FLUIDIZED BED COMBUSTION AS A RISK-RELATED TECHNOLOGY: A SCOPE

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Abstract The communication is addressed to risk-related problems of the fluidized bed combustion (FBC). The scope concerns three main areas:

- Combustion (incineration) of toxic and hazardous materials in fluidized beds
- Dust explosion hazard of various bulk materials in different handling facilities containing various fuels for FBC
- Operational hazard and common start-up failures in FBC
- Air-pollution and contamination of coal and bio mass fired fluidized bed combustors.

Keywords: Fluidized bed, combustion, wastes, risk, hazards

INTRODUCTION

The paper tries to define the well known and the potential risk-related spots of the FBC technology from the positions of the modern Safety-Related Engineering Approach in process design. The analysis is based on wide published materials from both the government legislation authorities and scientific research papers. The analysis of the FBC technologies from the point of view concerning the potential hazard and consequential risks is usually done in the restricted area of the operational problem of the FBC facilities Ehrlich (1995).

The analysis could spread on the entire chain of the combustion technology: fuel, fuel storage, fuel incineration, operational problems of the combustion device, gas and heavy metal emissions, ash disposal. This chain has three main elements:

- Fuel potential hazard in its natural existence.
- FBC operational hazards
  - Hazards related to the fuel storage and preparation.
  - Hazards inherent of the combustion process and furnace design.
- Hazards related to the residues of the combustion process: ash properties, disposals and emissions (gases and heavy metal).

The paper will comment these potential hazards and the risk related in accordance with the combustion consequence formulated above.

EVALUATING OF FBC HAZARDS

FUEL Potential Hazards

The FBC technologies have advantages with respect to other combustion technologies as incineration opportunities allowing co-fired of coal and various fuels most of them have biological natures. The hazard attributed to various biological fuels considered here is illustrated on Fig. 1. Generally, the principal fuel is the coal that is not dangerous in its natural disposal. Thus, the ability of the FB to burn fuels in the form of large particles (3mm - 5 cm) offers an opportunity of co-firing of mixtures of coal and various wastes. From a formal point of view the co-fired substances could be separated in two major groups:

- **Renewable fuels** based mainly on the agriculture residues and those based on the treatment of the wood. All of them could cause a danger upon certain conditions. Most important of them are the field fires and

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Fig. 1. Fuels for FBC and their Potential Hazards before the Combustion Process
the wood dust explosions. The residues of the pulp mills and paper making industry mainly in the form of a black liqueur and fibre sludge are in the focus of the FBC as fuels containing large amount of biomass and organic matter. Their disposals in the field or in the water could cause environmental contaminations and problems.

- **Wastes.** This common term concerns by-products of many process industries, communal, medical, military, agricultural fertilizers and sludge of different origin, shredded wastes. The schematic presentation of Fig.1 tries to address the attention on the potential hazards of these waste materials that could occur if a certain waste material could be out a control.

The common feature of all these fuels employed in a co-firing combustion is the ability to burn in a fluidized bed. Thus, the **risk-oriented position** of the FBC among the other existing technologies is the ability to incinerate a wide range of material being dangerous in uncontrolled disposals (Buron, 2000). In other words the FBC, despite the technical solutions and designs, has a great potential as a **risk-minimizing technology**. Some examples of procedures in FBC reducing the risks of the co-fired fuels are summarized in Table1.

**FLUIDIZED BED COMBUSTION - a scope of the potential hazards**

The Fluidized Bed Combustors have specific hazards that could be taken into account in the initial stage of the plant design as well as during the exploitation. Ehrlich (1995,1997) has discussed the major problem addressed to the safety design of FBC and the experience accumulated by US FBC plants has been incorporated in a series of developing NFPA’s standards (NFPA, 1989, 1993). The present scope is stressed on three major steps of FBC technology:

i) Fuel pre-treatment and fuel storage in the power plant

ii) Fuel supply into the furnace and the combustion process itself considered as an interaction between the hot solids and the entire auxilarities of the FB device.

iii) Emissions of the FB - both gases and ashes as well as FB wastes are disposed.

**Fuel pre-treatment and fuel storage in the power plant**

The fuel pre-treatment includes steps as drying (usually for sludges) (Linderoth, 1989; Kraft and Orender, 1993), size-reducing procedures, storage and mixing with adsorbent for SO$_2$ capture. Each of these steps may be related to special hazards such as:

- Explosions and self-ignition in the case of wood by-products treated and stored in large piles.
- Explosions under high pressure in supply devices of PFBC (Wilen et al., 1999; Wilen and Rautalin, 1999)
- Fire hazard in preliminary dryers of wood fuel (Bryers and Kramer, 1977)
- Fire and explosion of coal in thermal plant (Aparicio and Torrent, 1996).
- All types of dryers for preliminary dewatering of sludges produce vapour that can create an odour nuisance as well as to be pathogen for humans and animals.
- Obviously, the greater the temperature of the sludge dryers the more chance is of the dried sludge. In powder form the sludge will ignite at ~ 380-400oC, but weak exothermic reaction could occur at temperature less 100oC where the air content is between 25 to 125 g/m$^3$. Therefore, fire preventative measures must be implemented: low oxygen concentration (<9-12% v/v) or temperature wells < 100oC (Frost at al., 1990; Kiely, 1997).
- Other potentially hazardous substances of the sludges that are unaffected by the preliminary thermal dewatering are plastics and dioxins (Kiely, 1997).

**Combustion process**

**Operational hazard**

The coal combustion usually is carried out in a narrow temperature range of 815-899 °C. The bed is cooled by various techniques and immersed surfaces (Oka, 1994) keeping the bed temperature in that range thus
reducing the slagging, sintering and fouling if the hot particle bed. Moreover, the optimal temperature range allows lower emissions of NOx. The moderate combustion temperature and turbulence also provide and ideal environment for the combustion of various low-grade fuels and wood wastes, waste materials and high-grade coal. There are many diverse FBC designs for large and smaller units (Oka, 1994; Valk and Bijvoet, 1995; Verhoeff and Holtzer, 1995).

Most of FBC hazards are similar to those of suspension-fired boilers (Ehrlich, 1995, 1997). The specific hazards of FB technology have been commented by Ehrlich (1995, 1997):

- **Hot spills of solids.** The large FBC contains a large amount of hot solids fluidized in the furnace. The potential hazards are related to the furnace wall rupture or bottom ash-removal device failures. This requires the avoiding of the placement of critical components during the boiler design. Ehrlich (1995) mentioned of an accident with two killed maintenance workers when the hot solids of the dip leg suddenly flew into an empty but advanced furnace.

- **Lime burns.** The removal of the fuel’s sulphur requires limestone feed rate that exceed the stoichiometric ratio of calcium-to-sulphur (18kg/15kg=1:1) (Ehrlich, 1997). Higher ratios of 2:1 or more are not usual, since that causes ash rich of CaO, i.e. quicklime. The potential hazard of high temperatures generated when the quicklime rich ash contacts with water in an ash conditioner or during in-furnace maintaining operations.

- **Steam generation after trip.** The fluidized mass of hot particles can provide a sufficient sensible heat allowing a steam generation at near full capacity for a several minutes after the heat source loss if the fluidizing airflow continues. Thus, the loss of feedwater should lead to a fan trip as well as fuel trip (Ehrlich, 1997).

- **Operation at very high fuel-air ratios.** Since the FBC contain a large amount of hot solids it inherent combustion stability is undoubted. This permits operation as much as four times the normal fuel-to-air ratio. (Ehrlich, 1997) commented that in several cases the fuel accumulation in the bed led to rapid increase of the bed temperature. This may lead to sintering and slagging of particle and bed defluidization. Furnace explosion may occur also in fuel excess in the bed.

**Some additional operational hazards**

Problems causing combustor component failures exist due:

- **Particle sintering and agglomeration** (Grubor et al., 1999; Frost et al., 1990). If any softening takes place on the surface of either the mineral matter or the sorbent, then there is a risk of agglomeration and fouling. Agglomeration and fouling increase with increases in quantity of volatile alkali in the fuel. The factors that enhance agglomerate formation include local reducing conditions in the bed, high temperature (Frost at al., 1990), increased pressure and the presence of a fluxing agent.

- **Tube and membrane erosion and abrasion** (Maude, 1992; Leckner et al., 1985; Rademakers, 1995) in both ABB’s and AFB’s and recently developed CFBC’s.

  - During the early development of AFBC and PFBC concern was expressed over the ability of evaporators, superheaters/reheaters, air heaters and uncooled components where the metal temperatures are around, or in excess of 600°C corrosion was experienced with austenitic alloys with nickel contents. For higher temperatures, up to 900°C, high chromium ferritic alloys are most suitable. The thermodynamic approach (Rademakers, 1995) to identify the potential corrosion problems and resistant materials is limited, due the fact that in the different zones of the combustor reactions occur and there is no equilibrium. At lower temperatures, depending on many conditions at intermediate temperatures protective oxides can be formed. Under such conditions there is a competition between the oxidation and erosion (Rademakers, 1995) which can result in either erosion of the oxides or in wear of the tube metal.

  - In most recently developed CFBC’s the possibility of wear is greater due to the relatively high fluidizing velocity and the large particle size in the feedstock (Rademakers, 1995). In most CFBC’s the heat exchangers are placed in the convective gas passages. High gas velocities entraining particles can cause erosion of the first heat exchanger in the line (superheater) and the tube temperatures are sufficiently high to form protective oxides (Rademakers, 1995). The recent studies
have identified that the following components as being most at risk (Rademakers, 1995; EPRI/ANL, 1990).

- Particle fouling (Bryers and Kramer, 1977; Grubor et al., 1999) due to enhanced ash adhesion at surfaces.
- Fire-side corrosion and metal wastage of in-bed tubes and surfaces (Leckner and Hogberg, 1983; Johnson and Leckner, 1986; Rademakers, 1995; Verhoeff and Holtzer, 1995)
- Rapid corrosion of PFBC.
- Erosion of the coal feed system (rotary valves) due to the high-pressure difference between the mill and bunker outlet causing significant airflow (Verhoeff and Holtzer, 1995).
- Poor combustion of paper mill sludges due to high moisture content that results in reduced boiler efficiency and increasing emissions (Linderoth, 1989).
- Hot gases backflow through the feed system due to high pressure in the combustion chamber and ineffective feeding design.
- Incomplete combustion and odour formation in the case of sludge incineration (Frost et al., 1990) at low bed temperature.

Combustion maintenance

The combustion maintenance problems addressed to the potential risks are mainly related to the start-up procedures. The earlier lessons from the development of FBC technology are those of the bed initial temperature before the start-up of fuel supply into the furnace. Ehrlich (1997) gave an example of the initial bed heating with a charcoal ignited at ~330°C and kept the bed at ~500°C. However, when the operators were almost that the coal tested would ignite it would only devolatilize and cause problems. The accumulated volatiles would case a "puff" or a shake of the unit when would be ignited.

The hot start-up restarts provoked by equipment breakdowns causes problems (Ehrlich, 1995, 1997): 

- A critical experiment with a small amount of coal fed on the top of a slumped bed followed by a quick re-fluidization may lead to: 1) A smooth furnace restart if the combination of conditions such as bed temperature, bed mass and coal quantity are exactly right. 2) A unit "puff" and a six-meter flame shooting the access ports through which the coal is added.

- Unexpected events may occur if the control system fails. Two examples commented by Ehrlich (1995) are related to the CO accumulation in the furnace plenum (windbox) when the forced draft (FD) fan suddenly tripped, but the ID and secondary air fans continued to run for many minutes. The restart of the FD caused explosion in the windbox and the upstream ducts. The first accident occurred after a sudden defluidization of the hot bed, while in the second a large coal accumulation was discovered. In both cases the secondary fans causes an overpressure that put the gases generated inside the slumped bed toward the windbox and the air supply ducts. Ehrlich (1997) commented two possible explanations: The gases from the slumped bed contain CO which pushed into the windbox can explode if a CO/Air mixture of >12% CO is reached. Second, gas causing potential explosion is hydrogen as a coal gasification product. A H₂/Air mixture at > 4% explodes. In a stationary bed containing ~ 1% coal there are enough carbon and hydrogen to produce an explosive mixture. The ignition sources of both accidents are hot particles accumulated in the stationary bed. When the fan is turned on the re-fluidization starts in some parts of the bed that are thinnest. This cause fluidization instability dues the bubble appearance and particle back flow toward the air distributor. Thus downward pulse of a hot mass could drive hot particle into the adjaced windbox. The effect is known as “sifting”. The hot particles having some carbon present are adequate ignition source to start the explosion of the combustible gaseous mixture.

The hot restart problems provoked the acceptance of new start-up sequence for FBC plants. NFPA of USA has established a rigorous procedure including two step starting process considered by the NFPA's 8504 Committee appeared as a standard in August 1993 (NFPA, 1993). The start-up procedure (Ehrlich, 1995, 1997) concerns a purge procedure, like in the case of suspension-fired boilers, due to the existence of hot ignition sources in the unfluidized bed in the form of red hot limestone particle and carbon. The purge procedures must avoid the accumulation of an explosive fuel/air mixture above the bed that can contact with the ignition sources. It is consequence of two steps including the purging of the furnace space above the
slumped bed without any disturbance fluidization. The second step concerns a re-fluidization. If the average bed temperature is sufficiently high to ignite the fuel the main fuel flow may be supplied into the furnace directly, after a short outage. If the bed temperature is not enough to start the combustion, the purge should continue to clean the air supply ducts of any explosive mixture and then the bed re-heating by the warm-up burners must start.

### Table 1. Examples: Fuels and their potential hazards both in a natural state and in the preliminary treatment

<table>
<thead>
<tr>
<th>WASTE</th>
<th>Natural Hazard</th>
<th>Preliminary treatment</th>
<th>Co-firing fuel &amp; Inert bed</th>
<th>FB type</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper Mill Sludge</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary Clarifier Sludge</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wood barks</td>
<td>Fire</td>
<td>Drying</td>
<td>Fire</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paper Mill Sludge</td>
<td></td>
<td>Drying</td>
<td>Fire</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Toxic liquids (TNT)</td>
<td>Explosion</td>
<td>Drying</td>
<td>Explosion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biomass</td>
<td>Drying</td>
<td>Dust explosion; Flammability;</td>
<td>Total Inertization by Nitrogen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medical waste</td>
<td>Infections</td>
<td>Red bags arrangement</td>
<td>Infections</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bleach effluents from bleach-kraft mill</td>
<td>Chlorine release</td>
<td>Concentration</td>
<td>Chlorine release</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Exists as a potential operation

**FB Combustion by-products (gaseous and solids)**

**Emissions of gases** are attributes of all the combustion processes. Four main parameters affect the completeness of the combustion process and therefore the destruction of the waste (Buron, 2000): the temperature, the residence time in the furnace, the turbulence (air/waste) and the size of the waste particles. Despite the technical problems commented above, controversy surrounds the combustion of hazardous wastes burned in FBC units often contain toxic organic chemicals, heavy metals and chlorine, trace amounts of which may be released into the atmosphere in the form of emissions.

The limitation of emissions of SO$_2$ and NO$_x$ has been intensively investigated during the earlier years of research on FBC (Bramer, 1995) by adding limestone to the bed. In later years the efforts are focussed to reduce NO$_x$ in accordance with the acid rain problematic. The emission of of SO$_2$ and NO$_x$ are influenced of many parameters of the combustion process (Bramer, 1995):
Unstaged combustion (USC) of coal:

- **Bed temperature in unstaged combustion.** Optimal sulphur capture temperature is about 850 °C.
- **Freeboard temperature.** The experience of Twente University indicate that the NOx profiles in the freeboard zone are influenced of gas temperature and the type of cooling.
- **Limestone addition and limestone type.** The incomplete conversion of the limestone to CaSO₄ increases the limestone combustion but the Ca/S ratio > 2 leads to practically constant sulphur retention (~ 90 %).
- **Sorbent particle size.** The finer particles have approximately 10 % better sulphur retention compared to coarse limestone (data of TNO with Twente combustor and Carmeuse Engis limestone).
- **Coal type.** The calcium content in coal is very effective in reducing SO₂ emissions. For example a combustion of German brown coal with Ca₅/S = 2 reaches 90 % retention without adding limestone (Bramer, 1995).
- **Fly ash recycling.** This is relatively simple measure increasing the combustion efficiency of less reactive coals (Valk and Bijvoet, 1995).

Staged combustion (SC) of coal:

As the standards established after the middle of 1980's with respect the NOx emissions became more severe: NOx < 200 mg/nm³ (Bramer, 1995) the FBC's under oxidizing conditions are not capable to meet the requirements. The lower levels in FBC can be achieved by staged combustion. The experience of Twente University in the 4 MW combustor of TNO on staged combustion impact on SO₂ and NOx emissions focuses to the main process parameters:

- **Effect of the primary air ratio (PAR).** The lowering of the primary air ratio (Bramer, 1995) is an effective way to reduce NOx emissions (by 30 to 50 % when PAR decreased from 1.1 to 0.6). The freeboard temperature has relatively large effect on NOx emissions.
- **Effect of the bed temperature.** In contrast to USC the increase of the bed temperature and related to it freeboard temperature reduces the reactions forming NOx.
- **Bed material particle size.** The finer coal particles lower NOx emissions (Twente experiments at Ca/S = 1.5 , total air ratio = 1.2 and Tₜ=850 °C).

**Urea Injection.** The injection of reagents is the so-called secondary measure for reducing emission. Twente University experience (Bramer, 1995) shows that the emissions values of 200 mg/m³ is reached at molar ratio urea/NOx = 2. The freeboard of AFBC has appropriate reaction conditions for reduction of NOx by urea injection. The urea is as effective as ammonia used for the same purpose.

**Emissions- gases from Co-firings of bio fuels**

**Biomasses burned in FBC,** mainly woods and fibre sludges, contain a lot of nitrogen (Amand and Leckner). The waste burnt produces harmful substances that depend both on the combustion process, the fuel content of trace component such as nitrogen, sulphur and chlorine and the operating conditions of the furnace. Similar results have been obtained by sewage sludge incineration (Lewis and Haug, 1999). In both studies air-staging techniques, suggested initially for coal (Lyngfelt, 1998), have been applied to minimize the NOx emission hazard:

- Three (3) different air-staging cases tested for nitrogen emission minimization (Amand and Leckner) without limestone supply in an inert silica bed with excess air-ratio up to 1.23
- Reversed air-staging without secondary air injection in the combustion chamber and air-ratio of 1.05 (Lyngfelt, 1998)
- No air staging. All the air is introduced in the combustion chamber at air-ratio of 1.23
- Severe air staging with increased amount of air in the cyclone outlet at a combustor air-ratio of only 0.94.

Four (4) stage process (Lewis and Haug, 1999):

- **Stage 1:** Sub-stoichiometric fluidized bed operation at a nominal 30% stoichiometric air-ratio (SAR) in a bubbling sand bed.
- **Stage 2:** Sub-stoichiometric zone operating at nominal 80% SAR and a nominal residence time 2 seconds approximately.
- Stage 3: Stoichiometric zone operating at a nominal 100 % SAR and a nominal residence time 2-2.5 seconds to complete the gas phase reduction of NOx.
- Stage 4: Excess air zone (afterburner) operating at a nominal 135 % SAR to minimize CO and unburned hydrocarbons.

Both examples show that the more efficient combustion more efficient hazard minimization in the emissions.

Table 2. Troubles of the FB combustion and the consequent potential hazards (arranged by the present author) - Some examples

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Combustion Process</th>
<th>FB type and Safety Measures</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>Co-firing waste or Coal admixtures</td>
<td>Troubles related to:</td>
<td>Hazard</td>
</tr>
<tr>
<td>No</td>
<td>• Erosion &amp; abrasion</td>
<td>• Failure of cooling devices</td>
<td>All types except PFBC</td>
</tr>
<tr>
<td>Alkali Vanadium Low-melting Alumino-silicates Iron Calcium or Magnesium</td>
<td>• Fouling &amp; Corrosion</td>
<td>Cooling device failure • Uncontrolled bed temperature increase • Sintering &amp; Slagging</td>
<td>All types except PFBC</td>
</tr>
<tr>
<td>Fiber sludge with high moisture content</td>
<td>• Poor combustion • Lower combustion</td>
<td>• Increasing emissions</td>
<td>All types except PFBC</td>
</tr>
<tr>
<td>Fiber Sludge</td>
<td>• Release of fuel volatiles due to insufficient burnout</td>
<td>• High emissions of CO • High emissions of HCl and SO₂ • High levels of N₂ and NOx • High emissions of NH₃</td>
<td>CFB</td>
</tr>
<tr>
<td>Barks with high moisture content</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Toxic liquids (TNT)</td>
<td>• Fouling at the walls</td>
<td>• Sintering • Explosion of sintered waste</td>
<td>AFB</td>
</tr>
<tr>
<td>Effluents from bleach-kraft mill</td>
<td>• Fouling</td>
<td>• Stack emissions of HCl and chlorinated organic compounds</td>
<td>All types except PFBC</td>
</tr>
</tbody>
</table>
Emissions- gases from Co-firings of shredded wastes and sewage sludges

The "shredded" waste (Modigell et al., 1998) is mixture itself from vehicle utilization containing plastics and halogeneous hydrocarbons, ferrous - and non-ferrous metals and other inorganic metals. The shredded wastes as well as the sewage sludges are wastes with high contents of heavy metals and chlorine (Modigell et al., 1998). Because of low caloric values of these wastes the co-firing is usually performed

Heavy metal volatilization from shredded wastes and industrial sludges (e.g. Hg) usually condense in the cold parts of the flue gas cleaning equipment during the hot dust removal. The results of Modigell et al. (1998) shows that Cd and Hg completely evaporate during fluidized bed incineration and only ~ 12% of Pb remains solid. All the other heavy metals are solids under these conditions (850-870°C in the combustion chamber), only small amounts of Cu and Zn (<1%) are converted into the gaseous phases. Only slightly decrease in temperature of 20°C leads to capture of ~44% Pb in the cyclone. The specific conditions of shredded waste FB combustion cause volatilization of Cd, Hg and Pb in metallic or chloridic form, while Cu and Zn are most as chlorides with very low partial pressures, whereas the major fractions are solids as oxidic substances. Thus, two groups of heavy metal could be identified: volatile heavy metals (Cd, Pb and Hg) which partially condense in the cyclone and non-volatile heavy metals (Cr, Ni, Zn) and low-volatile Cu. The increase of the bed temperature (~890°C) (by additional input of fuel) improves Pb volatilization and the total Pb is converted in the gas phase. Generally, a significant heavy metal accumulation in the dust filter ash has been observed (Modigell et al., 1998). The cyclone operates as a second reaction chamber where the heavy metal adsorption on the dust particles (e.g. the solids residues).

Emissions- Solid residues of FB combustion

Ash is another by-product generated by the FB combustion. All the AFBC residues differ principally from solids residues of conventional pulverized coal combustion ash (Mulder et al., 1995), so called PCC ash. It is inert particulate material composed mainly by unburned carbon, salts and metals. It is usually collected at the bottom of the combustion chamber (bottom ash) and in the air pollution separators. Thus, the ash is often a hazardous waste (Buron, 2000). Moreover, as mentioned above, the overloading of limestone could lead to hazardous ash containing quicklime causing dangers. The removal causes problems and consequent hazards due to operational characteristics of:

- Baghouse problems:
  - Insufficient characteristics of the bag material (Lewis and Haug, 1999).
- Cyclone and cyclone ash system related to cyclones plugs due to low capacity (Nilsson and Anderson, 2001)- comments on Vartan PFBC plant near Stockholm.
- Poor cyclone operation resulting on enormously high dust loading to the gas turbine and erosion problems - Escatron PFBC plant (Spain) (Nilsson and Anderson, 2001)
- Hotgas ceramic filters ( tubular type) - Wakamatsu PFBC Plant (Japan) (Nilsson and Anderson, 2001)

The health problems of AFBC residues are related to the toxicological and genotoxicological properties of the fly ash (Mulder et al, 1995). According to Vink (1985) many of the organic compounds in the fly ash have been determined to be carcinogenic. They hardly present in the in fly ashes and in the stack ashes in low concentration only.

Heavy metals are components of wastes, which are very complex material systems containing a broad spectrum of noxious and toxic substances. An important intention in FBC technology is the inertization or separation of heavy metals in enable remaining ashes to be applied as building material (asphalt filers, sand-lime bricks, artificial gravel (Mulder et al., 1995) or applications in agricultural lands (Stout et al, 2001) (see below).

The environmental problems of the fly ash are mainly addressed to the contamination of surface and ground water (Mulder et al, 1995). Despite the increasing investigations on potential environmentally acceptable applications (see below) large quantities have to be disposed. The fly ash transport in a slurry form is technically preferable, but is environmentally less acceptable due the possibility to release toxic elements by the transport water.
The agricultural land disposals of some fly ashes are mainly related to disposals as fertilizers. The ashes as AFBC residue components should be divided in four groups (Stout et al, 2001):

- **Lime** (e.g. quicklime) that is mainly a mixture of CaO and MgO. This is a highly caustic material that can severely damage unprotected skin, lungs and eyes when exposed to water due to resulting exothermic reaction.
- **Essential plant nutrients** are those containing Ca, S, Mg, K and P. The metals as Fe, Mn, Mo, B, Cu and Zn are micronutrients existing in the ashes as oxides. This group does not cause hazards.
- **Heavy metals**. They exist probably as oxides. They are of concern, especially Cd, since they cause serious metabolic problems in animals and humans when they accumulated in the food chain. Compared to the sewage sludge AFBC residues contain very low levels of heavy metals. The oxide form of heavy metal in AFBC residues renders them much less available to plant than the organic forms in sewage sludge. Thus, the ash immobilization of the heavy metals reduces the risk and there is no hazard to animals consuming the plants.
- **Phytotoxic elements**. Levels of Al in AFBC residues are slightly less than those existing in soils. Aluminium can be phytotoxic when it is solubilized at low pH (< 5.0). However, Al toxicity is easy corrected by liming, so it is minor hazardous concern of AFBC residues.

In addition to potential hazards to human, AFBC residues can be extremely corrosive to application agriculture equipment (Stout et al, 2001).

**CONCLUSIONS**

The risk-oriented concept in FBC description developed here collects well-known facts available in the literature. The point of view tries to stress the attention on all the stages of FB combustion technologies that can cause potential hazards and risk. All the steps from the fuel preparation through the combustion process up to the ash disposal can create hazards. In most of the cases the risk minimization is incorporated in the particular combustion technology (e.g. sorbent injection and staging combustion for examples), while in the other situations there are inherent hazards such as dust explosion, metal wastage and consequent system element failures, toxicity of the ash, etc.

The attempt of the present author is not oriented only toward a complete collection and description of the risk-related elements of FBC. More important solution that needs the efforts of many experts is the evaluation and weighting of the safety problems in FBC subsystems and entire plants. I think that this a challenging direction for further investigations.

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