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BEST AVAILABLE TECHNOLOGIES FOR WASTE CO-FIRING APPLICATIONS

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Abstract

Thermal transformation of waste is one way in which the negative impact of human activities on the environment can be reduced. Thermal waste treatment is generally negatively associated by the public as hazardous and harmful to the environment. In this study the authors present the possibility of waste management in the process of co-firing with coal using BAT (Best Available Techniques) for both the combustion process and the exhaust gas purification process. Co-firing of coal with RDF (Refuse Derived Fuel) while ensuring stable production of electricity and heat supports the process of waste management which, if not burned, will end up in landfills, which, according to the authors, is the worst possible way to handle waste both from the point of view of environmental protection itself and from the point of view of energy efficiency.

Keywords: **BAT; CFB; Combustion; Emissions; FGT; RDF; WI.**

LIST OF ABBREVIATIONS

BAT – Best Available Techniques
BFB – Bubbling Fluidized Bed
CFB – Circulating Fluidized Bed Boiler
CFBS – Circulating Fluidized Bed Scrubber
CHP – Combined Heat and Power
FGT – Flue Gas Treatment
LHV – Lower Heating Value
PAC – Pulverised Activated Carbon
RDF – Refuse Derived Fuel
SNCR – Selective Non-Catalytic Reduction
TPOK – Thermal Municipal Waste Treatment (Termiczne Przekształcanie Odpadów Komunalnych)
TVOC – Total Volatile Organic Compound
WI – Waste Incineration

1. INTRODUCTION

Modern civilization is developing very dynamically, and the resulting from this fact increase in consumption is accelerating the industry that is trying to keep up with demand. As a result, a huge amount of waste is produced which threatens our environment, and thus people's health. Since ancient times, the traditional and most widespread method of dealing with waste is throwing garbage into holes dug in the ground and covering them with subsequent layers of soil. However, this is not a solution that can be accepted nowadays.

Only at the turn of the 19th and 20th centuries, as a result of the development of science, did the social awareness of the threat posed by improper waste management increase. Construction of the first waste incineration plants has begun. In parallel with the spread of this type of waste management, work was done on improving this process. As a result, highly efficient thermal waste treatment units are now used all around the world, able to meet the required from the legal and environmental point of view emission levels and standards.

Poland as a dynamically developing country is a good example showing how important it is to implement a fast and effective waste management program. With an annual level of industrial and municipal waste production of around 12 million tonnes [1], it is essential to implement new methods for waste treatment as soon as possible and to improve and optimize current waste management methods. Currently in Poland a total of 13 professional thermal municipal waste treatment facilities (so called TPOK) [2] are in use or under construction (Fig. 1), enabling the conversion of approximately 25% of waste into useful energy. Unfortunately, today over 40% of the waste still goes to landfills.

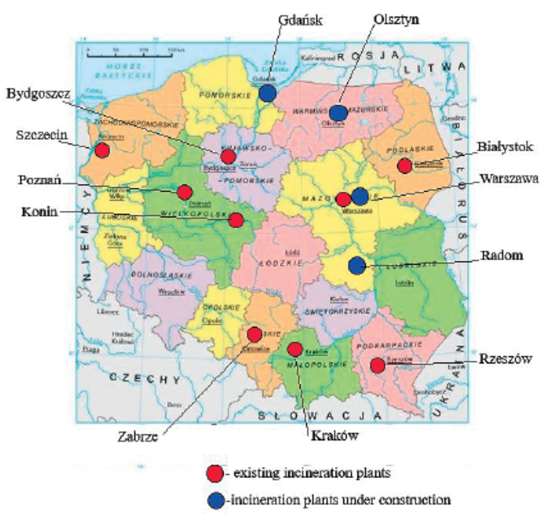

Figure 1.
Location of TPOK plants in Poland [2]

From the point of view of minimizing the negative impact of waste on the natural environment, waste management methods can be hierarchized in the following order [3]:

1 – Waste formation prevention,

2 – Following the Circular Economy concept,

3 – Recycling,

4 – Thermal transformation into energy through combustion or gasification,

5 – Landfilling.

The last option (landfilling) should only be used if there are no other suitable technologies for waste disposal. It should be remembered that since 2016 in Poland (and other EU's countries) it is forbidden to store waste fractions with a calorific value above 6 MJ/kg [4].

Figure 2 shows the shares of individual waste management methods in Poland compared to other European countries [5].

As it can be seen, Poland belongs to the countries with relatively high share of waste still being landfilled, while thermally treated is only around 24%.

Increased development is inseparably connected with the increased energy demand, which can also be obtained from waste. After proper processing of non-hazardous waste, alternative fuel, such as RDF (Refuse Derived Fuel), can be obtained, but it should be remembered that the thermal conversion of waste into energy should apply to those wastes that cannot be managed other than by landfilling.

Refuse Derived Fuel is produced from high-calorific waste that can come from households or from industry. Due to their high energy content, after appropriate transformation, it is possible to use them in thermal processes for energy generation.

The raw material for the production of RDF can be such materials as: plastics, paper, textiles, wood, mineral fractions, composite materials [6]. All these materials have a relatively high lower heating value (LHV) [7, 8], for example:

- wood – wet approximately 12 MJ/kg, dry approximately 19 MJ/kg, average 15 MJ/kg,
- plastics – strongly depends on the type of plastic, but on average about 24 MJ/kg,
- paper and cardboard – around 13 MJ/kg,
- textiles – 14 MJ/kg.

Using advanced processing technology, it is possible to receive fuel which can be used, e.g. in the combustion or co-combustion process [9].

Until now, the main recipients of RDF were cement plants but the requirements of this sector concerning calorific value of fuel are very high what created the problem concerning the use of already produced RDF that is not suitable for utilization in cement plants.

RDF can also be efficiently used for the production of heat in district heating systems but to maximize the use of chemical energy contained in this fuel production of electricity is also worth considering. If there are appropriate conditions, such as the possibility of combining both, the power grid and the heating network, the ideal solution may be cogeneration – simultaneous production of heat and electricity in a CHP

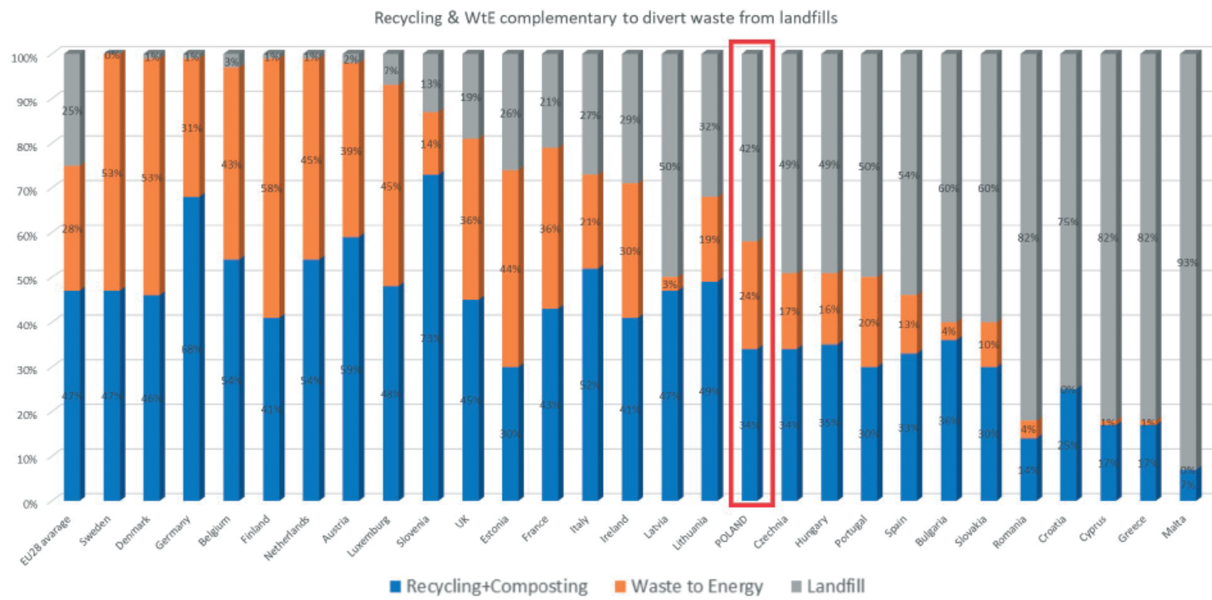

Figure 2.
Waste management methods in EU in 2019 [5]

Table 1.
Comparison of the CFB, BFB and Grate boiler technologies

Type of boiler	CFB	BFB*	Grate boiler
Boiler's efficiency	High	Average	Low
Steam parameters	High [1]	Low	Low
NOx emission	Low	Average	High
Fuels range	Widest 2	Narrow	Wide
Cost of combustion waste management	Average	High	Low
Share of fly ash	20–40%	80%	20%

* – Bubbling Fluidized Bed (BFB)
[1] – Steam temperature can be up to 50°C higher than in case of other boilers
[2] – Fuel share: Coal: 0–100%; Biomass: 0–100%, RDF: 0–100%.

(Combined Heat and Power) plant. This allows optimizing the efficient use of energy of fuel and indirectly have a positive impact on the environment.

To implement this plan, it is necessary to use the appropriate combustion technology, which is, e.g., a Circulating Fluidized Bed (CFB) boiler.

A CFB boiler can utilise such fuels (or their mixtures) as:

– fossil fuels (hard coal, lignite, peat, coal sludge),
– various types of biomass (e.g., forest, agricultural, biomass waste from the paper industry),
– waste fuels (e.g., demolition wood, industrial waste, sewage sludge, RDF and pre-RDF).

Circulating Fluidized Bed technology allows all these fuels to be burned in one boiler separately or mixed in any proportion [10].

Table 1 presents a comparison of available boiler waste incineration technologies in terms of efficiency, fuel ranges and costs associated with combustion waste management.

The possibility of RDF's utilization in the process of thermal transformation into energy is not limited only to the combustion technology itself but is also restricted by the need to meet the environmental requirements for the process of RDF combustion or co-firing (WI- Waste Incineration). It is necessary to control the acceptable maximum levels of emissions contained in the exhaust gas. New BAT conclusions for large combustion plants. presented in Commissioning Implementing Decision (EU) 2017/1442 (of 31 June 2017) will become obligatory from August 2021. Meeting these requirements is ensured by application of the combination of CFB technology with the proper and effective flue gas cleaning system technology.

This paper presents one of the possible combinations of efficient combustion and flue gas cleaning system which is co-firing of RDF with coal as a primary fuel in a circulating fluidized bed boiler (CFB).

CFB boilers can have a wide power range from 1 MW to over 1000 MW but due to the fact that the BAT conclusions do not address combustion of fuels in

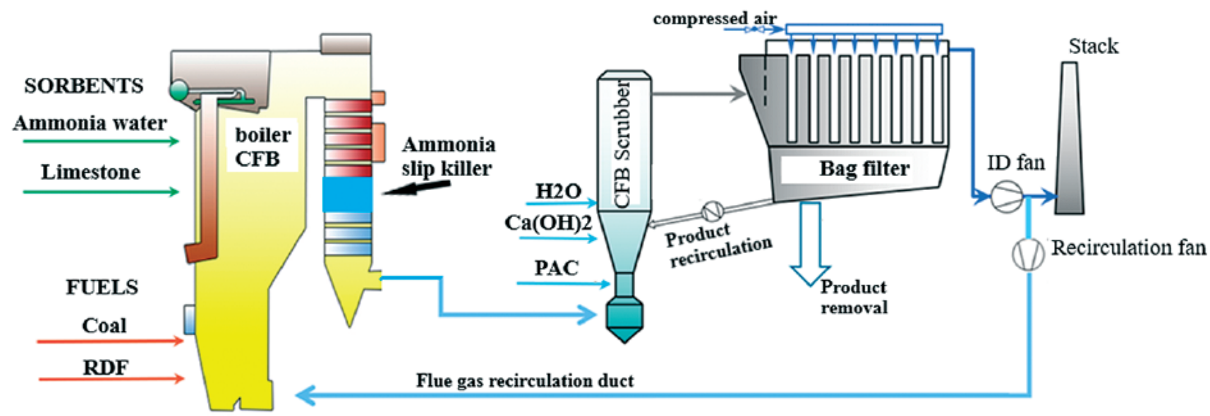

Figure 3.
Graphic diagram of the CFB boiler system in connection with the FGT installation

units with a rated thermal input of less than 15 MW and in this paper the minimum boiler size will be 15 MW. The upper limit of the boiler size is not specified.

2. DESIGN ASSUMPTION FOR THE CFB+FGT SYSTEM

Each project begins with the preparation of the main design assumptions. Some assumptions are included in Customer's requests, other form legislation requirement such environmental decisions requirements or building permit.

Examples of such assumptions considered in the design of CFB+FGT process are presented below:

– high availability,
– high boiler efficiency (up to or higher than 92%),
– steam temperature up to 530°C,
– low materials and energy consumption,
– high flexibility with respect to the type and quality of fuels burned (coal and RDF) and boiler loads,
– the size of the CFB boiler combustion chamber has to be adapted to the wide range of fuels' calorific value and total moisture (increase compared to single-fuel boilers),
– compliance with the Waste Incineration Directive (WI) imposes the need to ensure a minimum time and temperature level at which flue gas stays during the combustion process of RDF. It means that boiler design must ensure that minimum flue gas temperature of 850°C must be maintain for at least 2 seconds without the use of booster burners,
– the flue gas treatment installation FGT should be a semi-dry installation equipped with a fluidized bed reactor, bag filter and product recirculation system,
– between CFB boiler and FGT installation no pre-dedusting equipment will be installed
– adequate 100% redundancy of key boiler systems and tab 2s,
– boiler design will allow one catalyst layer to be installed in the future – space reservation,
– boiler should be equipped with a selective non-catalytic reduction system (SNCR) and limestone injection to the combustion chamber,
– reduction of flue gas impurities such as sulphur and nitrogen oxides, dioxins and furans, hydrogen chloride and hydrogen fluoride will be possible using cheap and widely available sorbents such as limestone powder, ammonia water, hydrated lime, pulverised activated carbon (PAC),
– coal as a basic fuel to be burned in the full range of 0–100%,
– RDF feeding should be possible as soon as the boiler's operation is stable, minimum temperature in the combustion chamber is 850°C maintained constantly and FGT is in full operation mode,
– the start-up fuel is light oil.

Figure 3 shows in graphical form the combined CFB boiler system together with the flue gas treatment installation.

3. CHARACTERISTICS OF FUELS

Coal fired in the CFB boiler will be bituminous coal from Polish mines. Basic parameters of the coal used in the analysis are presented in Table 2. Particle size of the coal fed to boiler should be within range 0.4–10 mm.

Table 2.
Characteristics of coal

Parameters	Unit	Standardized limits
Lower calorific value	MJ/kg	19–26
Carbon	%	58–78
Hydrogen	%	3–4.5
Nitrogen	%	1–2.6
Sulphur	%	0.4-1.4
Chlorine	%	0.1-0.4
Oxygen	%	5.5-8
Volatile matter	%	28-38
Humidity	%	<10
Bulk density	kg/m^3	750–1000
(Na+K)	%	<0.35
Sb	mg/kg	<5
As	mg/kg	<35
Cd	mg/kg	<4
Cr	mg/kg	<346
Co	mg/kg	<55
Cu	mg/kg	<225
Pb	mg/kg	<182
Ni	mg/kg	<227
Sn	mg/kg	<67
V	mg/kg	<333
Hg	mg/kg	<0.2
Zn	mg/kg	<262

For the design process purposes some assumptions regarding the fuel composition were made. The samples from the market were collected and analysed to determine the fuel parameters.

Local municipal waste processing systems (RIPOK) are the source of the RDF. Basic parameters of the RDF used in the analysis are presented in Table 3 [11, 12]. RDF is fed to the boiler in the fluff form when the total moisture limit 20% is not exceeding.

Maximum RDF particle size should not exceed sum of all sides 300 mm.

RDF may contain some non-fluidizable particles like ceramic, porcelain, gravel, stones, glass and all metal but a limit of this contamination should not exceed 2–3% of total RDF fed to boiler.

Table 3.
Characteristics of RDF

Parameters	Unit	Standardized limits
Lower calorific value	MJ/kg	6–25
Carbon	%	35–40
Hydrogen	%	5–8
Nitrogen	%	0–1
Oxygen	%	25–30
Sulphur	%	<0.5
Chlorine	%	<1
Ash content	%	<15
Volatile matter	%	50–80
Humidity	%	<20
Bulk density	kg/m^3	100–300
Sb	ppm	<20
As	ppm	<10
Cd	ppm	<5
Cu	ppm	<150
Pb	ppm	<100
Cu	ppm	<150
Pb	ppm	<100
Ni	ppm	<50
Hg	ppm	<1

4. EMISSIONS

As a result of stoichiometric calculations, it is possible to determine maximum levels of the emissions for individual harmful compounds contained in the exhaust gas. Results of stoichiometric calculations are presented in Table 4. These results constitute the design basis for the SNCR system, limestone injection system, hydrated lime injection system and pulverised activated carbon injection system.

Emissions levels associated with the best available technics (BAT-AELs) for emissions to air given in the BAT conclusions refer to concentrations, expressed as mass of emitted substance per volume of flue gas under the following standard conditions [13]: Dry gas at a temperature of 273.15 K, and a pressure of 101.3 kPa, and expressed in the units mg/Nm^3, $\mu g/Nm^3$ or ng I-TEQ/ Nm^3.

For combustion of solid fuels and waste co-incineration reference conditions for oxygen used to expresse BAT-AELs in this document is 6 vol-%.

When waste is co-incinerated together with non-waste fuels, the BAT-AELs for emissions to air given in BAT conclusions apply to the entire flue gas volume generated.

Table 4.
Predicted based emissions

Emission component – subject to reduction	Maximum baseline emissions	Unit
Dust	<30*	g/Nm^3
SO_2	<2700	mg/Nm^3
NOx	<210	mg/Nm^3
HCl	<1100	mg/Nm^3
HF	<65	mg/Nm^3
Hg	<0.06	mg/Nm^3
Cd+TI	<1.3	mg/Nm^3
Sb+As+Pb+Cr+Co+Cu+Mn+Ni+V	<265	mg/Nm^3

* – The given number refers to the amount of fly ash contained in the flue gas at the CFB outlet.

Table 5.
Minimum emissions monitoring scope and monitoring frequency (BAT-AELs)

Substance	**Minimum monitoring frequency***
Dust	Continuous
SO_2	Continuous
NO_x	Continuous
N_2O	Once every year
CO	Continuous
TVOC**	Continuous
HCL	Coal + RDF firing: continuous (WI) Coal firing: once every 3 months
HF	Coal + RDF firing: continuous (WI) Coal firing: once every 3 months
Metals and metalloids except mercury (As, Cd, Co, Cr, Cu, Mn, Ni, Pb, Sb, Se, Tl, V, Zn)	Coal + RDF firing – once every 6 months; Coal firing: once every year
Hg	Coal and/or Coal + RDF firing <300MW_{th}(1) – once every 3 months Coal and/or Coal + RDF firing 300MW_{th}(1) – continuous
Dioxins and furans (PCDD/PCDF)	Once every 6 months
NH_3	Continuous (when SNCR used)

** – anticipated from 08.2021 (BAT (EU) 2017/1442, 31.07.2017 compliance)
** – Total Volatile Organic Compound
(1) – Combustion plant total rated thermal input

Table 6.
Emission levels in case of coal firing (BAT-AELs)

Pollutant	Yearly average emission limit	Unit	BAT no.
Ash	5	mg/Nm^3@6%O_2	BAT 22
SO_2	200(1) ;150(2) ;75(3)	mg/Nm^3@6%O_2	BAT 21
NO_x	150(1);100(2);85(3)	mg/Nm^3@6%O_2	BAT 20
CO	140(4);100(5)	mg/Nm^3@6%O_2	BAT 20
NH3	10(7)	mg/Nm^3@6%O_2	BAT 7
HCL	6(1); 3(6)	mg/Nm^3@6%O_2	BAT 21
HF	3(1), 2(6)	mg/Nm^3@6%O_2	BAT 21
Hg	3(4); 2(5)	$\mu g/Nm^3$@6%O_2	BAT 23

(1)- Combustion plant total rated thermal input <100 MW_{th}
(2)- Combustion plant total rated thermal input 100-300 MW_{th}
(3)- Combustion plant total rated thermal input ≥ 300 MW_{th}
(4)- Combustion plant total rated thermal input <300 MW_{th}
(5)- Combustion plant total rated thermal input ≥300 MW_{th}
(6)- Combustion plant total rated thermal input ≥100 MW_{th}
(7)- when SNCR or SCR in use

As a result of the FGT's product recirculation system operation dust concentration in the flue gas at the inlet to the bag filter can reach the level of up to 250 t/h.

In accordance with the design assumptions the CFB boiler in combination with the FGT flue gas treatment installation will fully reduce the levels of emissions of pollutants contained in the flue gas to levels specified in the standards and regulations (BAT) applicable for co-firing of RDF with coal [13].

Table 5 presents minimum monitoring frequency required in coal firing case and coal with RDF co-firing case.

For the combined CFB + FGT installation meeting the emission requirements in the case of co-firing coal with RDF is more demanding than in the case of combustion of coal alone. Therefore, the case of burning only coal in the boiler will not be discussed in detail in this paper. The CFB+FGT system ensuring full control of emissions during coal co-firing with RDF, ensures it even more when burning coal alone.

In case of CFB technology it is possible to control SO_2, NO_x and NH_3 emissions (as a side effect of NO_x reduction with ammonia). The aim of flue gas treatment installation is to control the remaining emissions. It should be noted that the FGT installation is able to take full control of SO_2 emission in an emergency situation when limestone dosing system to the boiler's combustion chamber is out of operation.

Figure 4 shows the division of the emission control scope between the CFB and FGT system in co-firing mode.

Table 6 presents emission levels in case of coal firing in new CFB boiler provided in BAT (EU)2017/14423 compliance and anticipated from 08.2021.

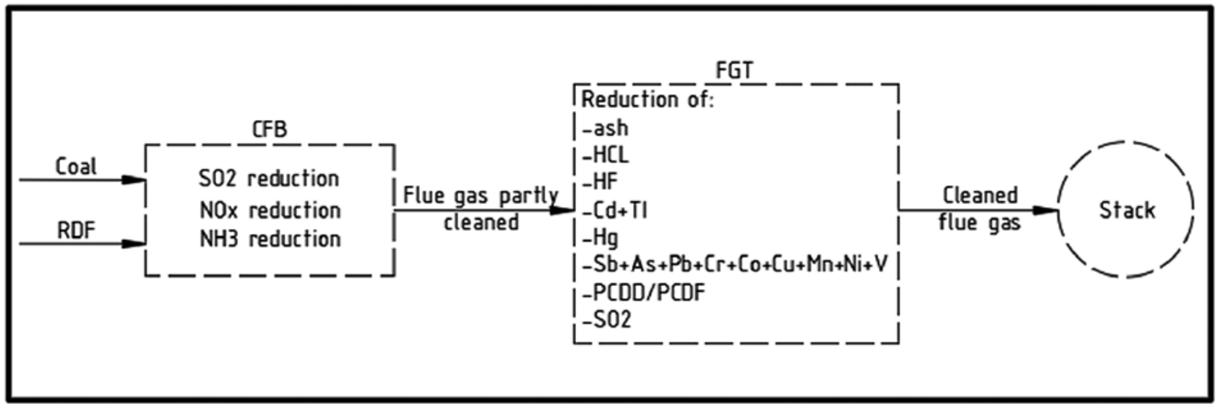

Figure 4.
Division of the CFB + FGT system emission control range for the co-firing coal with RDF operating mode

Table 7.
Emission levels in case for coal and RDF co-firing

Pollutant	Yearly average emission limit	Unit	BAT no.
Ash	5	$mg/Nm^3@6\%O_2$	BAT 68
SO_2	$200^{(1)}$;$150^{(2)}$;$75^{(3)}$	$mg/Nm^3@6\%O_2$	BAT 66
NO_x	$150^{(1)}$;$100^{(2)}$;$85^{(3)}$	$mg/Nm^3@6\%O_2$	BAT 64
CO	$140^{(4)}$;$100^{(5)}$	$mg/Nm^3@6\%O_2$	BAT 64
NH3	$10^{(7)}$	$mg/Nm^3@6\%O_2$	BAT 7
HCL	$6^{(1)}$; $3^{(6)}$	$mg/Nm^3@6\%O_2$	BAT 66
HF	$3^{(1)}$, $2^{(6)}$	$mg/Nm^3@6\%O_2$	BAT 66
Hg	$3^{(4)}$; $2^{(5)}$	$\mu g/Nm^3@6\%O_2$	BAT 70
Cd+TI	$12^{(4)}$; $6^{(5)}$	$\mu g/Nm^3@6\%O_2$	BAT 68
TVOC	5	$mg/Nm^3@6\%O_2$	BAT 71
PCDD/PCDF	0.03	ng I-TEQ/ $Nm^3@6\%O_2$	BAT 71
Sb+As+Pb+Cr+Co+Cu+Mn+Ni+V	$0.5^{(4)}$;$0.2^{(5)}$	$mg/Nm^3@6\%O_2$	BAT 68

$^{(1)}$- Combustion plant total rated thermal input <100 MW_{th}
$^{(2)}$- Combustion plant total rated thermal input 100–300 MW_{th}
$^{(3)}$- Combustion plant total rated thermal input ≥ 300 MW_{th}
$^{(4)}$- Combustion plant total rated thermal input <300 MW_{th}
$^{(5)}$- Combustion plant total rated thermal input ≥300 MW_{th}
$^{(6)}$- Combustion plant total rated thermal input ≥100 MW_{th}
$^{(7)}$- when SNCR or SCR in use

Table 7 presents emission levels in case of coal and RDF co-firing in new CFB boiler provided in BAT (EU)2017/14423 compliance and anticipated from 08.2021.

5. REDUCTION OF IMPURITIES IN THE CFB BOILER

Refuse derived fuel undoubtedly belongs to the group of fuels difficult for combustion. Combustion of such fuels requires extensive knowledge and many years of experience necessary to design correctly boiler and flue gas treatment plant.

Co-firing of coal with RDF is not only associated with the problem of reducing the level of impurities in flue gases but also with problems affecting the durability of boiler components, such as:

- increased sedimentation on the heat exchange surface (fouling),
- erosion of the boiler's components associated with poor quality RDF,
- corrosion associated with the presence of significant amounts of chlorine in RDF.

The following countermeasures are taken to protect against abovementioned negative impacts:

– reduction of flue gas velocity,
– limitation of flue gas temperature before the 1st and 2nd stage of superheater system,
– appropriate selection of materials for heat exchange elements,
– final stages of superheaters 3 and 4 are not in contact with flue gas (characteristic feature of the CFB boiler is possibility of immersion superheater coils in bed material separated from flue gas in cyclones or separators)
– appropriate selection and placement of the refractory lining.

Co-firing of the alternative RDF fuel with coal takes place in the combustion chamber of the CFB boiler which ensures intensive and thorough mixing of fuels with the bed material and sorbents dosed into the combustion chamber (limestone and ammonia).

The design of the boiler co-firing alternative fuel RDF with coal in accordance with the requirements of WI directive must ensure that this process will be carried out without the use of load burners at a temperature of not less than 850°C for a period of not less than 2 seconds.

A very important design criterion is properly selected fuel delivery to furnace locations and their numbers, e.g. in the case of a 150 MW_{th} boiler due to the size of the combustion chamber the most optimal solution is feeding coal and RDF to the lower part to the front and rear walls with independent and dedicated to each fuel feeding systems (Fig. 5) with the following arrangement of feeding points:

– 4 coal feeding points to the rear wall of the combustion chamber,
– 4 RDF feeding points on the front wall of the combustion chamber.

Accordingly, for reducing or increasing the size of the combustion chamber, the number of fuels feeding points increases or decreases. The goal is to ensure uniformity of the fuel stream feed to the boiler furnace.

6. FLUE GAS TREATMENT INSTALLATIONS

The FGT installation is responsible for the final reduction of those pollutants in flue gas that are not controlled or are controlled only partially by CFB technology.

The FGT installation is a semi-dry installation equipped with a fluidized bed reactor in which

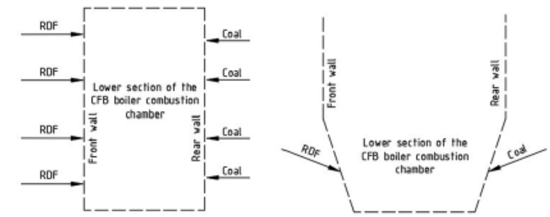

Figure 5.
Scheme of the fuel feeding to the combustion chamber of a CFB boiler

hydrated lime and activated carbon are injected into the flue gas stream in the form of dry dust.

The post-reaction product obtained in the bag filter is also introduced into the reactor by the recirculation system which effectively improves the degree of sorbent utilization thus reducing the proportion of unreacted calcium compounds in the product discharged out of the system. In order to control the optimum temperature from the point of view of exhaust gas purification processes water is injected into the reactor.

Another element of the FGT system layout is a bag filter divided into several compartments. Depending of the filter's design it is possible to separate one or more of the bag filter compartments that enables the boiler to work at full load and at the same time allows carrying out work, e.g. bag replacement.

The semi-dry FGT installation is characterized by the reliability and efficiency of flue gas treatment ensuring compliance with the restrictive emission levels presented in Table 5. One of the many advantages of this type of installation is the lack of liquid waste phase which significantly reduces the installation operational costs.

According to the design assumption presented in section 2 no dedusting installation was installed at the flue gas route from the CFB boiler for the FGT installation. This means that the total load of fly ash contained in the flue gas after leaving the last element of the boiler goes to the FGT system where it is separated from the flue gas in the bag filter.

The main components of the FGT installation shown in Fig. 6 are:

– circulating fluidized bed scrubber CFBS,
– bag filter,
– product recirculation slide,
– bag regeneration system,
– product removal and storage system,
– hydrated lime injection system into the scrubber,

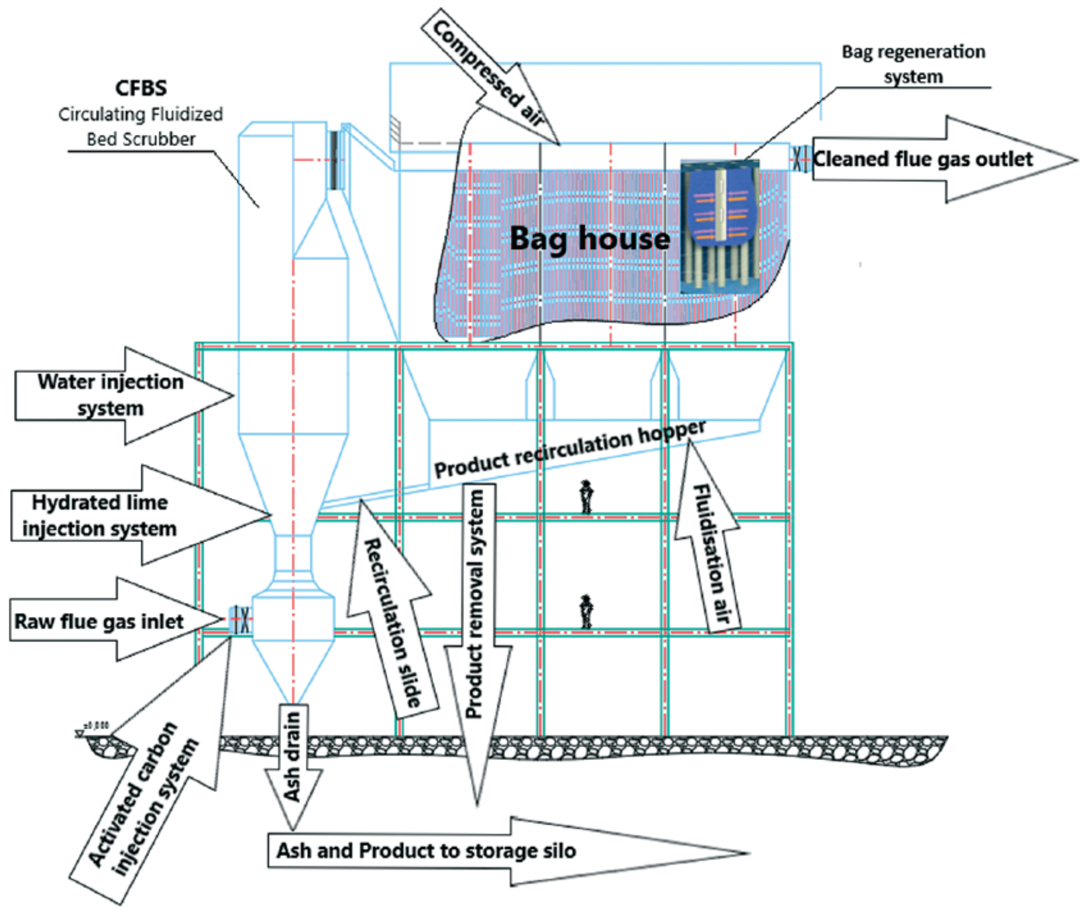

Figure 6.
Main components of the FGT semi-dry flue gas treatment system

– water injection into the scrubber,
– activated carbon injection system into flue gas duct upstream of the scrubber,
– fluidisation air system.

7. REDUCTION OF EMISSIONS OF HARMFUL EXHAUST COMPONENTS IN THE CFB-FGT SYSTEM

Emission control in the CFB + FGT combined system is mainly based on the continuous measurement of emissions according to the diagram shown in Fig. 7.

Measurement of SO_2 emission at the boiler outlet is a source of information for the limestone injecting system to the combustion chamber. Sulphur dioxide measurement carried out at the outlet of the FGT installation can perform the same function in the case when only coal is burned (no hydrated lime is dosed to the FGT installation) and in a situation where the FGT installation takes complete control over the reduction of SO_2 (in the case when limestone injection system is out of operation). SO_2 measurement system installed before and after the FGT installation also allows partial reduction of this compound in the boiler and final reduction in the FGT installation. Moreover, double measurements of SO_2 and HCL (before and after the FGT installation) give the opportunity to determine what the level of pollution reduction is. In combination with the continuous measurement of the hydrated lime consumption it allows controlling the efficiency of the reaction taking place in the FGT installation.

Fuel combustion technology in boilers with a circulating fluidized bed is characterized by the fact that additional external flue gas cleaning installations are not required to control SO_2 and NO_x emission levels. The SO_2 emission level in the CFB boiler is regulat-

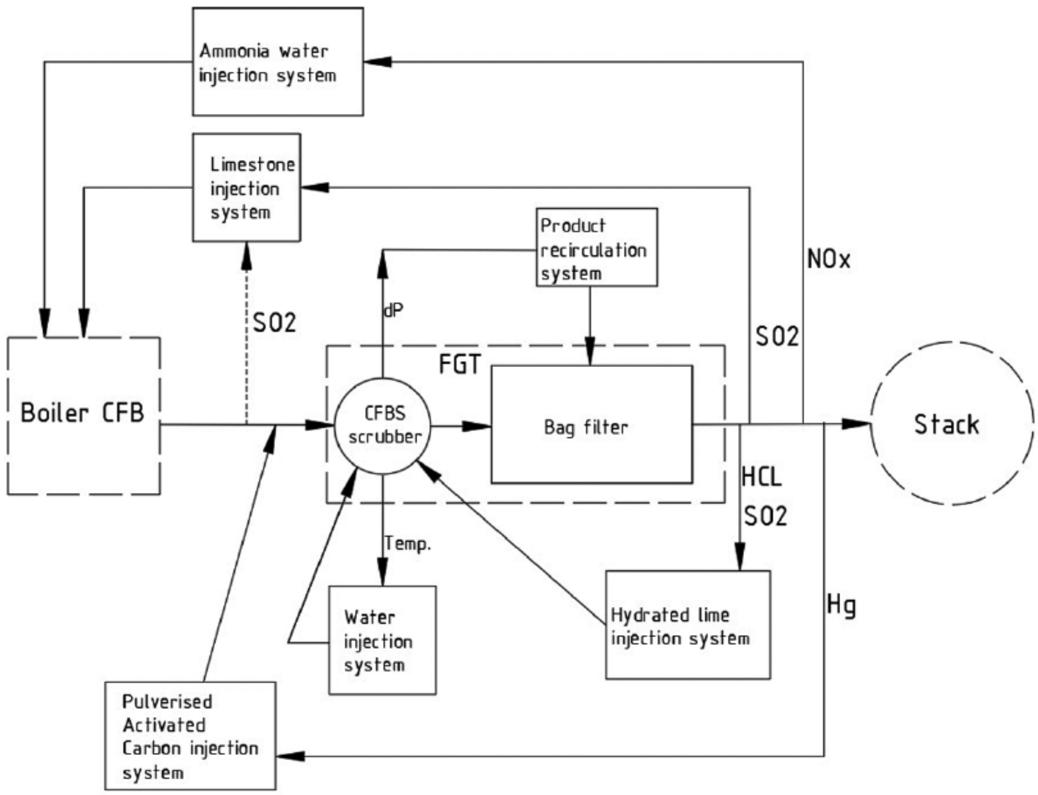

Figure 7.
Diagram of the emission control systems in CFB+FGT installation

ed by a primary method by introducing pulverised limestone ($CaCO_3$) into the combustion chamber which decomposes under the influence of heat resulting in the formation of quicklime (CaO) which then reacts with SO_x forming $CaSO_3$ and $CaSO_4$ compounds, derived from boiler with bottom and fly ash.

The NO_x emission is limited by the process of combustion in a circulating fluidized layer at a relatively low temperature not exceeding 900°C which, combined with the optimization of the excess air ratio and the gradation of air supply for combustion, allows reducing NO_x emissions by half compared to the initial value resulting only from the conditions of the low-temperature combustion process. The cool flue gas recirculation system to the combustion chamber allows controlling the temperature in the combustion chamber caused by differences in the quality of such a fuel as RDF. Further reduction of NO_x is conducted by the SNCR installation in which an aqueous ammonia solution (concentration up to 25%) is injected into the combustion chamber and separators. In this case NH_3 emissions will not be exceeded due to the fact that the amount of ammonia dosed to the combustion chamber will be small compared to high-temperature combustion processes (stoker-fired boilers). However, due to the fact that emission levels are constantly tightening it is recommended in new plants to reserve space for installing in future a single layer catalytic insert (so-called ammonia slip killer).

In the next step flue gas from the CFB boiler is introduced into the FGT's fluidized bed scrubber. Then the flue gas flows through the venturi (which is part of the reactor) significantly increases its speed. Hydrated lime is introduced to this flue gas stream trough nozzles installed in venturis wall. The mixture of the post reaction product and unreacted sorbent recycled from the bag filter hoppers via the recirculation air slides to the conical part of the scrubber (above venturi).

As a result of significant increases of the flue gas velocity in venturi section of the scrubber a fluidized bed is formed in its cylindrical section. The flue gas components are mixed with the sorbent and recirculated product in a turbulent manner ensuring a high level of mixing of pollutants contained in the flue gas with the sorbent. In order to maintain the right temperature of the processes taking place in the scrubber water is injected. The presence of water also intensifies the reaction taking place in the scrubber. Part of the bed material falls along the walls of the cylindrical part of the reactor downwards where it is again carried upwards. The remaining part of the bed material flows into the bag filter where it settles on the outer surface of the filter bag material where the second stage of sorbent reaction with impurities occurs.

The basic chemical reactions occurring in the FGT system are presented below:

$$Ca(OH)_2 + SO_2 \rightarrow CaSO_3 + H_2O$$

$$Ca(OH)_2 + SO_3 \rightarrow CaSO_4 + H_2O$$

$$CaSO_3 + \tfrac{1}{2}O_2 \rightarrow CaSO_4$$

$$Ca(OH)_2 + 2HCl \rightarrow CaCl_2 + 2H_2O$$

$$Ca(OH)_2 + 2HF \rightarrow CaF_2 + 2H_2O$$

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

As a result of the bag regeneration system action the material (cake) that settles on the outer surface of the bags is shaken off and falls to the bottom of the filter hoppers and then goes to the recirculation system.

Recirculation of the product and unreacted sorbent mixture significantly increases the efficiency of flue gas purification in the system which results in a decrease in the demand for sorbent and a reduction in the amount of unreacted sorbent in the product discharged from the FGT system. In the situation when the reaction possibilities in the circulated material were used or the maximum level of the product was achieved in the hoppers of the bag filter the material is discharged into an external storage silo which is then transported by means of hermetic tank trucks to the place of further processing or storage.

The combined CFB + FGD technology described in this paper allows the reduction of exhaust gas pollution to the following ranges of values:

– SO_2 – up to 99%

– SO_3 – up to 99%

– HCl, HF – up to 99%

– Hg (total) – up to 99% (activated carbon injection)

– Dioxins and Furans – up to 98%

– Dust – up to 99.9%

8. CONCLUSIONS

The use of the combined CFB + FGT technology is an example of new and high-efficiency units allowing the firing or co-firing of various fuels and their mixtures in a safe and ecological manner by meeting current and future emission limits. Both CFB and FGT technologies are recognised as the best available techniques (BAT).

This paper presents only one of many combinations of CFB boiler use which is the co-firing of two different fuels – coal (main fuel) and RDF (secondary fuel).

CFB technology enables the use of low calorific fuels whose independent combustion is either impossible or too difficult and therefore unprofitable.

CFB technology allows the combustion or co-firing of additional fuels (and their mixes) such as: lignite, coal sludge, forest and agricultural biomass, biomass waste from the paper industry, demolition wood, industrial waste, sewage sludge or pre-RDF.

The use of appropriate assumptions at the CFB and FGT design stage allows for later easy modernizations consisting in changing the ranges of fuels used and for adapting the system to meet the stricter standards related to environmental protection and reduces the amount of waste going to landfill.

CFB technology is an example of the application of proven combustion technology in high-efficiency boilers allowing for the co-combustion of various fuels and their mixtures. Combined with FGT technology the process of burning difficult fuels like RDF is carried out in a safe and environmentally friendly manner while meeting the strictest emission limits.

A characteristic feature of heat producing plants (CHP) is the security of ensuring continuity of heat energy production. Coal as the basic fuel can be stored in appropriate amounts at the CHP plant which is an appropriate buffer in the event of problems with secondary fuel (RDF) supplies.

Co-firing of RDF with coal as the primary fuel ensures stable steam production in the case of low or heterogeneous quality of RDF which in conjunction with doubling of viable CFB and FBT systems guarantees high availability.

The CFB + FGT system does not require much space for development which is why it is successfully used in retrofit cases when a new boiler is built in existing boiler rooms.

Existing CFB boilers can also be adapted to supply with other originally designed fuels and retrofitting these CFB boilers with FGT installation guarantees meeting the highest emission standards.

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