U.P.B. Sci. Bull., Series D, Vol. 77, Iss. 3, 2015 ISSN 1454-2358

COMPARATIVE ASPECTS AT SIZING OF THE FLUIDIZED BED STEAM BOILER FURNACES FOR DIFFERENT SOLID FUELS

Daniela HOARĂ[1], Gheorghe LĂZĂROIU[2]

In this article it is showed the sizing manner of the fluidized bed steam boiler furnaces sizing which was done for two types of fuel, presenting comparisons between the two cases. It also showed the effect of the boiler steam flow variation over the parameters with major sensitive from the sizing calculation.

Keywords: fluidized bed combustion, boiler furnace, sizing

1. Introduction

Fluidized bed combustion technology, in the last decade is again receiving worldwide research attention in view of its potential as an economic and environmentally acceptable technology for combustion a lot of category of solid fuels from fossil class. [1] According to estimates the International Energy Agency (IEA), centralized in the annual World Energy Outlook, fuels will account for 84 % growth in energy demand in the period 2005-2030. [2]

The fluidized bed combustion is one of the "clean" burning technology of the solid fuel used at the steam boilers from the power plants, which significantly reducing the air pollution comparative with other existing technologies. The technical and environmental requirements to ensure a good combustion for this technology are: [3]

- attainment of the flashpoint temperature of the fuel;
- realization of a bigger contact area between the fuel and the combustion air;
- ensuring of a sufficient residence time for fuel in the combustion zone;
- realization of a complete combustion, both from "chemical" point of view (meaning that in the flue gases should not exist combustible gases, such as CO) and from "physical" point of view (in the combustion products there are no vapor, drops liquid or solid particles);
- obtaining of the combustion products which are not harmful;

[1] PhD., Power Engineer Faculty, University POLITEHNICA of Bucharest, Romania, e-mail: hoaradaniela@gmail.com
[2] Prof., Power Engineer Faculty, University POLITEHNICA of Bucharest, Romania

The technology penetration in the energy market requires that the favorable decision for a technical solution to be done according to the global, technical, economic and environmental considerations, and it must take into account a number of applied criteria for the specific local situations. [4]

The fluidized bed combustion technology gives:

- controlling of the SO_2 and NOx emissions in the combustion chamber;
- elimination of the additional installations for flue gas cleaning;
- providing of a wide flexibility of the fuels usage, even with inferior characteristics.

The promotion of this technology was not based on immediate economic effects, but on estimation of possible fuel market fluctuations and on a permanent limiting trend of the pollution control. [4]

In this paper was presented the influence of using different types of solid fuels over the fluidized bed steam boiler furnaces sizing. There were considered two types of solid fuels: lignite and bituminous shale and there were followed the parameters with major influence over sizing. Thus, there were presented the comparative advantages of the two cases envisaged for a boiler steam flow variation, representing contributions to sizing of these furnaces types for the fuels considered. Experiments conducted so far for fluidized bed combustion of the two fuels have showed special perspectives offered by this lower fuel combustion technology, which can be a very efficient combustion system for the constructions expected to be achieved in the coming decades.

2. The advantages of fluidized bed combustion technology

The fluidized bed combustion technology has a series of advantages, such as: [4][5][6]

- high combustion efficiency: thanks to favorable reaction conditions (a carbon burning rate of 98÷99%);
- emissions reducing in flue gases by adding limestone (SO_2 desulphurising of 80÷90%), the being removed in a solid form; NO_x formation is reduced within the limits allowed by the rules, due to the furnace temperature and to the stepwise introduction of the combustion air;
- Economic coal preparation: grinding at the size of 0÷15 mm with a reduced power consumption about 25÷30%, through crushing and centrifugal separation without coal mills;
- possibility of using a various solid fuels with high combustion efficiency: with no major furnace changes, fluidized bed combustion boilers can use both superior coal from 21 to 25,2 MJ/kg and inferior coal from 4,2 to 5MJ/kg,

with a high sulfur content. In a individual cases it can burn heavy fuel products as: shale, petroleum coke, carbon electrodes, etc.;

- elasticity in operation and a rapidly variation of the load;
- inferior fuels with high ash content are burned in boilers with fluidized bed combustion without addition hydrocarbons;
- dry ash evacuation: the resulted dry ash with a granulation of 0÷10 mm can be used as additive for building materials. The absence of the slag crusher removes some of the current problems of coal boilers, determining an energy saving;
- corrosion reducing of the final heat exchange surfaces; heat transfer between the dispersion medium solid-gas and the heat exchange surfaces occurs primarily outside the combustion area, where the gases has been desulfurized, avoiding the final acid corrosion.

3. Description of the fluidized bed combustion boiler

Figure 1 presents a boiler with a fluidized bed combustion technology. The layer fluidization velocity corresponds to a pneumatic conveying system. The particles are collected and recirculated, possibly after passing through a conventional layer, cooled by the internal structure of a boiler. These operate at high linear speeds of fluidized bed circulation, in order to allow a residence time comparable to that of a gas. In the fluidized bed, circulation of the materials in the layer and high turbulence in the combustion chamber provides a good mixing and a long residence time of the fuel particles, providing a better combustion and control of emissions. The fluidized bed acts as a heat carrier, stabilizing the layer temperature.

In the fluidized bed combustion boiler, the crushed fuel and limestone (6÷12 mm) are injected into the combustion zone. The mixture of particles is suspended in a stream of air, which is admitted through the bottom of the boiler by means of the dispensing nozzles. Secondary air is admitted in boiler through the top of the fuel input area to meet the combustion air supply needs. Combustion takes place at temperatures above 850°C and the fine particles (<450 microns) are decanted into the furnace with a flue gas velocity of 4 ÷ 6 m/s. The particles are then collected by the solids separator and recirculated in the boiler. Circulation of the particles provides an efficient heat transfer to the walls of the boiler and a longer residence time for utilization of the carbon and limestone. The main parameters of the fluidized bed combustion process are: the temperature, the residence time and the turbulence. [5][6]

The furnace of the fluidized bed combustion boiler has a variable section with the height. The first part of the furnace is designed for the coal layer formation. There are heavy erosion conditions caused by the high concentration of solid particles, by the fluidization velocity and by the high chemical corrosion. The heat in this area is transmitted to the circulating solid phase. The top of the furnace area is destinated to complement the combustion. Here is mounted the radiation evaporator system. The boiler is in π shape. After festoon, there is a dust remover cyclone which retains a part of the ash particles. These enter through a control valve in a heat exchanger (cooling chamber) where are cooled and then are returned to the furnace. Due to this recirculation is maintained a constant temperature of the recirculation gases. [5][6]

The fluidized bed combustion boiler is considered an environmentally friendly boiler due to the fact that the fluidized bed combustion technology does not favor the occurrence of NO_x, and also, that it can be injected limestone into the furnace to retain the sulfur and to reduce the SO_2 formation.

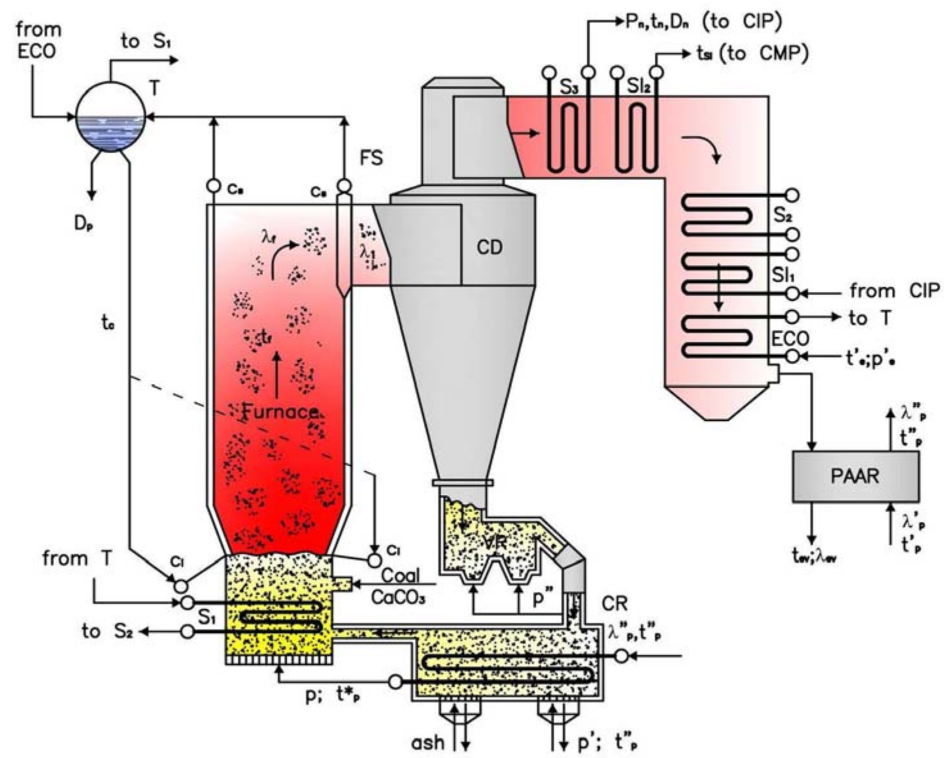


Fig. 1. The sketch of the fluidized bed combustion boiler [5][6]
FS – festoon, CD – cyclone, VR - control valve, CR - ash cooling chamber, PARR – rotary air preheater, ECO – economizer, CIP - high pressure part, CMP – low pressure part, SI – superheater, S – heat exchanger, T – drum, c – collector, Dp – purge flow, λ – air excess coefficient, p - pressure, t – temperature.

4. Sizing manner of the fluidized bed boiler furnace

The sizing method of the fluidized bed combustion boilers furnaces is shown in the Figure 2, where are highlighted the main functional modules of the technical calculations. [6][7][8]

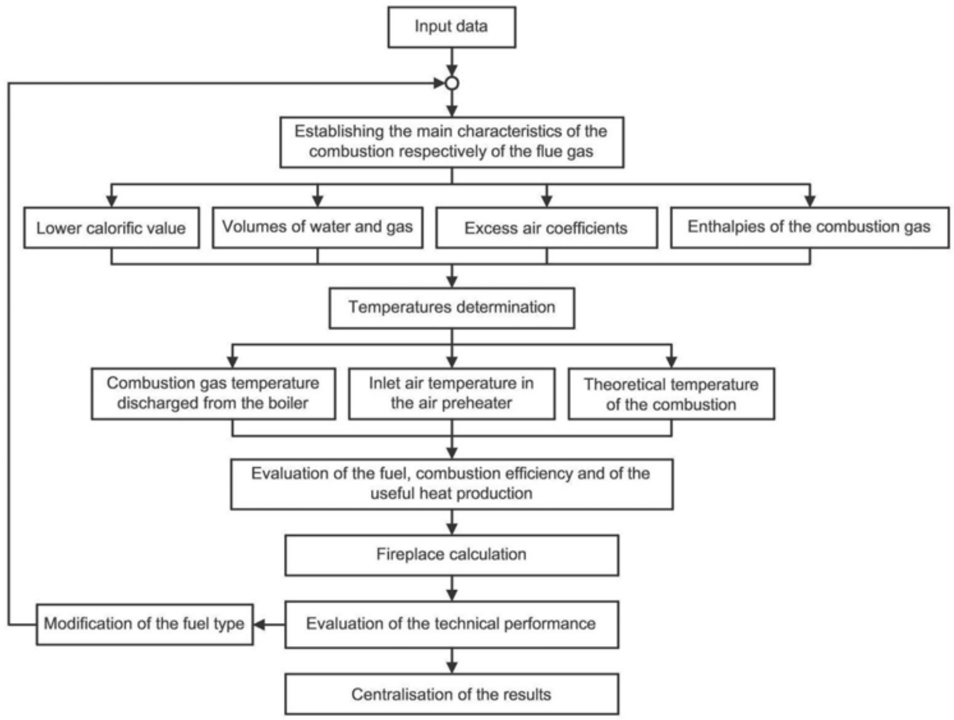


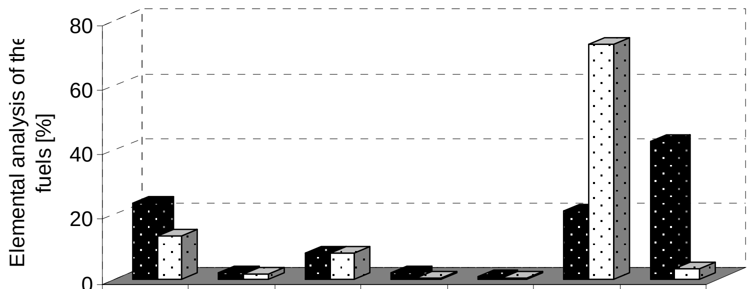
Fig. 2. Steps of the sizing calculation of fluidized bed boiler furnace

5. Utilization effect of various types of fuels over sizing of the fluidized bed combustion boiler furnace

A. Input data

Parameter	Notation	UM	Value
Nominal flow rate of the boiler	D_n	t/h	440
		kg/s	122,2
Nominal pressure of the boiler	p_n	bar	170,00
Nominal temperature of the boiler	t_n	ºC	570,00
Entrained ash fraction	a_{antr}	-	0,95
Feed water temperature	t'_e	ºC	250,00
Outlet air temperature from air preheater	t''_p	ºC	200,00
The heating capacity of the heat exchange surface immersed in the fluidized bed	Q_{S1}	kW	35.000,00

Fig. 3 presents the elemental analysis of solid fuels used in the sizing calculations of the fluidized bed combustion furnace.



	Ci	Hi	Oi	Ni	Sci	Ai	Wti
■ Lignite	23.5	2.0	8.2	2.0	0.8	21.0	42.5
□ Bituminous shale	13.3	1.7	8.2	0.2	0.42	72.8	3.3

Fig. 3. The elemental analysis of solid fuels [6][9][11]

where: C^i [%] – carbon content, H^i [%] – hydrogen content, S_c^i [%] - sulfur content, O^i [%] – oxygen content, N^i [%] – nitrogen content, A^i [%] – ash content, W_t^i [%] – moisture content.

B. Calculation of the lower fuel calorific value and of the air and flue gas volumes

Parameter	Notation	UM	Value	
			Lignite	Bituminous shale
Lower heating value of the fuel	Q_i^i	kJ/kg	8.153,15	5.316,95
Air and flue gas volumes	V_{Omin}	m^3_N/kg	0,50	0,29
Air stoichiometric volume	V_a^0	m^3_N/kg	2,38	1,37
Minimum wet air volume	V^0_{aum}	m^3_N/kg	2,41	1,40
Carbon dioxide volume	V_{CO2}	m^3_N/kg	0,44	0,25
Theoretical volume of the gas triatomic gases in the combustion products	V_{R02}	m^3_N/kg	0,44	0,25
Nitrogen volume from gases at the theoretical combustion	V_{N2}^0	m^3_N/kg	1,89	1,09
Water vapors volume at the theoretical combustion	V^0_{H2O}	m^3_N/kg	0,79	0,25
Theoretical volume of the anhydrous flue gases	V^0_{gu}	m^3_N/kg	2,34	1,34
Wet flue gas volume	V^0_g	m^3_N/kg	3,13	1,59
Real volume of the anhydrous flue gas	$V_{gu}(\lambda_i)$	m^3_N/kg	2,57	1,48
Real volume of the water vapors in the combustion with air excess	$V_{H2O}(\lambda_i)$	m^3_N/kg	0,79	0,25
Real volume of the flue gas at the end of the layer	$Vg(\lambda_i)$	m^3_N/kg	3,37	1,73

Real volume of the anhydrous flue gas	$Vg_u(\lambda_f)$	m^3_N/kg	2,81	1,61
Real volume of the water vapors in the combustion with air excess	$V_{H2O}(\lambda_f)$	m^3_N/kg	0,79	0,25
Real volume of the flue gas at the end of the furnace	$V_g(\lambda_f)$	m^3_N/kg	3,60	1,87
Real volume of the anhydrous flue gas	$V_{gu}(\lambda_{ev})$	m^3_N/kg	3,74	2,15
Real volume of the water vapors in the combustion with air excess	$V_{H2O}(\lambda_{ev})$	m^3_N/kg	0,79	0,25
Real volume of the exhaust flue gas	$V_g(\lambda_{ev})$	m^3_N/kg	4,53	2,40

Analyzing the data presented in the table above, it appears that the real volume value of the flue gases increases as they leave the boiler.

Utilization of the bituminous shale as fuel, which have a lower calorific value smaller than lignite, determine a diminution of the air and flue gases volumes, and in terms of real volumes of water vapors is found that they have a lower value when is using bituminous shale comparative with lignite, because the bituminous shale have a lower content of moisture than lignite.

C. Calculation of the flue gases enthalpy depending on t and λ

Table 1

Variation of the flue gases enthalpy depending on t şi λ

t ºC	$I_g(\lambda,t)$							
	λ=1		λ_i=1,1		λ_f=λ_1=1,2		λ_{ev}=1,59	
	Lignite	Bituminous shale	Lignite	Bituminous shale	Lignite	Bituminous shale	Lignite	Bituminous shale
100	455,6	276,5	487,6	295,0	519,6	313,5	644,3	385,6
200	924,8	564,9	989,1	602,1	1053,4	639,3	1304,2	784,2
400	1905,6	1170,8	2036,4	1246,4	2167,2	1322,0	2677,3	1616,9
600	2944,7	1816,9	3145,0	1932,7	3345,3	2048,5	4126,5	2500,1
800	4035,7	2486,3	4308,3	2643,9	4580,9	2801,4	5644,0	3415,9
1000	5175,3	3195,7	5522,3	3396,3	5869,3	3596,8	7222,5	4379,0
1200	6356,1	3937,1	6779,4	4181,8	7202,7	4426,4	8853,6	5380,7
1400	7579,5	4736,9	8080,7	5026,7	8581,9	5316,4	10536,7	6446,3
1600	8838,5	5589,1	9418,6	5924,5	9998,7	6259,8	12261,1	7567,5
1800	10127,7	6493,0	10787,2	6874,2	11446,7	7255,5	14018,8	8742,2
2000	11435,2	7398,7	12175,3	7826,4	12915,4	8254,2	15801,7	9922,6

After calculations enthalpies of flue gases, for the considered excess air coefficients, it appears that these values of enthalpies increase for an increase of the lower calorific value of the fuel.

D. Determination of the flue gas temperature evacuated from boiler (t_{ev}) and of the air temperature at the air preheater entrance (t'p)

Parameter	Notation	UM	Value	
			Lignite	Bituminous shale
Flue gases temperature evacuated from the boiler	$t_{ev}=f(p_n;W^{rap})$	ºC	160,00	130,00
Air temperature which enter in the air preheater	$t_p^{'}$	ºC	70,00	25,00
Excess air coefficient at the preheater entrance	λp'	-	1,31	1,31
Excess air coefficient at the exit from the preheater	λ_p''	-	1,06	1,06

E. Determination of the boiler efficiency

Parameter	Notation	UM	Value	
			Lignite	Bituminous shale
Exhaust gases enthalpy	$I_g(\lambda_{ev};t_{ev})$	kJ/kg	1040,25	505,15
Enthalpy of the humid air at t_0	$I^0_{aum}(t_0)$	kJ/kg	77,21	44,63
Specific enthalpy of the fuel at ambient temperature	i_{c0}	kJ/kg	60,33	30,06
Heat loss of the exhaust gas	Q_{ev}	kJ/kg	848,89	401,09
Heat loss of the exhaust gas	q_{ev}	%	10,41	7,54
Heat loss of the residues from furnace	q_{rf}	%	0,07	0,39
Boiler efficiency	η_i	%	88,14	90,90

Comparing the boiler efficiencies determined for the separate use of the two fuels, in the table above, it appears that when is using bituminous shale, boiler has a slightly higher efficiency than lignite, due to the low moisture content, although the lower calorific power is smaller.

F. Useful heat and fuel consumption

Parameter	Notation	UM	Value	
			Lignite	Bituminous shale
Feed water pressure	p'_e	bar	204.00	204.00
Feed water enthalpy	$i_e^{'}$	kJ/kg	1086.64	1086.64
Heat exchanged in economizer	Q_{ECO}	kW	30.989,82	30.989,82
Heat exchanged in the evaporator system	Q_{SV}	kW	139.146,31	139.146,31
Heat exchanged in the intermediary overheating system (three increments)	Q_S	kW	124.599,47	124.599,47
Heat exchanged in the intermediary overheating system (two increments)	Q_{SI}	kW	49.923,99	49.923,99
Total useful heat	Q_u	kW	344.659,59	344.659,59

The enthalpy of the humid air at the air preheater entrance	$I^0_{aum}(t'_p)$	kJ/kg	222,71	44,63
Fuel consumption	B	kg/s	46,23	72,58
Actual fuel consumption	B_{ef}	kg/s	45,82	72,07
Enthalpy of the moist air at the temperature t *	$I^0_{aum}(t^*)$	kJ/kg	842,50	486,98
The enthalpy of the humid air at the air preheater exit	$I^0_{aum}(t''_p)$	kJ/kg	643,04	371,69

The results of calculations presented in the table above shows that for both types of the used fuel, it is recorded a much higher fuel consumption when is using bituminous shale than lignite. Fuel consumption changes with the boiler nominal steam flow variation, depending on the type of fuel used, as shown in the Fig. 4.

Fig. 5 shows the variation of heat changed in the economizer, the evaporator system, the intermediary overheating system in two or three increments at the modification of the nominal steam flow of the fluidized bed combustion boiler. It is found that with increasing of the nominal steam flow, the amount of heat exchanged in the heat surfaces increases regardless of the type of fuel used.

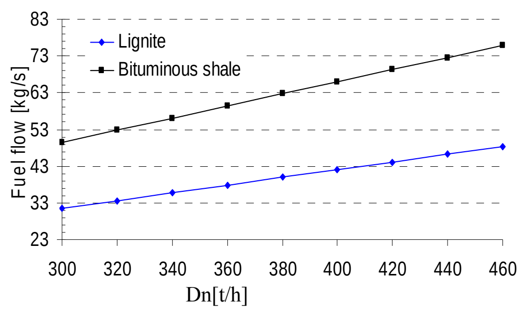


Fig. 4 Variation of the fuel consumption depending on D_n for the two fuel type

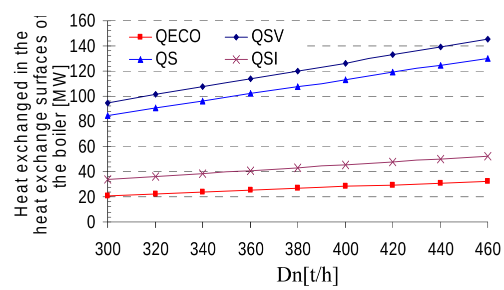


Fig. 5 Variation of heat exchanged in the heat exchange surfaces of the boiler according to the nominal steam flow

G. Determination of the theoretical combustion temperature, t_t, the temperature after festoon, t_{g1}, respectively at the end of the furnace, t_f

Parameter	Notation	UM	Value	
			Lignite	Bituminous shale
Gases enthalpy at the end of the furnace	$I_g(\lambda_f,t_t)$	kJ/kg	9.018,46	5.804,15
Theoretical combustion temperature	$t_t(\lambda_f)$	ºC	1.461,62	1.503,41
Gases enthalpy at λ_1 and tg_1	$I_g(\lambda_1,t_{g1})$	kJ/kg	5.054,31	3.296,66
Gas temperature after festoon	t_{g1}	ºC	873,49	924,52
Flue gases temperature at the end of the furnace	t_f	ºC	890,09	941,12

From the calculations results presented in the table above, it was found that the use of bituminous shale is achieved an increase in temperature at the end of the boiler and therefore a heat gain that will be exploited.

Tg_1 and t_f temperatures increases with increasing of flow rate of the steam boiler and for using of the bituminous shale, they have a higher value, as shown in the graphs of the Figure 6.

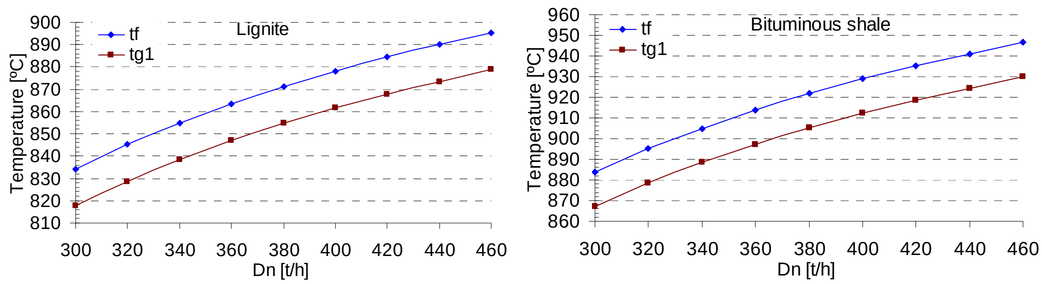


Fig. 6 Variation of the tg_1 and t_f temperatures depending on the nominal steam flow of the fluidized bed combustion boiler for lignite and bituminous shale usage

H. Furnace calculation

Parameter	Notation	UM	Value – Lignite	Value – Bituminous shale
The enthalpy of the humid air at the air preheater entrance	$I^0_{aum}(t''_A)$	kJ/kg	2.003,14	1.157,85
Enthalpy of the circulating ash	I_A	kJ/kg	627,10	404,20
Cross-sectional surface of the bottom of the furnace	F_{ti}	m^2	43,21	41,50
Furnace width at the bottom of the furnace	L_f	m	6,92	6,78
Furnace depth at the top of the furnace	l_f	m	6,246	6,121
Cross-sectional surface of the upper part of the furnace	F_{ts}	m^2	117,26	99,68
Furnace width of the upper part of the furnace	L_f	m	11,39	10,50
Furnace depth on the top part	l_f	m	10,30	9,49
Gases enthalpy at the end of the furnace	$I_g(\lambda_f,t_f)$	kJ/kg	5.161,25	3.362,68
Heat exchanged by radiation in the furnace	Q_r	kJ/kg	3.857,21	2.441,47
Furnace walls surface	F_{pl}	m^2	1.845,62	1.733,12
Height of the furnace upper part	h_{fs}	m	42,56	43,34
Total height of the furnace	h_{tf}	m	45,06	45,84

From the table above it appears that at the use of the bituminous shale is achieved a decrease in the cross-sectional surface of the lower part of the furnace respectively the cross-sectional section of the upper part of the furnace. Regarding their variation at the modification of the nominal steam flow, both surfaces increase with increasing of the nominal steam flow of fluidized bed combustion boiler, as shown in the graphs in the Figure 7.

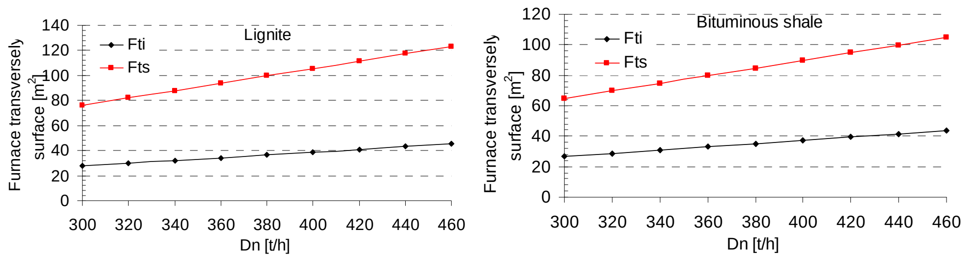


Fig. 7 The transverse surfaces of the upper and lower part of the furnace depending on D_n for the lignite and coal usage

The dimensions of the furnace of the fluidized bed combustion boiler it modify case with changing of the fuel type, so, when is using lignite with a lower calorific value bigger than bituminous shale, the size of the furnace is changed, the sizes of the upper and lower part of the furnace increase due to the increase of the transversal surfaces of the upper and lower parts of the boiler furnace. The upper and lower parts dimensions of the boiler furnace increase when the nominal steam flow of the boiler is larger, as is shown in Figure 8.

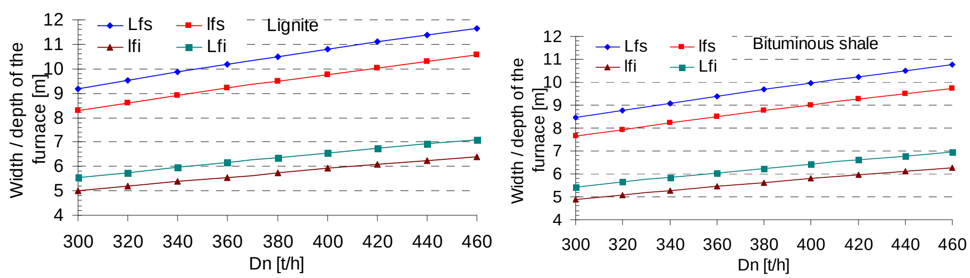
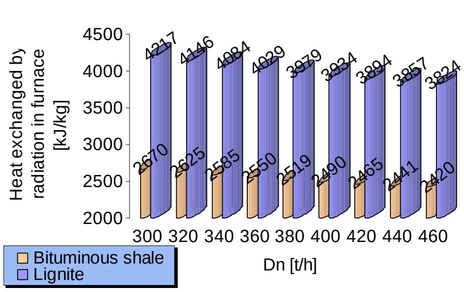


Fig. 8 Variation of the furnace width and depth at the upper and lower parts depending on D_n for lignite and bituminous shale utilization

From the results shown in the table above it is found that the heat exchanged through radiation in the furnace, Q_r, has a value with approximately 58% greater in the case of using lignite than bituminous shale. The increase in the nominal steam flow of the boiler, the heat exchanged in the combustion chamber will become smaller, as shown in Figure 9.

The sized surface of the furnace walls differ from using a fuel to another, so, when it is using bituminous shale, this is reduced by 6% and at increasing of the boiler steam flow this surface is increased as is shown in Figure 10.



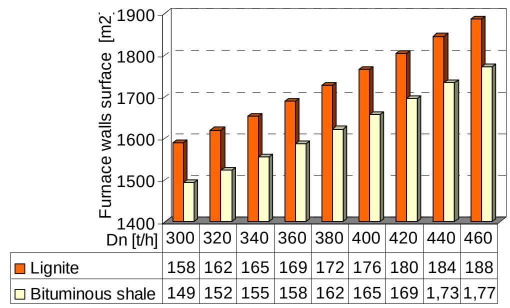


Fig. 9 Variation of heat exchanged by radiation in the furnace depending on the nominal steam flow of the boiler using lignite and bituminous shale fuels

Fig. 10 Variation of the furnace walls surface depending on the nominal steam flow of the boiler using lignite and bituminous shale utilization

The furnace height changes for using of different solid fuels. So, for bituminous shale comparative with lignite, the total and upper part heights are higher. At the increase of the nominal steam flow off the boiler, the furnace height decreases increasingly more (Figure 11).

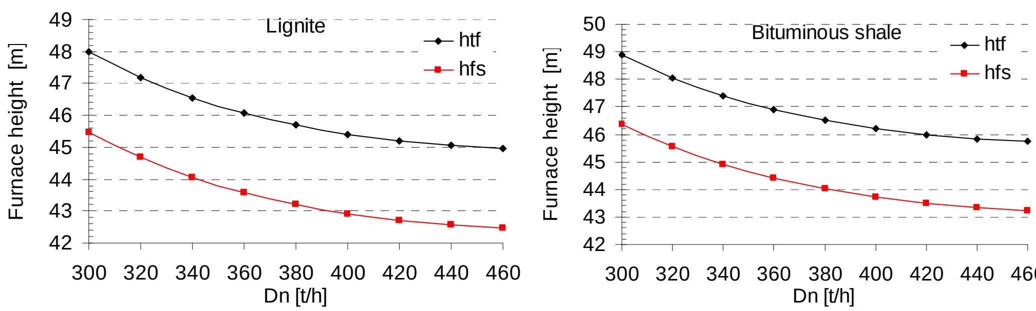


Fig. 11 Variation of the upper and total height of the furnace depending on the nominal steam flow of the boiler using lignite and bituminous shale fuels

5. Conclusions

I. In practice, often met steam boilers retrofitting which also have watched changing the fuel type due to its price modification over time. The refurbishment projects have presented an attractive economic aspects for the project beneficiary, not only through programs offered by the State, but also by reducing the fuel costs, because, regardless of the investment made, the weight of the fuel costs representing 80% of the total annual costs of heating power plant with fluidized bed combustion, referring to the fuel consumption, maintenance and operation.[12]

II. The fluidized bed combustion technology allow binding, the most part of the fuel sulfur, in the form of sulphates, evacuated with the ash layer. It avoids the corrosion phenomena in the terminal surfaces of the boilers and the harmful emissions of SO_2 and SO_3. For this purpose is injected in the layer, simultaneously with the fuel, amounts of sorbents - usually limestone ($CaCO_3$) or dolomite. Maximum efficiency is obtained for a molar ratio Ca/S=2÷3,5 and a grinding degree of 0÷0,3 mm. Thus, it obtain a sulfur binding from the fuel in a proportion of 90÷95%, when is added 6,24÷10,92 kg of dolomite for each kg of Sulfur. Given these issues, is preferred fuel sulfur content as low, to reduce the amount of sorbents used for Sulfur binding. Thus, it is found following aspects:

- bituminous shale has a lower sulfur content of 47,5% than lignite;
- fuel consumption for bituminous shale usage compared with lignite is higher with 57%;

Given these things, it appears that the use of bituminous shale, due to the fuel sulfur content lower than lignite, is required a smaller amount of sorbent. But, due to higher fuel consumption when is used bituminous shale compared with lignite, is required an additional amount of sorbent for Sulfur fixing.

III. Comparing the boiler efficiencies determined for the separate use of the two fuels, it was shown that when utilizing bituminous shale, boiler has a slightly higher efficiency than with lignite, due to significantly lower moisture content.

IV. The use of the bituminous shale as fuel achieves an increase of the temperature at the end of the boiler and therefore a heat gain can be exploited.

V. The heat exchanged by radiation in the furnace has a much higher value when using lignite comparative with bituminous shale (calculations presented in this paper showing an increase by 58%).

VI. In conclusion, at the furnace sizing of the steam boilers equipped with fluidized bed combustion technology should be considered technical, economical and environment advantages which could have the use of different types of the solid fuels.

R E F E R E N C E S

[1]. *R. Negoi, A. Badea, C. Mărculescu* , CFBC pilot installation with advanced flue gas purge system, University Politehnica of Bucharest Scientific Bulletin, Series C, Vol. 73, Iss. 1, 2011

[2]. *C. Dincă , A. Badea , T. Apostol* Life cycle impact assessment of fossil fuels, University Politehnica of Bucharest Scientific Bulletin, Series C, Vol. 71, Iss. 1, 2010

[3]. *V. Athanasovici,* Tratat de inginerie termică. Alimentări cu căldură. Cogenerare (Treaty of thermal engineering. Heat supply. Cogeneration), Editura Agir, Bucureşti , (Agir Publishing, Bucharest), 2010

[4]. *A. Roşu, C. Flueraru,* Aplicarea tehnologiei de ardere în strat fluidizat la cazanele energetice Româneşti (Application of fluidized bed combustion technology to the Romanian energy boilers), Revista Energetica nr. 5-A, Bucureşti, (Energetica Magazine, Bucharest), 1995
[5]. *J. Kovács,* Combustion Handbook, 2001
[6]. *I. Pîşe,* Generatoare de abur. Procese şi bilanțuri termoenergetice (Steam generators. Thermoenergetic processes and balances), Editura Politehnica Press (Politehnica Press Publishing), Vol.I, 2013
[7]. *C. Neaga*, Tratat de generatoare de abur (Treaty of steam generators), vol 1, Editura Agir, Bucureşti (Agir Publishing, Bucharest), 2001
[8]. *C. Neaga*, *Al. Epure,* Îndrumar. Calculul termic al generatoarelor de abur (Guidelines. Thermal calculating of the steam generators), Ed. Tehnică, Bucureşti (Technical Publishing, Bucharest), 1988
[9]. *I. Ionel, ş.a.*, Experimental results concerning the co-combustion of biomass in a stationary fluidised bed pilot with biogas support and CO_2 capture, 16th European Biomass Conference & Exhibition, June Valencia, Spain, 2008
[10]. *A. Leca, Ilie Prisecaru,* Proprietati termofizice si termodinamice - Solide, Lichide, Gaze (Thermophysical and thermodynamic properties - Solids, Liquids, Gases), Editura Tehnică, Bucuresti (Technical Publishing, Bucharest), Vol. 2, 1994
[11]. *S. Suman, K. Singh,* Estimating Thermodynamics Properties of Coal, Char, Tar and Ash, Indian journal of applied research, Volume: 4, Issue 1, Jan 2014
[12]. *D. Hoară,* Aspecte privind dimensionarea focarelor cazanelor de abur cu ardere în strat fluidizat la utilizarea diferitelor tipuri de combustibili solizi (Sizing aspects concerning to the fluidized bed steam boiler furnaces for different solid fuels), Raport Ştiințific nr. 2, Universitatea Politehnica Bucureşti (Scientific Report no. 2, University Politehnica of Bucharest), 2013