward to the economizer outlet header. Due to the difference in density of saturated steam and water, buoyancy tend to move gaseous part of mixture upward which additionally increases hydraulic resistance in heat receiver flow. By analizing velocity of heat abosrber in economizer (tab. 4, lines 3.10 - 3.12) it can be noted that values are close to the critical one – 0,3 m/s acc. to [6]. Mutual impact of these factors ensure conditions for occurance of vapour bubbles („plug“) which might result in significant decrease of heat receiver massflow through particular pipe bundles.

Table 4. Heat balance and thermal calculations results for the new operational conditions given in tab. 2.

No.	Parameter		Notation	Unit	Refinery gas H_d = 35,71 MJ/Nm^3			
					Fresh steam massflow rate			
					15 t/h	20 t/h	25 t/h	40 t/h
1	*2*		*3*	*4*	*5*	*6*	*7*	*8*
1.	**Heat balance**							
1.1.	Refinery gas massflow		M_{RG}	kg/h	463,2	843,5	1221,5	2475,2
1.2.	Waste gas massflow		M_{OG}	kg/h	60000,0	60000,0	60000,0	60000,0
1.3.	Waste gas inlet temperature		t_{OG}	ºC	0	677	677	677
1.4.	Intake air massflow		M_{VAZ}	kg/h	5802,0	9691,3	13557,7	35441,2
1.5.	Flue gas massflow		M_{DG}	kg/h	66265,2	70534,8	74779,2	97916,4
1.6.	Ambient air temperature		t_{hv}	ºC	12	12	12	12
1.5.	Preheated air temperature		t_{zv}	ºC	35	35	35	35
1.6.	Excess air coefficient		α	-	1,463	1,375	1,307	1,275
1.7.	Flue gas outlet temperature		t_{iz}	ºC	317	327	339	378
1.8.	Heat loss in outlet flue gas		q_2	%	34,03	29,89	27,43	25,91
1.9.	Boiler efficiency rate		η_k	%	64,50	68,75	71,20	72,98
1.10.	Thermal power of boiler		Q_{PK}	kW	11428,7	15369,1	19292,2	30869,0
2.	**Heat emitter – flue gas**							
2.1.	Flue gas adiabatic temperature		t_a	ºC	870	1008	1126	1308
2.2.	Temperature of flue gas at furnace outlet		t_l	ºC	725	821	900	1044
2.3.	Temperature of flue gas at superheaters outlet		t_2	ºC	651	725	786	905
2.4.	Temp. of flue gas at convect. evaporator inlet		t_3	ºC	643	715	774	891
2.5.	Temp. of flue gas at convec. evaporator outlet		t_4	ºC	458	490	518	586
2.6.	Temp. of flue gas at 2. stage economizer inlet		t_5	ºC	456	487	515	583
2.7.	Temp. of flue gas at 2. stage economizer outlet		t_6	ºC	392	411	429	481
2.8.	Flue gas velocity in 1. stage economizer		w_{gnv1}	m/s	6,62	7,25	7,90	11,20
2.9.	Flue gas velocity in 2. stage economizer		w_{gnv2}	m/s	7,36	8,15	8,96	12,83
2.10.	Flue gas velocity in superheaters		w_{gs}	m/s	6,57	7,65	8,69	12,88
3.	**Heat receiver – water and steam**							
3.1.	Feedwater temperature		t_{nv}	ºC	105	105	105	105
3.2.	Heat receiver temperature at economizer inlet		t_{nvul}	ºC	140	140	140	140
3.3.	Heat receiver temp. at 1. stage econom. outlet		t_{nv12}	ºC	218	211	206	204
3.4.	State of water at economizer outlet	Temperature	t_{nviz}	ºC	258	258	258	259
		Drying rate	x_{nviz}	%	6,64	4,03	2,17	1,14
3.5.	Temperature of saturated steam		t_{szp}	ºC	258	258	258	259
3.6.	Heat receiver temp. at 1. stage superheat. outlet		t_{s1iz}	ºC	358	365	369	372
3.7.	Heat receiver temp. at 2. stage superheat. inlet		t_{s2ul}	ºC	358	365	369	367
3.8.	Boiler outlet steam temperature		t_s	ºC	387	397	402	402
3.9.	Velocity of water in 1. stage economizer		w_{nv1}	m/s	0,22	0,29	0,36	0,58
3.10	Velocity of water in 2. stage economizer		w_{nv2}	m/s	0,24	0,32	0,40	0,63
3.11.	Velocity of steam in 1. stage superheater		w_{s1}	m/s	5,38	7,23	8,69	14,35
3.12.	Velocity of steam in 2. stage superheater		w_{s2}	m/s	6,43	8,72	10,93	17,48

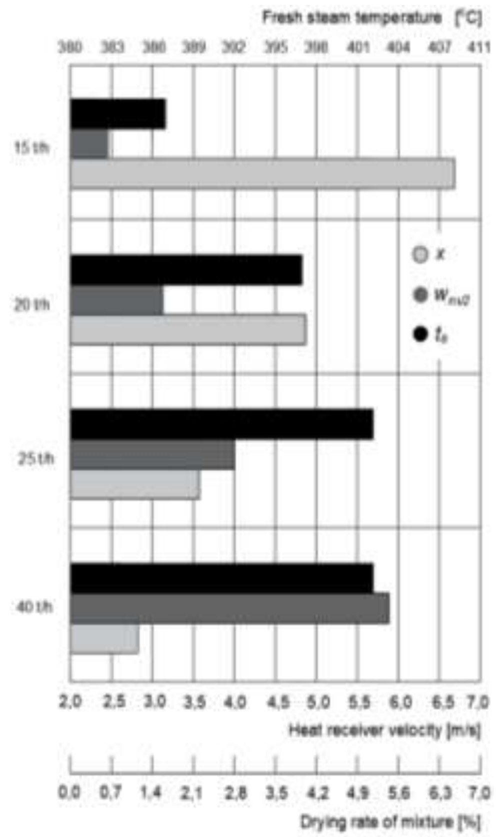

Figure 7 - Change of fresh steam outlet temperature, velocity of water in 2. stage economizer and mixture drying rate in dependance of steam mass flow rate for the regimes in new operational conditions.

Reducing of heat receiver massflow rate decreases cooling rate of pipes and, in long–term operation, might lead to the apperance of initial cracks on its surface. By increasing boiler steam massflow rate vapor share in two component mixture at the economizer outlet decreases. Nevertheless, it remains larger then 0% even for the heighest analyzed fresh steam massflow rate - 40 t/h (tab. 4, line 3.4).

4. ASSESING INFLUENCE OF FEEDWATER PREHEATING RATE IN NEW OPERATIONAL CONDITIONS

In previously analyzed calculations for the design conditions it is shown that increased preheating rate of feedwater gives higher flue gas and economizer heat receiver outlet temperature (tab 3, line 3.4, column 6 - 8, fig. 4).

By analyzing measurements taken on site [5] it is stated that preheating rate of feedwater in recent period varied while economizer inlet heat receiver temperature was in range between 105 and 160ºC. Additional calculations were performed in order to assess influence of preheating rate of feedwater on overall boiler performance in new conditions. Results of heat balance and thermal calculations for steam massflow rate of 25 t/h and different feedwater preheating rates in new operational conditions are shown in tab. 5.

By increasing inlet temperature of heat receiver in economizer potential for cooling flue gas reduces which consequently gives higher temperatures of heat emitter at the boiler outlet followed by increased heat loss in outlet flue gas and lower values of boiler efficiency rate (tab. 5, lines 1.11 – 1.12.).

Results in tab. 5 show that operation of boiler without preheating of feedwater ensures absence of initial evaporation of heat receiver in economizer. However, it is important to state that subcooling rate of heat receiver at the outlet of economizer remains low (15 ºC) which means that this heat exchanger works in conditions critically close to the occurrence of initial evaporation of heat receiver. By increasing temperature of water at economizer inlet drying rate of heat receiver at economizer outlet increases and reaches maximum value of 6 % for economizer water inlet temperature of 160ºC. Along with this trend it is important to point out that at lower values of saturation pressure volume and mass share of vapor in mixture differs significantly. At relatively lower drying rates of mixture larger portion of pipe inner cross-section is occupied by vapor (acc. to [6] with $x = 6\%$ and pressure of 45,0 bar, volume share of vapor equals 75%). Aside previously described possibility of occurrence of vapor „plug“ presence of vapor in economizer aggravates cooling of economizer pipes. Increasing of pipe wall temperature result in larger temperature dilatation of pipes which under certain operation conditions might leads to the exceedance of critical stress in economizer elements. Operation of economizer in such conditions is followed by appearance of initial crack which, in time, evolutes in complete dysfunction of this heat exchanger and entire boiler facility.

5. ANALYSIS OF BOILER OPERATIONAL PERFORMANCE AFTER PARTIAL CLEANING OF THE HEAT EXCHANGERS

During one of the unscheduled interruptions of boiler operation along with revitalization of economizer partial cleaning of heat exchangers in flue gas duct has been conducted. Promptly after cleaning procedure visual inspection of heat exchangers has been performed during which it was noted that evaporators pipes in furnace as well as economizer pipes were completely free from fouling layers while convective evaporator and superheaters were partially cleaned due to the inapproachability of these heat exchangers in flue gas duct. After reestablishing steam production (at rates below minimum level, as it was before interruption) boiler shortly operated closely to the design values of fouling rates of heat exchangers. Recently after, not changing the steam production rate, fouling of all heat exchangers started to increase resulting in higher temperatures of flue gas along flue gas duct.

Table 5. Heat balance and thermal calculations results for 25 t/h steam massflow rate and various feedwater preheating rates.

No.	Parameter		Notation	Unit	Refinery gas H_d = 35,71 MJ/Nm^3		
					Fresh steam masssflow rate – D = 25 t/h		
					Water inlet temperature at 1. stage economizer		
					105 ºC	140 ºC	160 ºC
1	*2*		*3*	*4*	*5*	*6*	*7*
1.	**Heat balance**						
1.1.	Refinery gas massflow		M_{RG}	kg/h	1191,9	1221,5	1250,0
1.2.	Waste gas massflow		M_{OG}	kg/h	60000,0	60000,0	60000,0
1.3.	Intake air massflow		M_{VAZ}	kg/h	13252,5	13557,7	13846,0
1.4.	Flue gas massflow		M_{DG}	kg/h	74444,4	74779,2	75096,0
1.5.	Thermal power of boiler		Q_{PK}	kW	19292,1	19292,2	19292
1.6.	Ambient air temperature		t_{hv}	ºC	12	12	12
1.7.	Preheated air temperature		t_{zv}	ºC	35	35	35
1.8.	Excess air coefficient		α	-	1,312	1,307	1,303
1.9.	Flue gas outlet temperature		t_{iz}	ºC	323	339	348
1.10.	Boiler efficiency rate		η_k	%	72,34	71,20	70,64
2.	**Heat emitter – flue gas**						
2.1.	Flue gas adiabatic temperature		t_a	ºC	1117	1126	1134
2.2.	Temperature of flue gas at furnace outlet		t_l	ºC	894	900	906
2.3.	Temperature of flue gas at superheaters outlet		t_2	ºC	782	786	791
2.4.	Temp. of flue gas at convective evaporator inlet		t_3	ºC	770	774	779
2.5.	Temp. of flue gas at convec. evaporator outlet		t_4	ºC	516	518	520
2.6.	Temp. of flue gas at 2. stage economizer inlet		t_5	ºC	513	515	517
2.7.	Temp. of flue gas at 2. stage economizer outlet		t_6	ºC	421	429	434
3.	**Heat receiver – water and steam**						
3.1.	Feedwater temperature		t_{nv}	ºC	105	105	105
3.2.	Heat receiver temperature at economizer inlet		t_{nvul}	ºC	105	140	160
3.3.	Heat receiver temp. at 1. stage econom. outlet		t_{nv12}	ºC	177	206	222
3.4.	State of water at economizer outlet	Temperature	t_{nviz}	ºC	243	258	258
		Drying rate	x_{nviz}	%	0	2,17	5,96
3.5.	Temperature of saturated steam		t_{szp}	ºC	258	258	258
3.6.	Heat receiver temp. at 1. stage superheat. outlet		t_{s2ul}	ºC	366	369	368
3.7.	Heat receiver temp. at 2. stage superheat. inlet		t_s	ºC	399	402	402

After some time, increasing of fouling vanished reaching steady state of its values reflected in constant temperatures of heat emitter and receiver along corresponding tracts. It is to be assumed that in this transition period fouling factors were increasing due to the operation of boiler with steam production rates below minimum level, that is, low velocities of heat emitter along flue gas tract and forced deposition of catalyst particles on outer surface of heat exchangers. Fouling layer were increasing from state of clean pipe to the thickness that corresponds to the steady state operation according to the boiler working conditions. After reaching steady state boiler operated with slightly lower temperatures of flue gas in comparison to its operation before cleaning (tab. 6, line 2.6). Control calculations for the new state of heat exchangers were conducted with previous adjusting of fouling factors according to measurements given in [5] taken after cleaning during steady state boiler operation. Comparative overview of the results for fresh steam massflow rate of 25 t/h and various values of fouling factors and water preheating rates is given in tab. 6.

Lower temperatures of flue gas after cleaning were achieved due to the lower fouling rates of heat exchangers which ensured more intense heat transfer process on heat exchangers before economizer along flue gas tract. Accordingly, after cleaning boiler operated with lower outlet flue gas temperature (tab. 6, line 1.10.) and higher efficiency rate in comparison to the regime before cleaning procedure (tab. 6, line 1.11.)

Table 6. Heat balance and thermal calcualtion results for fresh steam massflow rate of 25 t/h and different fouling rates of heat exchangers.

No.	Parameter		Notation	Unit	Refinery gas H_d = 35,71 MJ/Nm^3				
					Waste gas temperature – t_{WG} = 677 ºC				
					Fresh steam masssflow rate – D = 25 t/h				
					Design fouling	After cleaning	Before cleaning	Design fouling	After cleaning
					Water inlet temperature at 1. stage economizer				
					140 ºC	140 ºC	140 ºC	105 ºC	105 ºC
1	*2*		*3*	*4*	*5*	*6*	*7*	*8*	*9*
1.	**Heat balance**								
1.1.	Refinery gas massflow		M_{RG}	kg/h	960,3	1128,7	1221,5	924,9	1091,9
1.2.	Waste gas massflow		M_{OG}	kg/h	60000,0	60000,0	60000,0	60000.0	60000.0
1.3.	Intake air massflow		M_{VAZ}	kg/h	10884,9	12606,5	13557,7	10522,8	12229,2
1.4.	Flue gas air massflow		M_{DG}	kg/h	71845,2	73735,2	74779,2	71449.2	73321,2
1.5.	Thermal power of boiler		P_k	kW	19292,2	19292,2	19292,2	19292,2	19292,2
1.6.	Ambient air temperature		t_{hv}	ºC	12	12	12	12	12
1.7.	Preheated air temperature		t_{zv}	ºC	35	35	35	35	35
1.8.	Excess air coefficient		α	-	1,353	1,323	1,307	1.359	1,329
1.9.	Flue gas outlet temperature		t_{iz}	ºC	203	290	339	184	272
1.10.	Boiler efficiency rate		η_k	%	81,13	74,69	71,20	82,63	76,00
2.	**Heat emitter – flue gas**								
2.1.	Flue gas adiabatic temperature		t_a	ºC	1046	1098	1126	1035	1087
2.2.	Temperature of flue gas at furnace outlet		t_l	ºC	786	864	900	779	857
2.3.	Temp.of flue gas at superheaters outlet		t_2	ºC	626	737	786	621	731
2.4.	Temperature of flue gas at convective evaporator inlet		t_3	ºC	607	724	774	603	718
2.5.	Temperature of flue gas at convective evaporator outlet		t_4	ºC	329	459	518	328	457
2.6.	Temperature of flue gas at 2. stage economizer inlet		t_5	ºC	327	457	515	327	454
2.7.	Temperature of flue gas at 2. stage economizer outlet		t_6	ºC	261	374	429	251	364
3.	**Heat receiver – water and steam**								
3.1.	Feedwater temperature		t_{nv}	ºC	105	105	105	105	105
3.2.	Heat receiver temperature at 1. stage econom. outlet		t_{nv12}	ºC	180	200	206	151	171
3.3.	State of water at economizer outlet	Temp.	t_{nviz}	ºC	224	256	258	202	235
		Drying rate	x_{nviz}	%	0	0	2,17	0	0
3.4.	Temperature of saturated steam		t_{szp}	ºC	258	258	258	258	258
3.5.	Heat receiver temperature at 1. stage superheater outlet		t_{s1iz}	ºC	409	380	369	406	378
3.6.	Heat receiver temperature at 2. stage superheater inlet		t_{s2ul}	ºC	359	366	369	360	366
3.7.	Boiler outlet fresh steam temperature		t_s	ºC	402	402	402	402	402

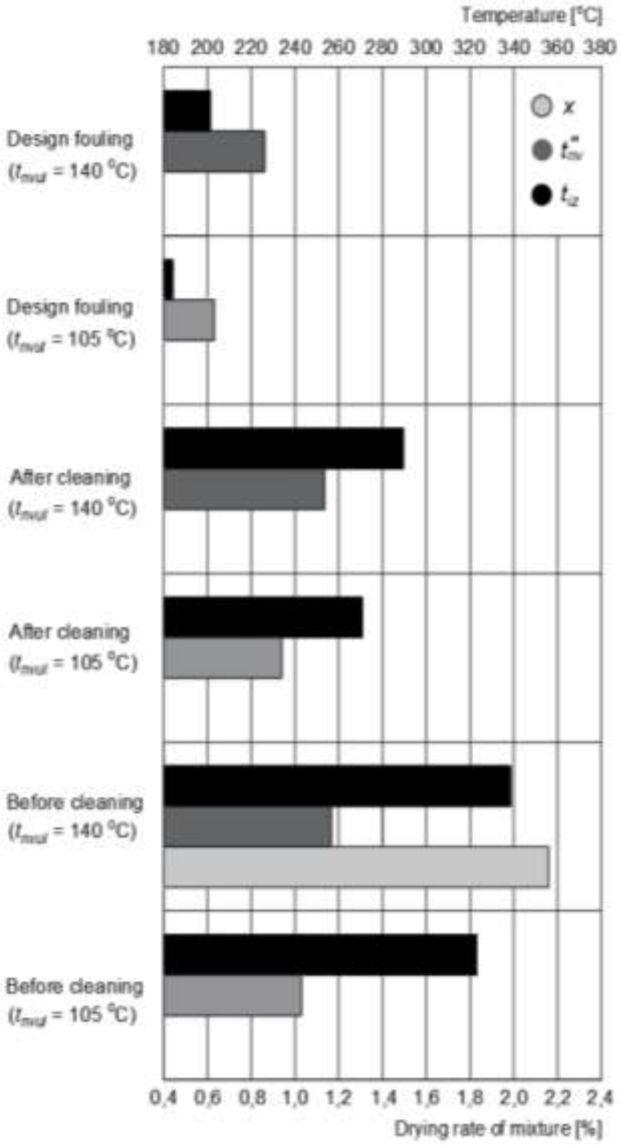

Figure 8 - Change of outlet flue gas temp., heat receiver temp. at economizer outlet and drying rate of heat receiver at economizer outlet for various fouling rates of heat exchangers

Lower temperature of flue gas at economizer inlet slightly reduced amount of heat transferred on this heat exchanger. Accordingly, economizer outlet temperature of heat receiver was 2ºC lower to the evaporation temperature at the boiler drum pressure. Although initial evaporation of heat receiver didn`t occur, subcooling rate of outlet water remained insufficiently low to guarantee safe and stable operation of boiler especially in case of occurring sudden changes in boiler operational parameters (additional reduction in steam production or increasing of fouling of heat exchangers before economizer, etc.).

Partial cleaning of heat exchangers resulted in lower temperatures of flue gas along flue gas tract and gave positive impact on economizer and overall boiler operation. However, due to impossibility of detail cleaning of all heat exchangers partial cleaning didn`t ensure sufficient subcooling rate of heat receiver at economizer outlet as well as increase in steam boiler reliability in long-term aspects.

Additionally, calculations have been performed for various fouling rates of heat exchangers and economizer water inlet temperature of 105ºC. Results show that after cleaning without feedwater preheating heat receiver at the economizer outlet is in liquid state with sufficient subcooling rate – more then 20ºC (tab. 6, column 9, lines 3.3 – 3.4). Operation of boiler with design values of heat exchangers fouling factors gives more favorable impact, that is, subcooling rate of economizer outlet more then 50ºC (tab. 6, column 8, lines 3.3 – 3.4), as it is expected.

6. CONCLUSION

In this paper results of analysis of process CO steam boiler operation with maximum fresh steam massflow rate of 75 t/h are presented. Boiler produces steam of 412ºC temperature and 45,5 bar pressure which is further utilized for domestic electricity production as well as for particular technological processes within oil and gas refinery.

Steam boiler is constructed to operate with various fuels as well as with two or three fuels simultaneously. In furnace of steam boiler it is enabled to introduce refinery gas, waste gas and fuel oil as well more then one fuel at the time. Massflow of waste gas is constant while the change in fresh steam massflow rate is to be achieved by adjusting massflow of refinery gas. Fuel oil has not been used in boiler operation for a while due to the application of valid ecological norms.

Due to the changes in superheated steam consumption in entire facility steam boiler operation is adjusted as to fit new steam production schedule of entire refinery. New regimes of boiler differs significantly in comparison to the designed conditions. Steam production rate is reduced below minimum level of boiler and it is within range of 15 to 25 t/h while massflow of waste gas is reduced for 90 to the 60 t/h. Outlet steam temperature is also reduced and in new conditions equals 402ºC.

During operation in such conditions frequent pipe burst on economizer occurs which requires immediate interruption in boiler operation as well as engagement of additional cost-consuming resources for the purpose of revitalization of this heat exchanger and resuming steam production. For the needs of detection of cause of frequent pipe burst control calculation for the designed operation conditions of boiler are performed. By analyzing results of these calculations it is stated that operation of boiler with RG+WG gives higher temperatures of flue gas along flue gas duct in comparison to the regime when boiler utilizes RG only. This trend occurs due to the higher massflow rate and velocities of heat emitter through every convective heat exchanger. Additionally, it is shown that by increasing heat receiver economizer inlet temperature subcooling rate of water at the economizer outlet decreases while the state of water is getting closer to the liquid saturation state of heat receiver at the boiler drum pressure. Nevertheless, at 140ºC economizer water inlet temperature initial evaporation of heat receiver in economizer pipes doesn`t occur while subcooling rates of water are sufficient to state that boiler operates safely and reliably in such operation regimes.

After reducing steam production rate below minimum level prescribed by boiler producer, velocities of flue gas in flue gas duct are significantly lower to the regimes with higher steam production rates which result in more intense deposition process of solid phase on pipes outer surfaces and finally to the higher fouling rates of every heat exchanger as well as higher heat emitter temperatures in entire flue gas duct. Reduced massflow of heat receiver in conjunction with higher flue gas temperatures leads to the initial evaporation of water in economizer pipes. In economizer, heat receiver circulate downwards which in case of appearance of initial vapor bubbles that is application of buoyancy force, increases hydraulic resistance in heat receiver flow. Additionally, when considering two phase steam-water flow in horizontally aligned pipes, heat receiver velocities shall be larger then critical value (0,3 m/s) acc. to [6]. When velocities are below critical level (which is the case when boiler operates when produces 25 t/h of steam in new operation conditions) accumulation of vapor bubbles might occur which additionally reduces massflow of heat receiver and intensity of cooling process of particular pipe bundles potentially leading it to a critically high temperatures of pipe walls. Such trend induces dilatation of pipes above permitted level resulting in occurrence of initial cracks in pipes which propagate until complete burst of bundle element which requires imidiate stoppage of boiler operation and interruption in steam production. Results of calculations showed that mass and volume share of vapor in mixture increases for the lower steam production rates (production rates of 15 and 20 t/h) which even more negatively influence cooling process of economizer pipe bundles. By increasing production rates up to 40 t/h, intensity of evaporation in economizer somewhat reduces but still occurs due to the higher fouling rates of heat exchangers and increased flue gas temperatures at economizer inlet achieved by higher refinery gas massflow.

Result of calculations also showed that when boiler operates in new conditions with 25 t/h steam production rate and water at economizer inlet is not preheated, initial evaporation in this heat exchanger doesn`t occur.

Nevertheless, subcooling rate of economizer heat receiver outlet state is critically low which implies that occurrence of small changes or disturbances in boiler operation (additional fouling of heat exchangers, changes in steam production rates) might lead to the appearance of initial vapor bubbles in economizer pipes and manifestation of all negative effects that follow evaporation in economizer pipe bundles.

After partial cleaning of heat exchangers in flue gas duct control calculation has been performed for steam production of 25 t/h and new state of outer surfaces of every heat exchanger. Results showed that lower flue gas temperatures in entire flue gas duct are achieved which reduces amount of heat transferred toward heat receiver on economizer. Consequently, heat receiver leaves economizer in liquid state with insufficiently low subcooling rate to guarantee safe and reliable operation of this heat exchanger.

Consequences of these negative effects occurred by lowering boiler steam production rate in new conditions might be reduced by adjusting boiler operational parameters to lessen the intensity of heat receiver evaporation in economizer. Bearing in mind presented results of all analysis, boiler will operate more safely and reliably with larger steam production rate (keeping it in acc. with overall steam production plan in entire refinery), possibly avoiding preheating of feedwater and performing more frequent and effective cleaning of heat exchangers during boiler operation as well as during scheduled stoppage in steam production.

If boiler operation with steam production rates lower then minimum level is required it is necessary to consider reconstructing economizer in order to maintain safe and reliable boiler operation.

REFERENCES

[1] D. Tucaković, et al., *Analiza stanja CO bojlera i predlog mera za efikasniji i pouzdaniji rad*, University in Belgrade – Faculty of Mechanical Engineering, Belgrade, October 2020.

[2] Lj. Brkić, et al., *Termički proračun parnih kotlova*, University in Belgrade – Faculty of Mechanical Engineering, Belgrade, 2015.

[3] Lj. Brkić, et al., *Parni kotlovi*, University in Belgrade – Faculty of Mechanical Engineering, Beograd, 2014.

[4] D. E. Crease, Reference Sheet - CO BOILER LENTJES – VENDOR DATA, Pancevo Refinary, Yugoslavia, 1980.

[5] Datasheets with measurements of flue gas and refinery gas composition, thermodynamical states off heat receiver in water-steam line and heat emitter in flue gas line, airflow, refinery gas flow and steam mass flow at boiler outlet delivered on 11.01.2020. by Refinary Pancevo authorized stuff.

[6] Lj. Brkić, et al, *Hidrodinamički proračun parnih kotlova*, University in Belgrade – Faculty of Mechanical Engineering and Art Inženjering, Belgrade, 2009.

REZIME

DETEKCIJA UZROKA PUCANJA CEVI NA ZAGREJAČU VODE PROCESNOG CO PARNOG KOTLA

U radu su prikazani rezultati analize rada procesnog parnog kotla sa maksimalnom kontinualnom produkcijom pare od 75 t/h pritiska 45,5 bar i temperature 412 oC. Predmetni kotao je deo postrojenja za proizvodnju pare u Rafineriji nafte u Pančevu, Srbija. Prema zahtevu naručioca predviđeno je da kotao radi sa više vrsta goriva kao i sa dve ili tri vrste goriva istovremeno. Pristupnim instalacijama u ložište je moguće dovesti rafinerijski gas, ložno ulje kao i otpadni gas visoke temperature. Otpadni gas se u kotao dovodi iz postrojenja za katalitički kreking (eng. FCC – Fuel catalyst cracking) i predstavlja dvokomponentu mešavine gasne faze i polidisperznih čestica prečnika ne većeg od 40 μm. Skorije promene u proizvodnji pare u rafineriji dovele su do potrebe za modifikacijom radnog režima kotla, odnosno, do modifikacije njegovih radnih parametara. Trenutno, u novim radnim uslovima, u toku rada kotla dešavaju se učestala pucanja cevi na zagrejaču vode što zahteva momentalni prekid proizvodnje pare kao i sprovođenje vremenski i finansijski zahtevanih postupaka u cilju otklanjanja uzroka zastoja i nastavka rada parnog kotla. U ovom radu predstavljeni su rezultati termičkog proračuna predmetnog kotla za projektne i nove uslove rada u cilju identifikacije uzroka učestalih neplankih zastoja u proizvodnji pare. Nakon izvršene analize rezultata proračuna date su preporuke u vezi modifikacije radnih parametara u cilju eliminisanja ili smanjivanja mogućnosti za pojavu neželjenih efakata na zagrejaču vode.

Ključne reči: *procesni parni kotao, otpadni gas, termički proračun, pucanje cevi*