BIOFLEX!

ERA-NET Bioenergy

Guidelines for advanced furnace/boiler and fuel design

  

BIOS BIOENERGIESYSTEME GmbH

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FFG Swedish Energy Agency FNR The National Centre for Research and Development

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Background and objectives

- The majority of modern biomass combustion plants is typically designed for a comparably narrow fuel range to be applied
  - **Small-scale systems (<500 kW_{th}):** wood pellets, wood chips with well defined and restricted qualities regarding moisture and ash contents
  - **Medium-scale systems (500 kW_{th} – 10 MW_{th}):** wood fuels with a broader range of moisture and ash contents as well as forest residues and waste wood
- There is an increasing demand for combustion systems, which can utilize a **broader range of biomass fuels**, including in terms of combustion related properties **challenging agricultural residues**.
- If such fuels are applied in combustion systems designed for wood fuels, they usually **cause operational and emission** related problems.
- Within the BIOFLEX! project, **guidelines for the adaptation of conventional state-of-the-art wood combustion technologies** to make them less sensitive regarding the application of such challenging fuels have been worked out.

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Challenging biomass fuels – relevant parameters and related problems

		Wood pellets – reference	Wheat straw pellets	Sunflower husk pellets	Grass pellets
Ash content	wt% d.b.	0.34	4.3	2.9	8.5
C	wt% d.b.	50.7	47.5	51.3	45.4
H	wt% d.b.	6.1	5.8	6.3	5.8
N	wt% d.b.	<0.1	0.44	0.65	2.50
S	mg/kg d.b.	52	717	1,490	2,260
Cl	mg/kg d.b.	64	2,090	383	3,600
Ca	mg/kg d.b.	811	2,860	3,810	7,560
Si	mg/kg d.b.	166	9,460	490	9,630
Mg	mg/kg d.b.	131.0	767	1,910	3,350
Na	mg/kg d.b.	15	42	6.4	369
K	mg/kg d.b.	414	8,450	7,450	21,200
P	mg/kg d.b.	55	638	752	3,610
Zn	mg/kg d.b.	9.0	6.8	14.5	28.1
Fuel indexes					
K+Na+Zn	mg/kg d.b.	438	8,499	7,471	21,597
(Si+P+K)/(Ca+Mg+Al)	mol/mol	0.7	5.3	1.3	2.8

Ash content ➔
- **high ash amounts (de-ashing)**
- **fly ash emissions**
- **deposit formation**

N ➔
- elevated NO_x emissions

S, Cl ➔
- HCl and SO_x emissions
- risks for low-temperature corrosion

K+Na+Zn ➔
- high potential for deposit formation and PM emissions

(Si+P+K)/(Ca+Mg+Al) ➔
- low ash melting temperatures ➔ slagging

Results of fuel analyses performed within BIOFLEX!
Compared with database values the samples are representative for the respective fuel assortment

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Concepts for enhanced fuel flexibility – general remarks

- **In most cases the high ash contents as well as the specific mixture of major ash forming elements (especially the contents of K, Si and Ca) cause significant operational problems**
  - **Slagging** on the grate disturbs the whole combustion process
  - Formation of **hard sintered or molten deposits** in furnaces reduce plant availability
  - **Deposit formation on heat exchangers surfaces** reduces thermal efficiency and plant availability
- **Consequently, controlling ash related problems forms the basis for fuel flexible operation**
- **Furthermore, issues related to increased NO_x, HCl, SO_x and particulate matter emissions need to be solved in a second step**
- **Small-scale and medium-scale combustion concepts typically differ significantly regarding furnace geometries and the plant concepts ➔ therefore, they have to be discussed separately**

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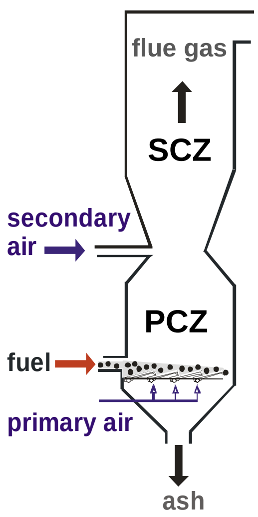
Advanced air staging – the basis for fuel flexibility (I)

- **Air staging is state-of-the-art in modern biomass combustion systems in all capacity ranges**
- **Boilers with air staging are characterized by**
  - two clearly separated combustion zones
    - primary combustion zone – PCZ
    - secondary combustion zone – SCZ
  - individually controlled combustion air supply into these zones with a primary air ratio of typically below 1.0.



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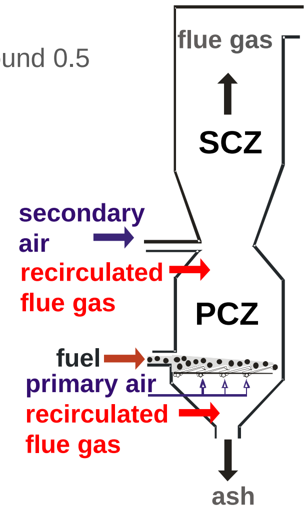
Advanced air staging – the basis for fuel flexibility (II)

- **Advanced air staging** **represents a further development of the air staging concept**
  - **Reduction of the primary air ratio** to values around 0.5
    - ➔ reduced fuel bed temperatures
      → reduced slagging
    - ➔ lower gas velocities at the fuel bed surface
      → less particle entrainment from the fuel bed with the flue gas
  - **Application of flue gas recirculation below and/or above the grate** as a second measure for temperature control in the fuel bed and the combustion zones
    - ➔ lower and controlled temperatures
      → less slagging on the grate
      → less formation of deposits on furnace walls
      → better mixing conditions in the PCZ



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Guidelines for small-scale systems (<500 kW$_{th}$)

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Measures to increase fuel flexibility in small-scale boilers – fuel feeding system

- **Fuel feeding system**
  - Must be adjusted to the energy density of the fuel
  - **Pelletised fuels:**
    common feeding systems from pellet boilers are applicable
  - **Chipped fuel from SRF (e.g. poplar):**
    common feeding systems from wood chip boilers are applicable
  - **Chopped agricultural fuels:**
    due to their low bulk density (and therefore energy density) common feeding systems are usually not suitable
    ➔ **recommendation:** use such fuels preferably in pelletised form

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Measures to increase fuel flexibility in small-scale boilers – grate concept and de-ashing (I)

- **Grate concept**
  - **Elevated ash contents: an ash layer** quickly forms on the grate which has to be continuously removed**.**
    - ➔The **grate area** has to be adjusted to the higher ash contents and to the longer residence time needed for a complete charcoal burnout
    - ➔**Moving grate systems** with continuous de-ashing are recommended
    - ➔Movements of the grate elements thereby **support breakage of sintered ash agglomerates**
    - ➔These measures support to **maintain an evenly distributed primary air supply** and to avoid channeling in the fuel bed

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Measures to increase fuel flexibility in small-scale boilers – grate concept and de-ashing (II)

- **De-ashing system**
  - **Pelletised fuels with high ash contents partly keep their shape during combustion**
    - → Ash pellets are formed → much higher volume than granular ashes
    - → Relevant regarding the design of the de-ashing system, the de-ashing screws and the ash bin
    - → With fuels with low ash melting temperatures: a certain formation of sintered and partly molten ash agglomerates must always be taken into account.
      → robust de-ashing screw designs are recommended

Measures to increase fuel flexibility in small-scale boilers – implementation of advanced air staging (I)

- **Furnace geometry**
  - **Two separated and well defined combustion zones**
  - **The zones must be geometrically separated**
    - dedicated zone with reducing atmosphere in the primary combustion zone shall be formed
    - relevant for low-NO_x-emission operation
  - **Recommended residence time in this reduction zone for efficient NO_x emission reduction:**
    - ideally ~1.0 s but
    - at least ~0.5 s
    - at flue gas temperatures above 800 to 900°C
  - **Backflow from the secondary into the primary combustion zone must be avoided**

Measures to increase fuel flexibility in small-scale boilers – implementation of advanced air staging (II)

- **Air ratios**
  - **Recommended air ratio in the fuel bed: around 0.7**
    - ➔ **At a given total excess air ratio (λ_{total}), the secondary air flow can be increased when low primary air ratios are applied**
      - ➔ better mixing of the combustion air and the flue gases
      - ➔ improved gas phase burnout
- **Flue gas recirculation**
  - **Flue gas recirculation into the primary combustion zone above the fuel bed is recommended**
    (aim: keep temperatures in the primary combustion zone at about 900°C)
    - ➔ The **fuel bed surface is cooled** due to less radiation from above
    - ➔ An **intensive mixing** of the gases released from the fuel bed can be achieved
    - ➔ The **formation of molten fly ash particles** which cause deposit build-up in the combustion chamber can be avoided due to the lower temperatures
    - ➔ The **temperatures** in the secondary combustion chamber can be reduced

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Measures to increase fuel flexibility in small-scale boilers – implementation of advanced air staging (III)

- **Minimisation of false air intake**
  - **An exact control of the combustion air flows is essential**
  - **False air is a disrupting factor since it represents an uncontrolled and not defined combustion air intake.**
  - **Sources for false air (which should be eliminated)**
    - not well sealed inspection openings of the furnace
    - fuel feeding system
      ➔ application of as air tight as possible rotary valves in the fuel supply line
    - de-ashing system
      ➔ improved sealing of ash containers and the ash discharge lines

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Measures to increase fuel flexibility in small-scale boilers – furnace cooling and boiler concept

- **Furnace cooling**
  - **The primary combustion chamber should be well insulated** (cooling by low primary air ratio and flue gas recirculation)
  - **Water cooled walls in the secondary combustion chamber must be designed considering the cooling effect of flue gas recirculation**
    - ➔Residence time at high temperatures (above 900 – 1000°C) must be long enough.
    - ➔Therefore, it is recommended to also insulate also a part of the secondary combustion chamber
- **Boiler design**
  - **Implement automated mechanical boiler cleaning devices**
  - **To avoid low-temperature corrosion, the return temperature shall be kept above 60 to 65°C (by an appropriate control)**

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Guidelines for medium-scale systems ($500\ kW_{th}$ – $10\ MW_{th}$)

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Measures to increase fuel flexibility in medium-scale boilers – fuel feeding system

- **Fuel feeding system**
  - **Screw feeding systems as well as hydraulic piston feeders are usually applied**
  - **Both systems are also applicable for fuel-flexible combustion systems**
  - **It is important to select and design the fuel feeding system with respect to the bulk flow properties of the fuel assortments under consideration**

    ➔ The fuel must be evenly distributed over the whole grate area at the entrance
  - **The fuel should not be compacted too much during fuel feeding to facilitate an even gas flow through the fuel bed**
    (compression by piston feeders can cause problems)

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Measures to increase fuel flexibility in medium-scale boilers – grate concept and de-ashing (I)

- **Grate concept**
  - **Only moving grate systems should be applied (no underfeed stokers)**
  - **Inclined moving grates are preferred**

    ➔ better mixing of the fuel bed

    ➔ sintered or partly molten ash agglomerates can be broken
  - **The grate area has to be adjusted to the moisture content and the ash content of the fuels (facilitate complete charcoal burnout).**
  - **Grates with more than two independently movable zones with separate primary air supply are preferred**

    ➔ Provide flexibility regarding different moisture contents, ash contents and bulk densities

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Measures to increase fuel flexibility in medium-scale boilers – grate concept and de-ashing (II)

- **Grate concept (continued)**
  - **Water cooled grates (at least with a cooled frame) can reduce problems with slag formation on the grate**
  - **Grate must be well sealed against the walls of the primary combustion zone ➔ air flows along the walls can lead to local temperature peaks and consequently to ash melting effects.**
  - **Use small grate bars in order to avoid large areas without primary air supply**
  - **Move the grate sections almost continuously to keep the charcoal and ash bed in motion**

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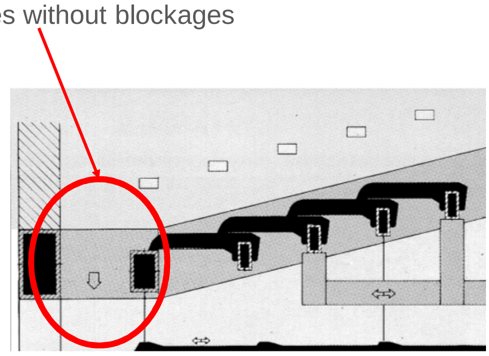
Measures to increase fuel flexibility in medium-scale boilers – grate concept and de-ashing (III)

- **De-Ashing**
  - **During the combustion of ash rich fuels larger partly sintered ash agglomerates may form**
  - **They may block the ash discharge opening at the end of the grate** ➔ This opening must be designed wide enough to also be able to discharge larger ash agglomerates without blockages
  - **The de-ashing screws resp. sliding bar conveyors should be robust to avoid problems in case of the occurrence of slag pieces**
  - **The de-ashing system and the de-ashing interval must be adjusted to the ash contents of the biomass fuels**



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Measures to increase fuel flexibility in medium-scale boilers – implementation of advanced air staging (I)

- **Furnace geometry**
  - **In principle, the same issues as for small-scale plants have to be considered**
- **Recommended air ratio in the fuel bed: around 0.5 – 0.6**
- **Flue gas recirculation**
  - **Flue gas recirculation below the grate and into the primary combustion zone above the fuel bed is recommended**
  - **Flue recirculation below the fuel bed**
    ➔ measure to cool the fuel bed
    ➔ avoid slag formation
    ➔ do not inject recirculated flue gas into the charcoal combustion zone
  - **Flue recirculation above the fuel bed** (into the primary combustion zone)
    ➔ temperature control in the furnace
    ➔ improves the mixing of the gases in the reduction zone and thus supports NO_x-reduction reactions

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Measures to increase fuel flexibility in medium-scale boilers – implementation of advanced air staging (II)

- **Minimisation of false air intake**
  - **Sources for false air (which should be eliminated)**
    ➔ not well sealed inspection openings of the furnace
    ➔ opening for fuel bed level controls (e.g. photoelectric sensors)
    ➔ fuel feeding system
    ➔ de-ashing system
  - **It is recommended to check the false air intake during the initial start-up phase. Proposed procedure:**
    – measure the primary and secondary air flows
    – calculate the total air flow based on a mass and energy balance using the load, the fuel moisture content, the NCV and the flue gas temperature and oxygen content of the flue gas at boiler outlet as input data
    – False air = calculated air demand – measured air demand
  - **False air flows detected should be considered when calculating the primary air ratios**
    ➔ the set values for the air supply control should be adjusted accordingly to include also the influence of false air

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Measures to increase fuel flexibility in medium-scale boilers – Boiler design (I)

- **Boiler design**
  - **Automated boiler cleaning systems based on pressurised air are recommended**
    - ➔ Should be foreseen in any case (increased ash contents and especially increased K-contents lead to increased fouling).
    - ➔ Should be operated more frequently than in wood combustion systems
    - ➔ Increased fouling should already be considered during boiler design.
- **High temperature corrosion**
  - **Hot water boilers: only limited risks regarding high temperature Cl-corrosion**
  - **Risks increase with increasing wall temperatures of the heat exchangers and therefore, corrosion risks have to be regarded for thermal oil boilers and especially for superheaters in steam boilers.**
  - **An efficient boiler cleaning system reduces the residence time of corrosive compounds on the boiler tube surfaces and thereby help to reduce corrosion related risks.**

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Measures to increase fuel flexibility in medium-scale boilers – Boiler design (II)

- **Low temperature corrosion**
  - **Especially relevant for S and Cl rich fuels**
  - **It is recommended to keep the gas-side boiler surface temperatures**
    - for dry fuels and flue gas water contents of up to 15 vol.%: above 70°C
    - for fuels with high moisture contents and consequently flue gas water contents of more than 20 vol.%: above 90°C.

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Measures to increase fuel flexibility in medium-scale boilers – Secondary emission control

- **Small-scale plants**
  - **Usually an electrostatic precipitator (ESP) must be foreseen to keep the dust emission limits**
- **Medium-scale plants**
  - **ESP or baghouse filter is needed in any case**
    - If no other measures for emission control must be implemented (e.g. dry sorption for HCl and/or SO_2 removal), the application of an **ESP** is recommended
    - In combination with dry sorption systems, **baghouse filters** shall be applied.
    - However, regarding the **majority of chemically untreated agricultural biomass** fuels, **no problems regarding limit values for SO_2 emissions** should occur
  - **For fuels with high N contents the implementation of advanced air staging concepts may not be sufficient to keep the NO_x emission limit values**
    ➔ In such cases a SNCR (selective non catalytic reduction) system must be implemented.

Conclusions and recommendations

- **Test runs within BIOFLEX have revealed that when considering the guidelines discussed also challenging fuels such as straw pellets and grass pellets can be utilised in appropriately adapted small and medium-scale furnaces and boilers.**
- **To optimally and efficiently implement the measures proposed, especially regarding the advanced air staging concept, CFD (computational fluid dynamics) simulations are strongly recommended**
  - **to analyse different options and approaches in order to optimally implement primary measures into combustion concepts**
  - **to analyse the effects of different design options without time consuming reconstructions of testing units**
  - **to contribute to a significantly faster and more target oriented solution process**
  - **to increase the success rate of a new development considerably**

Thank you for your attention

Project webpage: https://bioflex-eranet.eu/

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