Енергозберігаючі технології

UDK 621

DOI: 10.33070/etars.4.2020.02

O.I. Topal, PhD, I.L. Holenko, PhD, M.M. Yurchenko, junior research worker
Coal Energy Technology Institute of National Academy of Sciences of Ukraine, Kyiv
Andriivska Str., 19, 04070, Kyiv, Ukraine, dr.topal@gmail.com

The Use of Experience of Coal Combustion in a Circulating Fluidized Bed for Designing of Medium Capacity Steam Boilers for Burning of Wet Waste of Coal Preparation and RDF in Ukraine

The necessity to implement advanced combustion technologies to utilize MSW/SRF/RDF and coal reject waste is an important problem for Ukraine to be solved. The introduction of such technologies will favor to involve annually about 2 mln t of RDF and partly cover deficit of bituminous coal, lack of which is currently faced. The technological niche for CFB combustion of RDF/SRF has certain optimal range bearing in mind technological, ecological (2010/75/EU Directive etc.) and financial performance. In view of this it seems reasonable to implement CFB for RDF/SRF firing starting from boiler steam capacity of 50-75 t/h while stoker firing of RDF could be efficiently implemented for lower range. The design of such boiler should rely upon lessons learned of commissioning and operating large-scale CFB boiler (having steam capacity of 670 t/h; 545/545 °C) we obtained at Starobeshevo Power Plant in Ukraine. Accounting for the above the analysis of implementation and modifications made at large-scale CFB boiler (cyclones, seal pot, fluidized bed heat exchangers) has been done. The experience was used to design (along with KB "Energomashproekt") medium-scale CFB boiler (having steam capacity of 75 t/h; 500 °C) to burn high ash coal washing wastes and RDF/SRF. The sketch-3D-design of such boiler is presented with key performance. *Bibl. 6, Fig. 4, Tab. 4.*

Key words: combustion, wastes, refuse derived fuel, boiler, energy.

Introduction. The energy market share to use coal in Ukraine becomes narrow from years to years. The Energy Strategy of Ukraine by the year of 2035 assumes significant decrease in the use of coal in electricity production. The situation is complicated due to annexing the coal-rich Donbass region as well as high domestic coal price (especially in Lvov-Volyn region) approaching, in some cases, the value of 4000 UAH/t (140 USD/t) for high ash raw coal, and limited

number of mines (34 pcs), included profitable ones, left under control of Ukraine. All the above makes it difficult to introduce and develop coal-based technologies in Ukraine. Meanwhile, high ecological performance, fuel flexibility and positive experience [1] gained while introducing circulating fluidized bed (CFB) combustion technology at large-scale in Starobeshevo Thermal Power Plant (TPP) (CFB-boiler: 670 t steam /h; 545/545 °C) can be further used to address

the new market conditions and challenges with regard to SRF (solid recovered fuel)/RDF (refuse derived fuel) thermal treatment and waste management [2].

Problems to be solved. Despite the overall decay of fossil-based thermal treatment technology use, CFB combustion is considered to be proven one having promising niche in the market due to fuel flexibility and environmental performance. The further proper use of CFB may relate to effective combustion of alternative fuel such as RDF/SRF in small-scale boiler unit compared to earlier use in large-scale applications [3, 4, 5].

The wider use of CFB to burn RDF/SRF compared to Stoker combustion seems reasonable at least for boiler unit having more than 20 MWe capacity (about 70-75 t steam /h and 500 °C). Stoker firing of wastes (RDF) for lower capacities is assumed to prevail because of low CAPEX, simpler/reliable operation and low own needs compared to CFB boiler. The use of CFB to burn RDF/SRF fuel is not widely tested within small

to medium range. The experience and lessons learned from large scale CFB-operation can be adopted while designing the medium-size CFB-boiler.

In view of this the objective of the study is 1) to consolidate the experience and bottle-necks gained while commissioning the 670 t/h CFB-boiler [6]; 2) to consider the design and make basic performance estimate for medium size CFB-boiler to burn high ash coal rejects (case 1) and RDF (case 2).

The results of the study. As it was mentioned, lack of coal force to look for alternative fuel to be involved as additional energy sources for electricity and heat production while meeting high ecological standards on emissions according to the Directive 2010/75/EU. Among those fuels high ash coal rejects can be used: in the territory of Ukraine there are accumulated significant reserves of coal preparation wastes. The estimate of the coal wastes by types and quantities is given in (Fig.1).

Figure 1 – Coal mining and preparation/cleaning wastes.

It is seen that the quality of wastes (high ash, water content etc) favors to consider CFB technology as a proper choice to use.

The lessons learned from CFB-reconstruction project at Starobeshvo Thermal Power Plant (TPP), Ukraine [6]. Among the CIS countries the Ukraine is the first one

where clean technology of high ash coal waste combustion in circulating fluidized bed (CFB) has been implemented in energy sector within the framework of rehabilitation project for 200 MWe power unit No. 4 at Starobeshevo TPP (Ukraine, Donetsk region, city of Novy Svit).

The rehabilitation project aimed at construction of CFB-boiler at Starobeshevo TPP was initiated by signing in 11.12.1996 the Credit Agreement with European Bank for Reconstruction and Development (EBRD) taking on Guarantee of Ukraine. The choice of the company, the license of that was used during CFB-technology implementation, was based on the results of international open tender held in 2000 having two phases (technical and commercial).

The rehabilitation project included removal of aged pulverized-coal (PC) boiler of TP-100 type that was in operation about 233 thousand hours and installation of a new CFB-boiler (ACFB-670) with design steam capacity of 670 t/h. Before the projects was started, the condense type steam turbine (K-200-130) had been modernized. The last favored the prolongation of its operation lifetime for 20-25 years and led to increasing the installed capacity of the unit from 200 to 215 MWe.

During the execution of the tender the scope of work was as follows according to three lots: Lot No.1 "Boiler": removal of aged PC-boiler (TP-100 type, steam capacity of 640 t/h) by a new CFB-boiler; Lot No.2 "Drier": construction of anthracite schlammm drier with design productivity of 220 t/h (dry product), including raw schlammm handling and supply system; construction of a new side discharge tippler for raw schlammm unloading with relevant railway routes. Lot No.3 "Electrostatic precipitator-ESP": installation of ESP for deep cleaning of flue gas from dust. The winner of tender became: on Lot No.1 "Boiler" and No.2 "Drier" – Lurgi Lenticjes AG (now LL Plant Engineering, Germany); Lot No.3 "Electrostatic precipitator" – Alstom Power Environmental System AB (Sweden). All the contracts were signed in 2000. and conducted as "turn-key" ones. Financing the project was based on loan of EBRD as well as on own resources of generating utility of JSC "Donbassenergo" (owner of the Starobeshevo TPP). The total cost of the project was 117.5 mln. €, incl. EBRD's loan – 84.5 mln. €, own fund of JSC "Donbassenergo" – 33 mln. €. Specific capital cost on reconstruction was recently estimated as 583 € on installed kW.

The main milestones of the CFB-project.

According to the contract the work on construction and equipment installation was completed on September 2004. Later on till the 2005, July 29th the boiler commissioning was under way using different mixture of design fuel. On 2005,

July 29th, some problem was encountered resulting in destruction of convective pass of the boiler. Upon the completion of work on reviving the damaged convective pass (during 2005-2007), the boiler commissioning has been proceeded. At the beginning of 2008 "hot" start-up runs were conducted, and hydraulic testing was made in April-May. The commissioning runs, aimed at determination of stable combustion regimes for high ash anthracite (and/or high ash coal rejects and their mixtures), were carried out till the December, 2010. During the 2011, 27-30th January the continuous 72-hours trial run was conducted ensuring and proving the following performance: electrical capacity – 210 MW; load change range – 190–217 MW; steam parameters – designed ones (see below); fuel – anthracite schlammm/mixtures with low heating value (LHV) of 4300–4800 kcal/kg; the use of natural gas was not needed. During February-March of 2011 the guarantee tests were performed and guarantee boiler performance was proved.

It is necessary to note that the implementation of CFB-technology in Ukraine was made accounting for combustion tests held in Ukraine, Germany etc. on evaluation of behavior of high ash anthracite/schlammm burning as well as the results of pilot-scale testing held on rigs of Coal Energy Technology Institute and foreign companies (Lurgi, CRE, B&W).

During the CFB-boiler commissioning the unique experience has been gained on adaptation of CFB-combustion technology accounting for special features of anthracite/schlammm waste and domestic conditions (traditions) of boiler operation. Based on this experience the new unique technical solutions were developed allowing stable combustion of low-reactivity fuel and improvement of the main CFB-boiler systems.

Fuel characteristics. As a main fuel of CFB-boiler it was assumed to use very high ash anthracite schlammm accumulated at the settling pond of Cleaning Factories which are located near the TPP, as a reserved one – anthracite (see Table 1). The use of fuel blends has been also considered in a form of mixtures of high ash anthracite schlammm and anthracite with schlammm share ranging from 85 to 100 % (weight). One of the guarantee fuel point is mixture of 15 % of anthracite and 85 % of schlammm.

The distinctive feature of initial anthracite schlammm is its very small particle size. In general the size of the anthracite particles fed into the boil-

er was mainly dependent on the operation mode of impact hammer mill. According to the project the maximum size of it was as much as 3 mm.

Table 1 – Proximate and ultimate analysis of design fuel for 200 MW CFB-boiler unit of Starobeshevo TPP (Ukraine)

Component	Anthracite Schlamm (culm)	Anthracite
C ^r , %	37.881	59.616
H ^r , %	0.7452	1.1664
S ^r , %	1.1592	1.7496
N ^r , %	0.3312	0.5184
O ^r , %	1.2834	1.7496
Ash content A ^r (as received), %	50.6	25.2
Water content W ^r , %	8.0	10.0
Volatile, %	5.0	4.0
Low heating value (LHV) Q _i ^r , MJ/kg	12.923	20.7

Fuel handling system of CFB-boiler was designed to dry wet schlamm with initial water content of 22,5 % that is supplied from settling ponds of nearest cleaning factories. Design productivity of drier (for schlamm dried to W^r=8 %) is about 220 t/h (inlet flow rate ≈ 260 t/h). The drier system consists of: hot flue gas generator, rotatitg drum drier, dust separator – baghouse filter, auxiliary equipment, control system, and stack.

Steam-water system. Main design performance of CFB-steam-generator of No.4 power unit of Starobeshevo Power Plant is given in Table 2.

To meet the above performance, the steam-water system is used basing on natural circulation of steam-water mixture. This system consists of the following main elements: steam drum, evaporating surfaces, primary steam superheating surfaces, secondary steam heating surfaces (reheat), economizer etc.

CFB combustion in the power unit N4 at Starobeshevskoy TPP was organized as follows. Initial culm (with moisture of 18-22%) is dried in a drum dryer to the moisture content of 8 % and then fed to the receiving bunker of power unit. In the case of anthracite use, it is crushed in hammer mill to particles of less than 3 mm. Fuel (anthracite culm, anthracite, or a mixture thereof) is fed to the furnace using four transporters in four feed points on the slopes of seal pots and then fed by gravity in lower part of furnace, where gas is distributed over the caps to of fluidize bed.

Table 2 – Design performance of CFB-steam generator

Parameter	Value
Steam capacity, t/h	670
Live steam at the inlet of HP part of steam turbine:	
Pressure, MPa	12.7
Temperature, °C	540
Reheat steam at the inlet of MP part of steam turbine:	
Temperature, °C	540
Feed water at the inlet of the boiler:	
Pressure, MPa	18.0
Temperature, °C	244
Range of load change (N) of boiler, %	50-100
Minimal load, %	40
Boiler efficiency, %	
At N=100 %	90.5
At N=50 %	90.0
Fuel flow rate, t/h	
Anthracite	95
Anthracite schlamm (dried)	160

The furnace of CFB boiler is rectangular. Its shape is formed by gas-tight welded panels that are part of boiling loop. The lower part of the furnace is divided into two sections. Pre-furnaces form two pant-legs having FB-grates. Dimensions of the furnace: height is 40 m, depth is 13 m, and width is 11 m. Top of the furnace is lined up to the level of 9 m. CFB fuel combustion is at 880-920 °C that limits the creation of thermal nitrogen oxides. In addition, limestone is fed to the furnace for sulfur oxides fixation. New CFB-boiler uses the system of steam-water mixture natural circulation. Steam is generated for the most part in the boiler evaporating surfaces forming the furnace. Additional evaporating surfaces, superheating and reheating surfaces are located in external fluidized bed heat exchangers (FBHE).

System of coke-ash residue return. A distinctive feature of CFB combustion is a multiple circulation of bed material due to the system of coke-ash residue (CAR) return. The design of this system by Lurgi CFB-technology in the power unit N4 at Starobeshevskaya TPP includes: four external cyclones, standpipes, seal pots, peak valves for redistribution of coke-ash flow between FBHE. Cyclones, standpipes and seal pots are designed to return the particles to the furnace and provide (seal pot) quasi-gas-tight interconnection between the cyclone outlet (bottom) and furnace.

An electrostatic filter of Alstom Power

(Sweden), which fly ash capture efficiency exceeds 99.9 % and enables to provide dust content in flue gases at 50 mg/m^3 , is used at the outlet of convection pass to ensure the environmental standards of the flue gas cleaning from dust.

Experience in equipment set up and modification. The need for the implementation of new technical solutions and equipment modifications have been identified on the basis of heat engineering tests carried out at the commissioning stage. The main faults of some boiler systems were: unstable operation of cyclones (their packaging); overheating and rupture of pipes of evaporative surfaces located in external fluidized bed heat exchangers (FBHE); limitation of productivity of fluidized bed ash-coolers (FBAC) by bottom ash removal.

To eliminate these faults, planned modification of existing equipment of the boiler, which stipulates "hot" start-up stoppage, was conducted during 2008-2011.

1) Modification of seal-pots, standpipes, and their control systems. The basic mechanical work on modernization of the return path elements included installation of two-section air boxes and separate air duct to each box, which equipped with control valves. Additionally, excess pressure sensors were installed for control of fluidized bed in standpipes (at the bottom of convective pass). Pressure sensors have also been installed in the seal pot cells. The tube bundle was equipped with an automated blowing system.

2) Modernization of evaporating surfaces of external fluidized bed heat exchangers (FBHE). The bundles of slightly inclined pipes was replaced with ones of S-shaped configuration (with a pipe slope of 10°), resulting in the improvement of the steam-water mixture circulation and elimination of non-designed overheating of pipes.

3) Modernization of fluidized bed ash-coolers (FBAC). The bottom ash removal system consists of two fluidized bed ash-coolers (FBAC 1 and FBAC 2). FBAC operation became unsatisfactory when load increases to more than 160 MW. At the FBAC modification, there were an increase in air velocities in the boxes, configuration of gas distribution grid was changed, there was an increase in FBAC height and in discharge openings, the configuration of discharge openings was changed (for rectangular instead of round), and new feed

worms were installed to remove large agglomerates. These measures to modernize equipment and improve the technological scheme of CFB process enabled to pass successfully both 72-hour integrated test in early 2011, and performance tests in mid-2011, when guaranteed performance of CFB-boiler were achieved.

The technological scheme for utilization of high ash bituminous/coking coal washering waste has been developed for typical coal cleaning factory (CCF). The design accounted for the bottle-necks of operation of large-scale CFB-boiler considered. A typical CCF was considered having annual output is about 8 mln t/ There is a possibility to clean coal for 5 different coal classes (coal particle sizes). The CCF's wastes to be utilized are of two types: 1) ultra high ash (UHA) coal waste and so called "promproduct" - intermediate coal waste having moderate ash content ($A^d \approx 36-39\%$).

UHA coal waste is resulted from coal particle floatation – the process of cleaning of coking coal based on its washering in heavy liquids. UHA coal waste has extreme ash content and moisture, the latter is because of the problem to effectively dry clay-containing and very fine particles. As typical example it was selected the CCF that produces: 1 mln t of UHA coal waste annually (having ash content $A^d \approx 64\%$; moisture $W^r \approx 37\%$); and up to 160 ths. t of "promproduct" annually (moderate ash content coal cleaning waste).

Within the framework of work aimed at site selection for the implementation of a new clean coal CFB technology it was evaluated a number of parameters and CFB-boiler performance, including electrical capacity of the CFB Power Plant (PP) capable of firing dried UHA coal waste.

It is found that the maximum electrical capacity of the CFB-Boiler Unit fueled by UHA coal waste of such amount can be about 88 MWe with annual UHA waste consumption at about 684 ths. t (annual operation period of PP - 7000 hours). Originally it was planned to demonstrate the viability of the technology at power unit having 20 MWe capacity based on a CFB-boiler with steam output of 75 t/hour. The technological scheme and preliminary drawings (concept of boiler design) for the boiler were prepared by CETI along with partner (SPKTB Energomashproekt) are shown on Fig. 3 and Fig. 4 correspondingly.

During the development of CFB-boiler design it was determined and evaluated its technical and economical performance as a part of 20 MWe power unit being fueled by two types of coal wastes: UHA coal waste and “promproduct” which characteristics are given in Table 3.

Table 3 – Design parameters of ultra high ash coal waste and “promproduct”

Fuel	W^r , %	A^r , %	Ultimate analysis, %					Low heating value Q_i^r , kcal/kg
			C^r	H^r	O^r	N^r	S^r	
UHA coal waste	8	58,88	25,85	1,85	4,65	0,50	0,27	2200
Promproduct	6	39,48	44,49	2,95	5,74	0,82	0,52	4000

Notes: UHA parameters are given for wastes-after-drying.

The variants of complete complex treatment for UHA coal waste and “promproduct” (including fuel handling, preparation, drying, combustion and electricity production) were considered on the basis of their combustion in a CFB-boiler. The main systems of the treatment complex include:

1. UHA coal waste handling and preparation system designed to decrease the moisture content of initial UHA waste from $W^r=35-37$ % to $W^r=7-8$ % and facilitate its particle agglomeration. Promproduct is not to be dried because it has initial moisture content applicable for CFB combustion.

2. The concept design of CFB-Boiler (E-75-6,3-500 F type) with natural circulation having steam capacity of 75 t/h, steam temperature of 500 °C and pressure 6.3 MPa, capable of regulating load within the range of 60-100 % of nominal output was prepared.

It is assumed that the CFB Power Unit has 20 MWe capacity and work in condensed mode of operation (with load regulation within 60-100 % of MCR – maximum continuous rating). The generation of electricity can be based on steam turbine of SST-150 type of Siemens company. Boiler island is also accompanied with the following systems: limestone preparation and feeding system aimed in-furnace removal of SO_x emissions; sieve for agglomerated and dried UHA waste (included in fuel drying system); electrostatic precipitator (ESP) and other auxiliary equipment.

Figure 3 – General process flow sheet for ultra high ash and “promproduct” CFB combustion at E-75-6,3-500 F CFB boiler unit.

The operation of this CFB-boiler while burning high ash wastes will allow to achieve low NO_x and SO_x emissions (less than 200 mg/m^3 at 6% O_2 at STP conditions (standard temperature and pressure)) and meet the requirements of Eu-

ropean Directive 2010/75/EU. Summarized performance of the developed by CETI and partners variants for high ash wastes utilization in environmentally acceptable manner with electricity production is given in Table 4.

Table 4 – Main characteristics of variants of electricity production with the use of clean combustion of coal cleaning waste in CFB based on 20 MWe CFB Boiler Unit

Parameters	Value	
Power unit capacity (electrical)	20 MWe	20 MWe
Fuel	UHA coal wastes	Moderate ash content coal waste “promproduct”/RDF
Low heating value, Q_i^r , kcal/kg	2200	3800-4200
Ash content (dry basis), A^d , %	64	41,7/10-15
Moisture, W_t^r , %	8	6/15-20
Steam turbine	SST-150	SST-150
Mode of operation of steam turbine	condensed	condensed
CFB-boiler performance		
Steam capacity, t/h	75	75
Live steam pressure napy, MPa	6,3	6,3
Live steam temperature, °C	500	500
Combustion process and fuel consumption		
Flow rate of dried fuel at the inlet of boiler, t/h (ths. t/year)	26,6 (190)	14-15/12-14 (100)/(60-80)
Flow rate of air for combustion, ths. normal m^3/h	87,2	83/50-70
Flow rate of flue gas, ths. normal m^3/h	95	88/70-90
Flow rate of ash, t/h (ths. t/year)	15,7 (109,9)	5,8 (40,6)/1,2-2,5 (10-15)
Fuel handling and preparation		
Flow rate of raw UHA waste for power unit ($A^d=64$ %, $W_{t_{\text{нл}}}^r=37$ %), t/h (ths. t/year)	38,85 (272)	-
Flow rate of moisture removed while drying raw UHA waste from $W_t^r=37$ % to 8 %, t/h	12,25	-
Flow rate of raw UHA waste at the inlet of 2-nd stage of drying system ($A^d=64$ %, $W_{t_{\text{нл}}}^r=25$ %), t/h	32,63	-
Fuel consumption (natural gas) on heat generator of UHA waste drum-type driers, ths. m^3/h (ths. m^3/year)	1,86 (13)	-
Fuel consumption on heat generator of UHA waste drum-type driers (promproduct usage), t/h. (ths. t/year)	3,72 (26)	-

The 3D-design of E-75-6,3-500 CFB-boiler is given in Fig4. It is seen that pant-leg design is not used which may result in more stable operation of lower part of the furnace, the seal pot and stand pipe are properly organized accounting for the problem with air distribution for this elements; FBHE is not used.

Total capital investment on 20 MWe CFB Power Plant is estimated to be about 26,5 mln USD including: boiler (along with construction) – 6,75 mln USD, steam turbine with generator and auxiliary – 6,88 mln USD, fuel handling and preparation system – 1,5 mln USD. Evaluation of capital cost needed for E-75-6,3-500F boiler

Shevchenko V. A. Realizatsiya Tekhnolohyy Szhyhanyia Vysokozolnoho Antratsyta Y Otkhodov Eho Obhashchenyia V Tsyrkuluyushchem Kypishchem Sloe Na Enerhobloke №4 (210 MVt) Starobeshevskoi TES [The implementation of circulating fluidized bed technology to burn high ash anthracite and its preparation

wastes at 210 MWe boiler unit No4 of Starobeshevo Thermal Power Plant], Enerhotekhnolohyy y resursosberezhenye, 2011, №6, p. 3–11.

Received September 18, 2020

Топал О.І., канд. техн. наук, **Голенко І.Л.,** канд. техн. наук, **Юрченко М.М.**
Інститут вугільних енерготехнологій НАН України, Київ
вул. Андріївська, 19, 04070 Київ, e-mail: dr.topal@gmail.com

Використання досвіду впровадження технології циркулюючого киплячого шару для конструювання котлів середньої продуктивності для спалювання мокрих відходів вуглезбагачення та RDF в Україні

Необхідність впровадження сучасних енергетичних технологій спалювання для термічної утилізації ТПВ/SRF/RDF та відходів вуглезбагачення є важливим завданням для України, яке потрібно негайно вирішувати. Впровадження таких технологій сприятиме щорічному залученню близько 2 млн т RDF і дозволить частково покрити дефіцит кам'яного вугілля, брак якого наразі відчувається. Технологічна ніша для спалювання у циркулюючому киплячому шарі (ЦКШ/CFB) таких палив як RDF/SRF має певний оптимальний діапазон, враховуючи технологічні, екологічні (Директива 2010/75/ЄС тощо) та фінансові показники. З огляду на це, видається доцільним впроваджувати ЦКШ для спалювання RDF / SRF для котлів, починаючи з паропроductивності 50-75 т/год, тоді як спалювання RDF для котлів з меншою паропроductивністю можливо ефективно реалізувати за технологією Stoker (на рухомих ґратках). Конструкція такого котла повинна спиратися на досвід пуско-налагоджувальних робіт та експлуатацію енергетичного (потужного) ЦКШ-котлоагрегату (паропроductивність 670 т/год; 545/545 С), отримані нами на Старобешівській ТЕС в Україні. З урахуванням вищезазначеного, було проведено аналіз впровадження та модифікацій, здійснених у ЦКШ-котлоагрегаті (циклони, ущільнювальний котел, теплообмінники з киплячим шаром). Набутий досвід був використаний при спільних з КБ «Енергомашпроект» роботах з проектування котла середньої паропроductивності (75 т/год; 500 °С), призначеного для спалювання RDF/SRF та високозольних відходів мокрого вуглезбагачення, аналіз запасів яких також наведено. Ескізний 3D-дизайн такого котла представлений разом із ключовими характеристиками. *Бібл. 6, рис. 4, табл. 4.*

Ключові слова: спалювання, відходи, вторинне паливо, котлоагрегат, енергія.

Топал А.И., к.т.н., **Голенко И.Л.,** к.т.н., **Юрченко М.М.,** м.н.с
Институт угольных энерготехнологий НАН Украины, Киев
ул. Андреевская 19, Киев, e-mail: dr.topal@gmail.com

Использование опыта внедрения технологии циркулирующего кипящего слоя для конструирования котлов средней производительности для сжигания мокрых отходов углеобогащения и RDF в Украине

Необходимость внедрения современных энергетических технологий сжигания для термической утилизации ТВО/SRF/RDF и отходов углеобогащения является важной задачей для Украины, которое нужно немедленно решать. Внедрение таких технологий будет способствовать ежегодно привлечению около 2 млн т RDF и позволит частично покрыть дефицит угля, недостаток которого сейчас ощущается. Технологическая ниша для сжигания в циркули-

рующем кипящем слое (ЦКС/CFB) таких топлив как RDF/SRF имеет определенный оптимальный диапазон, учитывая технологические, экологические (Директива 2010/75/ЕС и т.д.) и финансовые показатели. Учитывая это, представляется целесообразным внедрять ЦКС для сжигания RDF/SRF для котлов, начиная с паропроизводительности 50-75 т/ч, тогда как сжигание RDF для котлов с меньшей паропроизводительностью возможно эффективно реализовать по технологии Stoker (на подвижных решетках). Конструкция такого котла должна опираться на опыт пуско-наладочных работ и эксплуатацию энергетического (мощного) ЦКС-котлоагрегата (паропроизводительность 670 т/ч; 545/545 °С), полученные нами на Старобешевской ТЭС в Украине. С учетом вышесказанного, был проведен анализ внедрения и модификаций, осуществленных в ЦКС-котлоагрегате (циклоны, уплотнительный котел, теплообменники с кипящим слоем). Приобретенный опыт был использован при совместных с КБ «Энергомашпроект» работах по проектированию котла средней паропроизводительности (75 т/ч; 500 °С), предназначенного для сжигания RDF/SRF и высокозольных отходов мокрого углеобогащения, анализ запасов которых также приведены. Эскизный 3D-дизайн такого котла представлен вместе с ключевыми характеристиками. *Библ. 6, рис. 4, табл. 4.*

Ключевые слова: сжигание, отходы, вторичное топливо, котлоагрегат, энергия.

Теплофізичні основи енергетичних процесів

УДК 662.951.2

DOI: 10.33070/etars.4.2020.03

Сігал І.Я.¹, докт. техн. наук, проф. Сміхула А.В.¹, канд. техн. наук,

Сігал О.І.², канд. техн. наук, Марасін О.В.¹, канд. техн. наук

¹ **Інститут газу НАН України, Київ**

вул. Дегтярівська, 39, 03113 Київ, Україна, e-mail: isigal@ukr.net

² **Інститут технічної теплофізики НАН України, Київ**

вул. Желябова, 2а, 03680 Київ, Україна, e-mail: office@engecology.com

Дослідження горіння відірваних газових струменів при стабілізації фронту полум'я на вертикальній поверхні

Досліджено умови стабілізації горіння відірваних газових струменів на вертикальній поверхні у діапазоні діаметрів сопел $d_0 = 1,6\text{--}3,0$ мм. Показано механізм стабілізації полум'я відіраного струменя газу на вертикальній поверхні, який дає можливість при стабільному горінні збільшити швидкість витікання газу через одне сопло у 3 рази й більше у порівнянні з дифузійним горінням вільного струменя газу, що ніяк не стабілізований. Встановлено оптимальну відстань до вертикальної вогнетривкої поверхні у калібрах сопла щодо створення щільних подових пальникових пристроїв. Обґрунтовано необхідність використання мінімальних по зриву кутів атаки при конструюванні щільних подових пальників, які були експериментально встановлені. Експериментально показано, що, починаючи з тиску газу в трубі-колекторі $p \approx 500$ мм вод. ст. та, відповідно, швидкості його витікання через сопло більше $W_g \approx 100$ м/с, при відстані до вертикальної поверхні, на якій стабілізується факел $15 < L/d_0 \leq 30$, для діапазону діаметрів сопел $d_0 = 1,6\text{--}3,0$ мм безрозмірна площа основи s_g/s_0 еліптичного циліндру E_b менше у 2–2,5 рази максимальної, що спостерігається на відстані $L/d_0 \approx 40$. *Бібл. 15, рис. 6.*

Ключові слова: стабілізація полум'я, удар струменя, щільний пальник, горіння.