DEVELOPMENT OF CASTABLES FOR BIOMASS FURNACES

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Abstract
Heat installation for incineration of various types of biomass underwent enormous innovations over the past years. Used refractory linings have to keep up with these changes. Their service-life in furnaces is affected by specific conditions and influences, such as alkali bursting, low-fusing ashes corrosion, extreme thermal shocks, sometimes requirements on subtle and complicated shapes of lining and many others. This article sums up current development of castables (monoliths and adapting pieces), approaches to the problem solution and experience from the numerous operating applications realised by the company Průmyslová keramika.

1. Introduction

Burning of biomass represents one of several methods for generating energy from renewable sources. Moreover, emissions from burning renewable sources of energy do not increase concentrations of so-called greenhouse gases because they are “fast-moving fuels”, which means that CO_2 released in atmosphere is consumed through the photosynthesis process in a relatively short time. Enormous development of new biomass burners lays new requirements on their refractory lining. Even though burning of organic materials comprised under the term biomass [1] may seem trouble-free in relation to linings, the reality is often very different. The following article will deal in particular with defects of linings of the mentioned units, factors influencing their service-life, methods of resolution of problems, both structural, operational and especially in the area of development of suitable refractory materials. In this case, it concerns liquefied refractory concretes and adapting pieces prefabricated from them.

2. Energy-producing equipment for biomass burning

The term biomass includes all organic material formed during photosynthesis process or material of animal origin. Except for wood, which is the most common, it includes:
Residual (waste) biomass:
- forestry wooden waste
- wooden and other waste of cellulose, paper, forest and furniture industries
- plant residues from agricultural primary production (straw, tailings, litter for livestock, etc.).
- plant residues from landscape maintenance
- municipal biological waste
- waste from food industry.

Intentionally grown biomass:
- grassy energy crop (sorrel)
- woody energy crop (willow)
- corn (maize and other cereals)

Energy from biomass is obtained by direct incineration or by burning products of both wet and dry biochemical processes, such as biogas, wood-gas and others. There exists a whole range of heat installations differing one from the other by technology of burning and also output that may vary from several kW to hundreds of MW. These installations may be divided in:

- hot-water boilers for direct incineration of biomass;
- steam boilers for direct heating with possible combination with a steam turbine;
- gasifier combined with a boiler or co-generation unit (internal combustion engine or turbine);
- co-generation unit for use of biogas;
- various combination of the said systems.

3. Defects of linings, their causes and solutions

As it arises from the above shown review, biomass burning units represent a wide and diverse range of installations and systems. Their operation depends on different technological systems, outputs, operational modes and they use various fuels. However, some defects and damages of refractory linings prevail. They may be divided into three basic groups:
1) Reactions of lining materials with alkali compounds
2) Corrosion caused by ash melts
3) Damage of lining caused by violent and frequent changes of temperature

3.1. Reactions of lining materials with alkali compounds

During operation of furnaces, we often observe defects of linings that show themselves by peeling off of surface layers, cracking of walling, creeping of individual parts, bumping of entire dilatation fields. Such creeping or bumping runs in the direction towards the warm, working side of the lining. It is caused by reaction of alkali compounds (in particular potassium) present in the furnace environment with some mineralogical components of the refractory lining. These reactions form new compounds (especially feldspars, but also Al_2O_3 β-modifications, and others) of higher volume (lower density) than original minerals. The stated possible increase of volume is 7 to 30 % depending on the compound formed [2]. The described phenomenon is called *alkali bursting* and it is the main cause of the described defects. Strain created in the lining causes peeling off of layers, formation of cracks and sometimes creeping of parts.

The source of alkalis is fuel itself, concretely its incombustible inorganic fractions. Table 1 shows chemical analyses of ashes of some common fuels representing biomass. The shown values evidence often high content of potassium and also calcium in residual ashes. These materials are commonly designated as melts. They are low-fusing compounds easily evaporating under operating temperatures and transported in gaseous form throughout the entire furnace area. That is why they may cause defects in parts of linings that do not need to be necessarily in direct contact with fuel. The defects are most often observed in temperature areas from 800 to 1000 °C.

Table 1 Analyses of ashes (% w.)

Ash	**Wood and slabs**	**Slabs**	**Corn and rape straw**	**Hay pellets**	**Pellets from corn residues**	**Corn residues and silage**	**Wheat**	**Triticale**
SiO_2	35.8	32.9	53.4	28.4	31.8	44.7	70	321
TiO_2	0.8	0.6	0.1	0.1	0.2	0.2	0.1	0.1
Al_2O_3	8.7	9.3	3.0	0.9	2.4	3.0	0.8	2.0
Fe_2O_3	3.6	3.0	0.9	0.5	1.1	1.4	0.7	1.0
CaO	39.5	42.7	14.5	7.0	12.8	11.5	4.8	33.5
MgO	5.2	3.2	4.0	6.6	6.1	6.0	15.9	4.0

K_2O	2.6	2.1	17.5	27.3	18.2	15.1	34.9	13.0
Na_2O	0.8	0.5	1.0	0.2	0.4	0.5	0.3	0.4
Σ	97.0	94.3	94.4	71.0	73.0	82.4	64.5	86.1

Alkali corrosion is difficult to prevent through structural organisation of a unit. The solution consists in selection of a suitable refractory material, in our case it is refractory concrete. It is necessary to use such material that does not react with alkalis at all, or that forms compounds that are not accompanied with volume changes. It requires selection of suitable aggregate (grog) and, in particular, optimal composition of the matrix. During development, we use two basic methods:

- first, we monitor volume changes after firing on pressed pellets that are formed from mixtures of fine refractory compounds and various alkali salts [3], [4]. The test pieces (pellets) are shown on fig. 1.
- hot reactions of alkali compounds and ashes directly in holes of refractory concrete joists, where we evaluate structure of the joist after exposure, any cracking, penetration of alkalis into the refractory concrete fragments, etc. The test joists are shown on fig. 2.

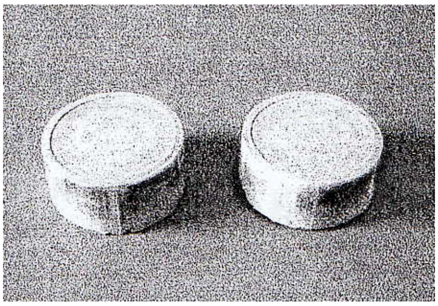

Fig. 1 Pellets

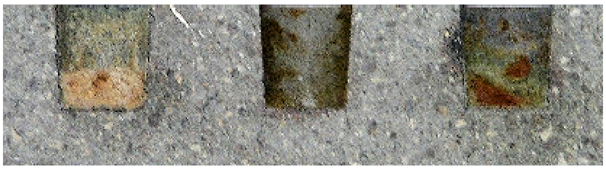

Fig. 2 Joists

3.2. Corrosion of lining due to ash melt

It arises from the shown analyses of ashes that, due to high volume of alkali salts, in particular potassium, residual ashes will change into melt under quite low temperatures. Under commonly achieved operating temperatures in furnaces, they will exist in semi-liquid to liquid state and corrode quite rapidly the refractory lining in contact.

Solution of this condition has two layers. The first one should prevent presence of melt in the furnace area, therefore it concerns especially designers of furnaces and their users. Furnaces should not be designed for and operated at unnecessarily high temperatures. Speed of corrosion of a refractory material by ash melts is influenced in particular by temperature. Increasing temperature makes any present melt less viscous and more reactive.

Some sources state that speed of corrosion caused by melt gets two times faster if temperature increases by 30 to 50 °C. [5]

Considering chemical composition of ashes, even operation under quite low temperatures often does not prevent formation of melt. Then it is necessary to apply refractory materials resistant to melt corrosion. As the chemical composition of ashes is similar to that of alkali glass melt, materials usually used in glass melting furnaces are used. Corrosion resistance is tested both using the crucible as well as finger method; we prefer the finger one. During this test, a rod of a tested refractory material is immersed in a crucible with melted ash and the crucible is rotating throughout the whole time of test. A big advantage of the test is more intensive corrosion because the method shows higher ratio between the weight of corrosive agent (ash) and refractory material than the static crucible method. It is necessary to stress, nevertheless, that there are quite few places exposed to melt corrosion in the whole range of linings of biomass incineration furnaces. However, the increasing volume of incineration of straw and straw pellets, frequency of such problematic places will increase too.

3.3. Damage of linings caused by violent changes of temperatures

Even though defects of linings are often said to be caused by other factors, the majority of cracking, crushing and breaking off is caused by frequent changes of temperature of the lining. This is connected with operation of furnaces because only few furnaces work continuously for a long time. Operation without cooling down is common especially for large furnaces whose output represents tens of MW. The smaller a furnace is, the more frequent are interruptions of operation, which is accompanied with rapid cooling down and then warming up or its lining.

Prolongation of service-life of linings depends partially on a designer of the heat installation, but in particular on the refractory material used. Periodically operating furnaces must be designed especially with smaller dilatation units, optimum anchoring of walling and corresponding width and distribution of dilatation joints.

There are several ways to develop refractory monoliths and adapting pieces resistant to temperature changes.

- *Increase of tension strength of refractory concretes,* where addition of needles of refractory steel, so-called dispersed reinforcement, proved to be efficient. However, their use is limited by temperature at which the steel fibres are still functional.
- *Increase of thermal conductivity of ceramic body,* where temperatures equalise faster in the section of lining, which means that pressure, that is the cause of destructions, drops too. In the described area, thermal conductivity is most often increased by addition of silicon carbide. These solutions are frequent, but application of silicon carbide materials is limited at temperatures above 1100 °C when oxidation begins. SiC materials are also less resistant to corrosion by ash melts.
- *Use of aggregate (grog) with low coefficient of thermal expansion.* The best known ones are silica glass and cordierite. Their use is partially limited due to operating temperature (in particular in case of silica glass – recrystallising), lower corrosion resistance and higher price.
- *Adjustment of matrix structure.* In our case, this is recently a new development direction that does not impair the previous methods [6]. The principle is to form intentional inhomogeneities, if possible microcracks, in the matrix structure, which substantially reduces spreading of cracks. This method is suitable for most of material compositions of refractory concrete and it is convenient for liquefied mixtures with reduced content of cement. The so adjusted refractory concretes have practically no upper temperature limit in comparison with the above described methods. Table 2 shows results of temperature change resistance tests performed using a modified DIN 51068 method, when joists were used in place of prescribed rolls as testing bodies. Refractory concrete with an adjusted matrix are marked as HT.

Table 2 Refractory concrete castables for linings of biomass furnaces

Refractory concrete			**1450**	**1450-RA**	**1500-SIC-10-RA**	**1450-SIC-ZR-RA**	**U-1700-ZM**	**1450-RA-HT**	**1450-SIC-15-RA-HT**	**1450-SIC-ZR-RA-HT**
Refractory concrete type			LCC	LCC	LCC	LCC	ULCC	LCC	LCC	LCC
Material base			AS	AS	AS, SiC	AS,SiC,ZrO_2	zirkonmullit	AS	AS, SiC	AS,SiC,ZrO_2
Classification temperature		°C	1450	1450	1500	1450	1700	1450	1450	1450
Al2O3		%	46	40	43	33	63	39	36	34
SiO2		%	47	50	41	42	24	49	42	40
CaO		%	1	1.8	1.8	2	0.7	1.8	2	2
SiC		%			10	9			15	9
ZrO2		%				9	9,5			10
Test certificate no.			377/09	46/09	49/10	NSZ-10	M-40-ko	404/09	104/09	NSZ-5
Forming water		l/100kg	5.8	5.6	5.6	5.5	4.2	5.8	6	5,8
Weight in volume	110°C	kgm-3	2250	2240	2310	2410	2650	2250	2300	2410
	800°C	kgm-3	2230	2220	2290	2400	2630	2320	2290	2380
	CT°C	kgm-3	2270	2260	2270	2450	2670	2240	2270	2470
Pressure strength	110°C	MPa	68.9	101.3	55.7	80	56.7	96.1	92,8	84,1
	800°C	MPa	93.2	118.2	54.1	78.2	75.1	103.2	132,5	100,8
	CT°C	MPa	107.2	95	68.8	74.7	136.3	69.1	111,1	93,9
Apparent porosity	800°C	%		12.3	17.4	13.2	10.3	15.2	13,3	12,2
	CT°C	%		9.4	15.2	11	11.9	13.7	14,5	14,1
Permanent length changes	800°C	%	-0.2	-0.2	-0.1	-0.2	-0.1	-0.2	-0,2	-0,3
	CT°C	%	-0.8	-0.8	-0.1	-0.7	-0.4	-0.1	-0,5	-1,1
Resistance to alkali peeling off			-	+ +	+ +	+ +	-	+ +	+ +	+ +
Resistance to ash melt corrosion			+	+	+	+ +	+ + +	+	-	+ +
Resistance to temperature changes (joists 150x25x25 mm)	1200°C	cycles	8 44(2%FS) 73(4%FS)	13	21	20	28	>100	>100	83

Abbreviations and symbols used: CT classification temperature, AS aluminium silicate, FS refractory steel needles

- non-resistant, + low resistant, ++ resistant, +++ very resistant

Note: Refractory concrete castables containing SiC fired at CT in reduction environment

4. Recommended refractory castables for biomass furnaces

The previous table 2 sums up the basic types of refractory castables that are used in various parts of linings of heat installations incinerating biomass group fuels. Except for basic physical and chemical, mechanical and technological data, the table specifies also their suitability for individual areas of operating load, as described in previous paragraphs. In general it is not possible to propose one universal lining material for a given area. Regarding operating conditions, lining load, incinerated fuel and cost-efficiency of operation, it is necessary to choose different refractory material for different furnaces and places in them.

5. Conclusion

The text describes only the most frequent damages of linings and directions of development of refractory concretes resistant to such defects. There are, of course, many other factors that affect linings that are not described here. Neither are mentioned various refractory materials from the field of refractory monoliths that are used for the purpose of protection of heat-transfer surfaces of furnace membranes, gunning materials and others. Of course, burnt construction materials are used for linings of the described furnaces too. Considering production line of the company that prepared this article, the question was aimed at hydraulically bound liquefied refractory concrete that is installed in the given furnaces either as monoliths or as pre-fabricated adapting pieces.

6. Literature

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