IS THE FUTURE OF BFBC TECHNOLOGY IN DISTRIBUTIVE POWER GENERATION?

by

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Last ten years the attention of the research and development efforts in developed countries has been moved from bubbling FBC to circulating FBC. Low prices of the liquid fuel and gas and more stringent emission standards make burning of coal in bubbling FBC boilers and furnaces non competitive compared to the boilers burning liquid fuels or natural gas in the range of unit power from small to medium. As the only market for FBC boilers rests the electric power generation in large utility boilers.
The situation in undeveloped countries is different. There is still need for use of the local fuels (coal, biomass, wastes) in order to substitute expensive imported liquid fuels or natural gas, especially in the field of energy generation in industry and district heating. At the same time, distributive energy generation become more and more interesting, and is mainly based on local and low quality fuels. Unit sizes suitable for distributive energy generation range from 0.5 MW_{th} up to 500 MW_{th}.
BFBC boilers and furnaces are economically acceptable in this power range. In BFBC boilers and furnaces is possible to burn, at the same time or alternatively, fuels of different origin and quality, biomass of different type and industrial and municipal wastes. In addition, boiler manufacturers in undeveloped countries can produce BFBC boilers and furnaces, independently or based on cooperation with the world known licensers of the FBC technology. According to the author's opinion, BFBC technology is the best solution for distributive energy generation.

Modern trends in energy production

Key principles in national energy policies

In spite of many differences in the natural resources and structure of energy systems in different countries, from the 1st World energy crisis, some common principles

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of the national energy policies were formulated [1]. In the majority of countries (especially in developed countries) those principles were put in the basis of the strategy of energy system development:

(1) Independence on the import of energy or fuels is the main aim of every energy policy. This means: optimum fuel mix, diversity of fuels suppliers, optimal use of domestic energy resources, maximal use of renewable energy resources, use of unconventional fuels. Such orientation at the same time means use of low quality coals (high sulphur, high ash, and high moisture), coal washery and separation rejects, use of biomass, and industrial and municipal wastes.

(2) Development and use of clean combustion technologies. Modern combustion technologies have to satisfy several severe requirements, coming mainly from the use of low quality coals, and unconventional fuels, as well as from the use of renewable energy recourses. Energy technologies have to be: highly efficient (combustion efficiency >99%, boiler efficiency >85%), with high fuel flexibility (burning at the same time or consecutively different fuels), wide range of load following (1:5) and low emissions (SO_2 < 200 ppm, NO_x < 200 ppm). Coal flexibility has to encounter – coal, biomass and industrial and municipal waste.

(3) Protection of environment becomes one of the main issues in energy production. New technology has to be ecologically acceptable using any of the mentioned fuel. Emission standards are every day more and more stringent. Conventional emission standards for particles, CO, SO_2 and NO_x, are now spread on CO_2, and many new gases responsible for global warming and climate changes.

(4) Energy efficiency and energy savings become one of the largest energy resources. Specific energy consumption per unit production is one of the main criteria for modern industry. Sustainable energy development becomes most important in the savings of natural resources of every nation, in ecology protection and, presently main method for diminishing of CO_2 emission. These criteria also stimulate use of renewable energy resources, use of biomass and wastes.

Distributive power production

Power generation will be faced in 21st century with three challenges: growth of population, poverty and deterioration of environment. To supply energy for 9–10 billions of people till 2050, it will be necessary to produce minimum 1000 kWh per year and per person of electricity. That means every two days one power plant of 1000 MW.

One of the recent methods to cope with these challenges is use of alternative and renewable energy recourses in distributive energy production [2]. Distributive energy production (both electric energy and heat) is local production in small units, adapted to the local energy needs and conditions. Presently, electric energy production is centralized in large systems. Modern trends are to transform such systems in a network of small, distributed units. This concept, already used, for a long time, for heat energy production, is now spread to electric energy production, too.

Distributive power production has the following advantages:

- Power plant or district heating plant can be situated close to the final energy consumer with lower power losses in transfer and distribution,
- It is easier to find suitable location for small units,
- Design and construction need shorter time,
- Energy can be accumulated (in form of fuel) and used in the period of pick load,
- New technologies can be used more easily and more economically,
- New technologies used are ecologically more acceptable, and
- Distributive, small units are oriented to the local fuels, different fuels, giving higher fuel flexibility and smaller expenses for fuel transport.

Distributive power production is also more suitable for consumers:

- They will have energy with higher availability and of the better quality,
- Depending on the fuel used, energy prices are generally lower,
- Small local units can be switched on according to the needs of consumers, and overload can be avoided, and
- It is easier to implement co-generation of electric and heat energy, and to increase overall efficiency of the energy transformations.

Distributive power generation is a new method for energy supply, enabling smaller investment costs, smaller energy prices and more secure energy supply. Using new technologies and renewable energy resources the impact on the environment can be smaller. Modern communication technologies can integrate large number of units in one ”large” power plant. There is no more need for long power lines and energy losses during transport are smaller, and supply more secure, and less sensible on weather changes.

Specific features of the distributive power generation are:

✧ **Modular arrangement**. It is possible to add or to switch of units in operation, and easy satisfy power needs.
✧ **Short construction time.** Small units can be planned, located and erected faster that large ones. The risk to miss requested consumption or to prolong previewed construction period is smaller.
✧ **Fuel diversity**. Fuel diversity and use of renewable energy recourses offer smaller risk in prediction of the fuel costs, and will assure stable fuel costs.
✧ **Following of the changes in energy needs**. Small units enable adding of the necessary number of units in order to follow change energy consumption.
✧ **Reliability and availability**. Large number of small units is more reliable than small number of large units, probability of forced shut-up is smaller, and time-out of the units is smaller.
✧ **Distributive energy production avoids need for long supply lines, and diminishes energy losses in transport and distribution.**
✧ **Choice and control is on the local level**. Small power units can be chosen by local authorities, which are in position to suit number of units and power of units to the local energy recourses and local consumption.
✧ **Smaller emissions.** Small units can be so chosen to have smaller impact on the environment, smaller emissions and can be better controlled by local authorities.

Distributive power generation can have several disadvantages:

- Companies are pushed to spend their own money for investment in power units,
- Administrative procedure for obtaining right to exploit natural recourses can be complicated,
- Consumers will not have right to return money in the case of interruption of energy supply,
- Positive influence of large system on supply security will be lost,
- Costs for ensure reserve of power or help that can be obtained from large system can be large,
- Connection of the local power units with large energy system can be influenced by monopolistic behavior of the large system, and
- Standards posed by government in emission control can be unfair for small units.

Spreading of the distributive power production depends on the overcoming of the mentioned disadvantages.

Local fuels and choice of technologies

On of the main advantages of the distributive power production is the possibility to use local fuels. There are plenty of local fuels or local energy recourses, which cannot be used due to the large transportation costs. The only possibility to use such energy recourses is to use them on site, for local energy needs. If in this discussion we skip of solar energy, wind energy, small hydro turbines and gas combustion (due to the different reasons), the local fuels, which are generally available, are:

- Coal from small mines, which is not possible to transport on large distances due to the large transportation costs,
- Often large quantity of the coal rejects from coal separation plants stocked in the past, are available on stocks,
- Biomass of different origin and characteristics, and
- Industrial and municipal waste.

The mentioned local fuels have the following characteristics:

- Local coals are generally low quality coals (high ash, high moisture, high sulphur), available for burning as mined, without prior separation, washing and size classification,
- Ash content can be up to 70%, water content up to 60%, and sulphur up to 10%, particle size from fines (rests after coal washing) to several hundreds of millimeters,
- Mainly coal particle size is less that 15 mm,
- Biomass is mainly waste from forestry, wood production or processing, agriculture wastes, fruit trees cutting, waste from food production, wastes from paper and pulp industry, with high moisture content, unsuitable particle shape and different in particle size, and
- Industrial waste can be very different in size and characteristics also, with emission of different harmful gases during combustion.

Those fuels pose the specific requirements to the combustion technologies 3 :

- Efficient combustion of coal, biomass and industrial and municipal waste,

- Burning of fuel as received or as mined, without costly preparation, high ash, high moisture,
- High combustion efficiency in spite of the unsuitable fuel characteristics,
- High combustion efficiency in the unit power range from 0.5 MW_{th} to 100 MW_{th},
- High fuel flexibility due to the very different and changeable fuel characteristics (ahs and moisture content, different particle size and shape,
- Possible high SO_2 emission,
- Possibility to burn different fuels at the same time or one after another, and
- Wide range of load following.

For heat or combined heat and electricity generation, there are three possible combustion technologies: grate combustion boilers, pulverized coal combustion boilers and fluidized bed combustion boilers. Grate combustion boilers can burn only high rank colas, with particle size more than 25 mm, without fines. For low SO_2 and NO_x emissions, post-cleaning equipments are necessary, making those boilers extremely expensive. Pulverized coal combustion boilers are economic only for medium and large unit power. Those boilers also need post flue gas cleaning in order to cope modern emission standards for SO_2 and NO_x. The only technology, which can satisfy mentioned requirements coming from the characteristics of local, low quality fuels is fluidized bed combustion.

Bubbling fluidized bed combustion: history and future

A brief survey of FBC boiler units commissioned in the last several years, can reveal the tendency that in developed countries, number of bubbling FBC boiler is in slow increase, while the number of circulating FBC boilers grew up sharply 4, 5 . R&D and demonstration programs are also devoted mainly to the processes in circulating FBC boilers 6, 7 . Some reasons are quoted below:

(a) Oil and gas prices were low on the world market in that period,

(b) In developed countries, the tendency is accepted to use gas in small and medium size units (<MW_{th}), due to the low prices and small environmental impact,

(c) The only market for coal burning boilers in developed countries is still utility electrical energy production, in boiler units, larger than 200 MW_e,

(d) Introduction of IGCC processes, and combined cycles need large capacity boilers and gasificators, and

(e) In developed countries, emission standards are more and more stringent, with the tendency to diminish CO_2 emission also.

It is than logical, that much attention in R&D and demonstration programs was paid to the development of CFBC boilers, and that majority of FBC boilers commissioned in last years were with circulating fluidized bed.

Recent attention paid to the distributive power production, returned interest to the bubbling fluidized bed combustion, both for boilers, furnaces and incinerators.

Besides indisputable advantages of CFBC boilers, comparing with bubbling fluidized bed combustion (BFBC) boilers, especially for large boiler units, in distributive power production smaller units are necessary, so interest for bubbling bed boilers and incinerators is again recovered.

It can be stated, that BFBC boilers have still, and will have in the future also, significant role in distributive energy production. In countries in which economic situation is difficult and structure of primary energy resources are limited, there is need to use local fuels, in spite of the advantages of gas burning. That means, that the use of coal, biomass and wastes is necessary instead of imported gas and liquid fuels, BFBC boilers and hot-gas generators, again will obtain significant role in energy production, in industry, agriculture and for district heating. At the same time, those countries have no now, and will not have in the near future, extremely strong emission standards, according to their economic power 8 .

In developed countries also, BFBC boilers and hot-gas generators are more and more used for energy production in industry, agriculture and for district heating when burning industrial and municipal wastes, mainly for incineration, but also for energy production 9 . The market for BFBC boilers and hot-gas generators can be defined as follows:

- for heat energy production in agriculture and food industry,
- for heat and electrical energy production in industry,
- for district heating, mainly in towns near small coal mines,
- for biomass combustion,
- for combustion of low rank coals, coal wastes, washery and separation rejects, and
- for incineration of industrial and municipal wastes.

It can be concluded, that bubbling FBC technology is the best solution for distributive power production, having in mind range of unit power most often present in distributive power production, requirements of the modern energy production and characteristics of local fuels. The characteristics of the bubbling FBC advocating for this technology compared with conventional one are [8, 10]:

- Efficient, economic and ecologically acceptable burning of low quality coals, biomass, industrial and municipal wastes, and other unconventional fuels,
- Combustion of different fuels without costly preparation, in as mined or as received form,
- Combustion of fuels with particle size 0–50 mm,
- Combustion of fuels with large content of ash and moisture,
- Combustion efficiency more that 99%,
- Boiler efficiency more that 85%,
- Large fuel flexibility, possibility to burn at the same time or consecutively fuels of different origin and quality,
- Inherent desulphurization by the limestone added to the furnace, desulphurization degree more than 90%,
- Efficient ignition and combustion of low reactive fuels (coke, anthracite),
- Small and medium size units (0,5 to 500 MW_{th}) are competitive to the other combustion technologies, including CFBC,

- Wide range of load following, up to the 1:5,
- Small and medium size units in wide range of load change can satisfy emission standards (<200 ppm for SO_2 and NO_x and 2 mg/m^3 for particles), and
- It can be concluded, that the future of bubbling FBC boilers and furnaces is in distributive energy production, both for electricity and heat production, in industry, agriculture and district heating using local fuels.

Some examples of BFBC boilers and furnaces in exploitation showing

Number of small and medium size BFBC units is so large, that it is impossible to give exact statistical data. Several examples of the BFBC boilers, furnaces or incinerators given below, is the best way to present diversity of fuels and fields of application of this technology.

Case 1 – Repowering of pulverized coal combustion boilers [11]

In paper manufacturer Metsa Serla in Finland, PC boiler, generating 93 MW of heat, producing steam 33 kg/s at 535 °C, was burning peat with 50% of moisture content, previously dried and milled (Fig. 1, left). The boiler could not burn sludge, and only small amount of bark. Plant suffered from high NO_x emissions (200–300 mg/MJ) and high losses with unburned carbon in fly ash. Conversion to BFBC was done by Foster Wheeler (Fig. 1, right). The power was increased to 113 MW, efficiency was increased, and flue gas and unburned carbon losses decreased. The NO_x levels were reduced to 100–150 mg/MJ. The peat needs not to be dried and milled, and sludge can be burned with 60–70% of moisture. The bark and all other wastes produced by the paper plant could be burned, mixed or one at a time. The plant refurbishment took five weeks.

Case 2 – Cogeneration plant burning biomass [12

Vastermalmsverket is the main production plant in the system of district heating in town Falun, Sweden, and was put in operation in 1994 by Foster Wheeler (former Ahlstrom Termoflow) (Fig. 2a). This is cogeneration plant, with 9 MWe and 30 MW of heat output. Steam data: 10,2 kg/s, 6.3 MPa, and 510 °C. Till October 1996 the boiler was 18 000 h in operation (Fig. 2b). Fuel burned is the mixture of waste from forest cutting (50%), chip (10%), saw dust (15%) and bark (25%). Moisture content in the fuel is 45–50%. Design emissions: dust < 25 mg/Nm^3, CO < 200 mg/MJ, NO_x< 100 mg/MJ. Real emissions: dust < 5 mg/Nm^3, CO < 200 mg/MJ, No_x < 50 mg/MJ. With addition of NH_3, N_2O emission is less than 8 mg/MJ.

Case 3 – Cogeneration large scale demonstration plant in pulp and paper mill [13]

Cogeneration plant Ontario, Canada, was built in 1994, with 14 MW_e of electric power and process steam (Fig. 3). Steam parameters: 65.5 MPa, 482 °C. Design fuel is 95% of wood waste and 5% of sludge. Average moisture of fuel is 50–60%. Boiler uses

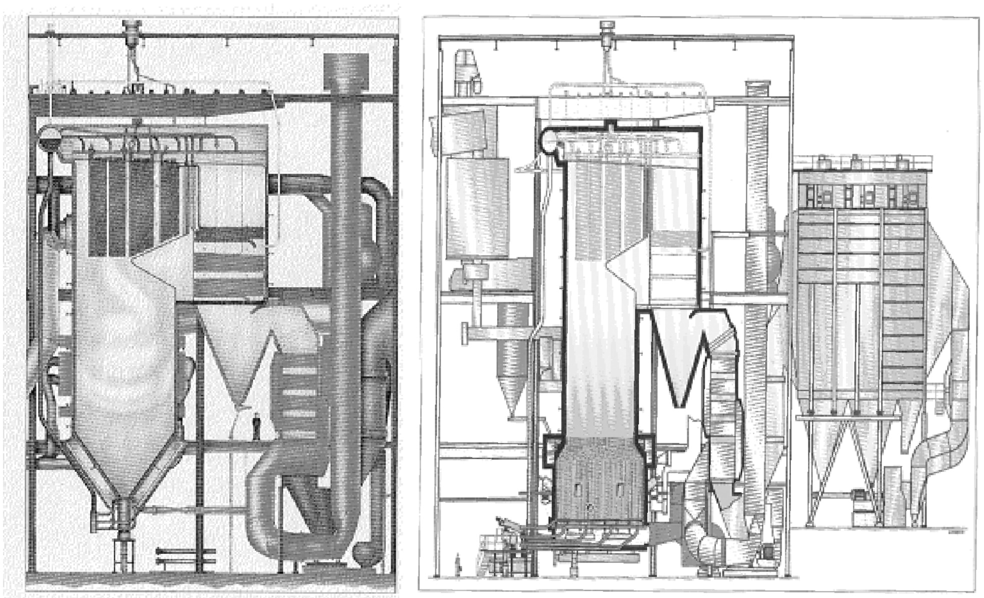

Figure 1. Left – Old arrangement of the Mesta Serla's Simplete plant, pulverized coal combustion; Right – The new arrangement with bubbling fluidized bed combustion 11

the improved bubbling bed combustion process by introduction of internal bed circulation using un-even fluidization velocity distribution.

Case 4 – BFBC boiler for burning washery rejects and waste-char in sponge iron plant 14]

Bharat Heavy Electricals Ltd., India, commissioned in 1995 a 100 t/h bubbling FBC steam boiler, to burn kiln char, washery rejects and fly ash, with maximum 60% ash content, and calorific value 8.3 MJ/kg. Steam parameters are 100 t/h, 35 MPa, and 430 °C. Bed cross section 50 m^2. During operation different fuels were tested successfully: coal fines (17.0 MJ/kg), char (16.0 MJ/kg). Fuel was pneumatically fed under the bed surface. General view of the boiler is given on Fig. 4.

Case 5 – Sewage sludge incineration plant with BFBC boiler [15]

Incineration plant in Dodrecht, Holland, was commissioned in 1993 burning 10–12 t/h of row sludge, with combustible dry matter 16–20% and ash content 35% (Fig. 5). Natural gas is used as additional fuel to balance insufficient heating value of the sludge. Boiler capacity is 7.5 MW_{th}, bed area 7.5 m^2, and bed height 3 m. NO_x in flue gas is less that 200 ppm, and post treatment is used to eliminate SO_2, HCL and Hg.

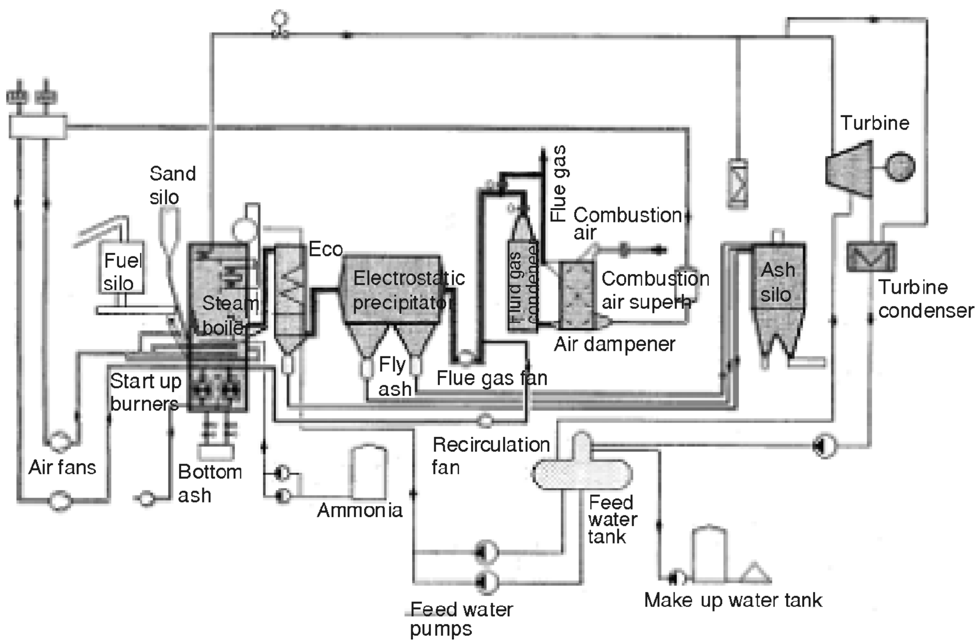

Figure 2(a). Process diagram of the cogeneration plant burning biomass, Vastermalmsverket, Sweden [12]

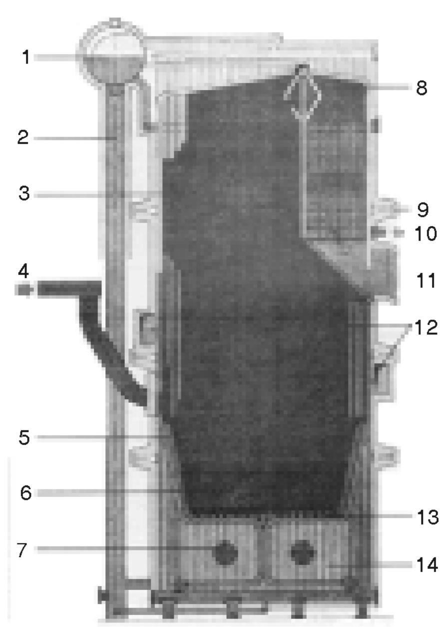

Figure 2(b). Cross section of the boiler unit at cogeneration plant burning biomass, Vastermalmsverket, Sweden 12
1– steam drum, 2 – downcommers, 3 – furnace, 4 – solid fuel, 5 – refractory lining, 6 – fluidized bed, 7 – start-up burners, 8 – plenum, 9 – buckstays and tie bars, 10 – inlet water, 11 – flue gases, outlet, 12 – secondary air, 13 – bubble-caps, 14 – ait inlet

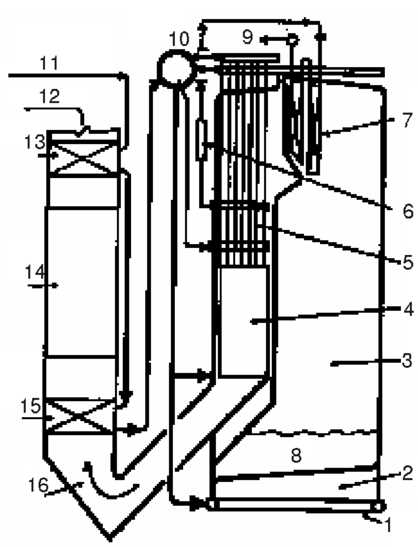

Figure 3. Shematic of the internally circulating bubbling bed boiler in pulp and paper mill, Ontario, Canada 13
1 – waterwall header, 2 – air plenum, 3 – furnace, 4 – evaporator, 5 – low temperature super heater, 6 – desuperheater, 7 – high temperature super heater, 8 – fluidized bed, 9 – steam outlet, 10 – drum, 11 – feedwater, 12 – flue gases outlet, 13 – economizer, 14 – air heater, 15 – economizer, 16 – flue gases

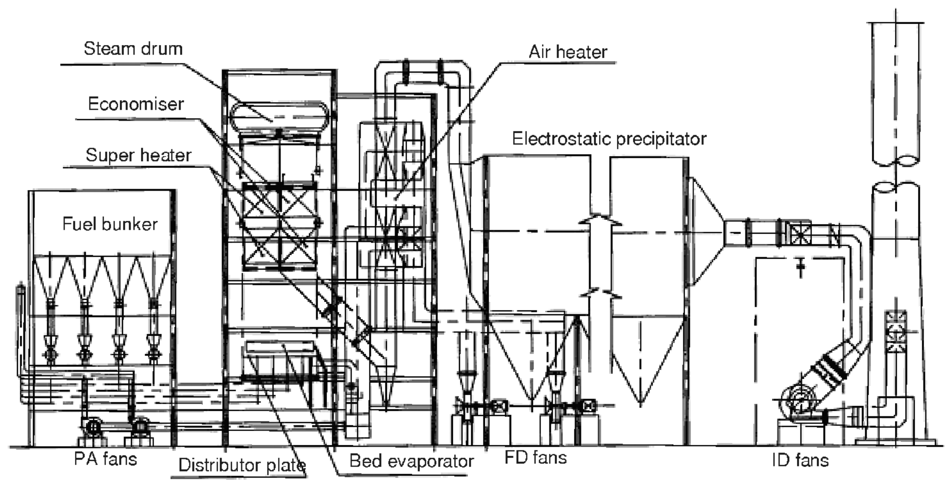

Figure 4. 100 t/h bubbling FBC boiler burning washery rejects, waste-char, coal fines and fly ash 14

– Waste-to-energy BFBC system burning RDF (refuse derived fuel) [16]

In mid-1999 in the City of Ravenna, Italy, a fluid bed boiler/waste-to-energy system was started-up to combust approximately 50,000 tones per year of processed municipal waste and to generate approximately 7 MW_e (Fig. 6). The fuel mixture is comprised of two waste streams, refuse derived fuel (RDF) and RSA, a source-specific

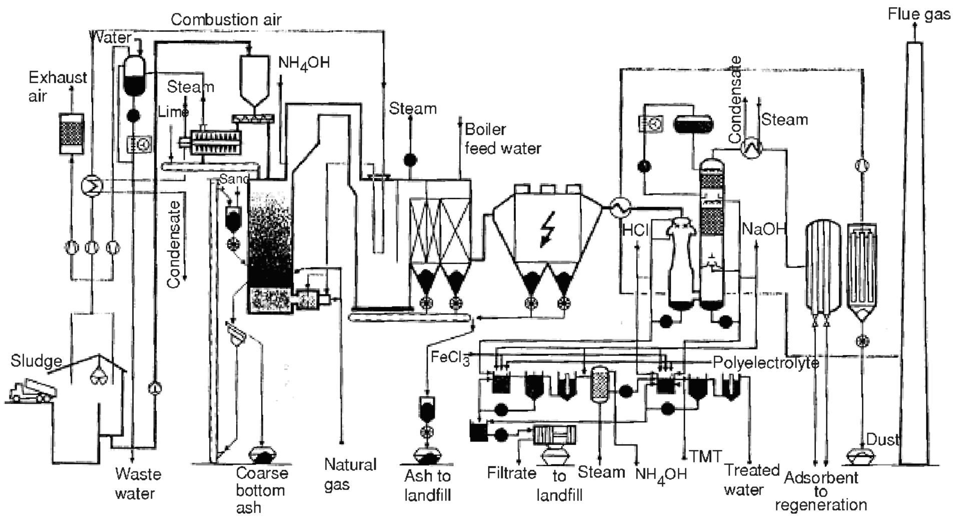

Figure 5. Sewage sludge incineration plant with BFBC boiler in Dodrecht, Holland [15]

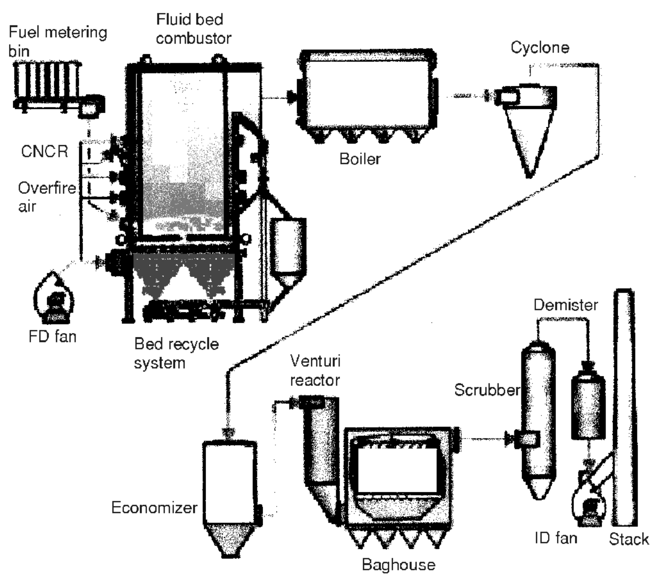

Figure 6. Waste-to-energy BFBC system burning RDF (refuse derived fuel) in Ravena, Italy [16]

waste stream composed primarily of cardboard, paper, wood and plastic. Fuel characteristics are: ash 20%, moisture 15–25%, heating value 14.5–16.7 MJ/kg, the particle size is less than 10 mm in any dimension, with 90 percent below 7.5 mm, but not more than 10 percent below 0.5 mm. The material is substantially free of metal content, especially metal wire of any size. The processing of the waste incorporates material shredding to size, followed by magnetic separation. The combustor is also designed to receive up to 10 percent of the furnace energy input as 5 kg boxes of contaminated medical wastes. Steam parameters: flow rate 20–25 t/h, 41 MPa and 380 °C.

The required emission levels were obtained by additional ammonia addition, and wet scrubbing: particles < 10 mg/Nm^3, $SO_x < 100$ ppm, $NO_x < 200$ ppm, HCl < 10 ppm, HF + HBr < 2 ppm, HCN < 0.5 ppm, PCB + PCN + PCT < 0.1 ppm, CO < 50 ppm, PAH < 0.1 ppm, total metals < 0.6 ppm, As, Cr, Co < 0.5 ppm.

Case 7 – BFBC boiler in MacMillan Bloedel's Powell River mill [17]

In 1996, Foster Wheeler Pyropower Inc. supplied a bubbling fluidized bed boiler to MacMillan Bloedel's Powell River mill (Fig. 7). The boiler has 73.7 kg/s steam flow rate, 6.205 MPa and 477 °C. It is the largest biomass fired bubbling fluidized bed boiler in North America. The BFB boiler is designed to fire a fuel mixture of bark, primary and secondary mill effluent sledges. In addition to high moisture content and a low heating value, the fuel is also contaminated with sea salt. This makes problem of bed material agglomeration difficult. Fuel characteristics are: moisture 23–30%, ash 2.5–16%, heating value 14 MJ/kg, alkali content in ash 10–15% (Na_2O + K_2O), or Na equivalent 0.3–0.5% in fuel. For solving bed agglomeration problem due to the high alkali content, it was recommended: (1) Select a bed material that resists the formation of low-melting-point compounds; (2) Avoid excessively high combustor temperatures; (3) Achieve stable and uniform fluidization and mixing in the bed; (4) Drain and

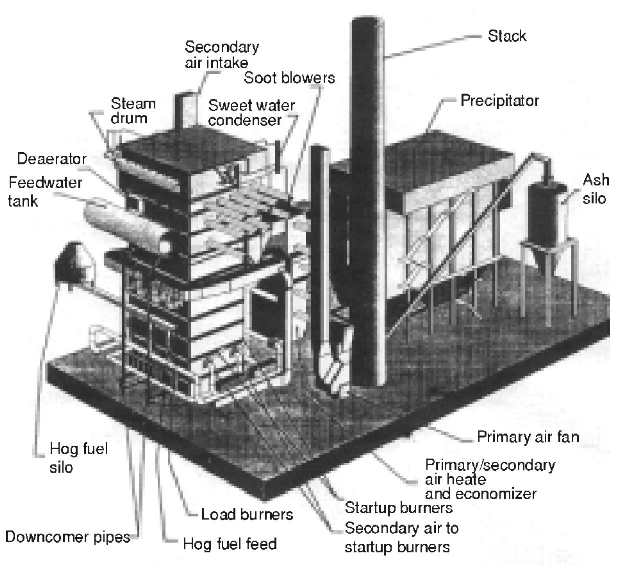

Figure 7. BFBC boiler in MacMillan Bloedel's Powell River mill burning bark and paper mill sludge [17]

replenish bed material at a sufficient rate to control alkali accumulation. Emissions from the boiler are: No_x < 150 mg/m^3, CO < 130 mg/Sm^3, particles < 3.9 mg/Sm^3.

Case 8 – Flow sheet sewage sludge incineration plant Höchst AG [18]

Single stage incineration plant in Höchst AG, Griesheim, Germany, burning sewage sludge of the industrial dewatering by membrane filter presses with average composition: water 57%, inorganic 20%, organic matter 23%, was built based on the technology developed by TU Hamburg Harburg (Fig. 8).

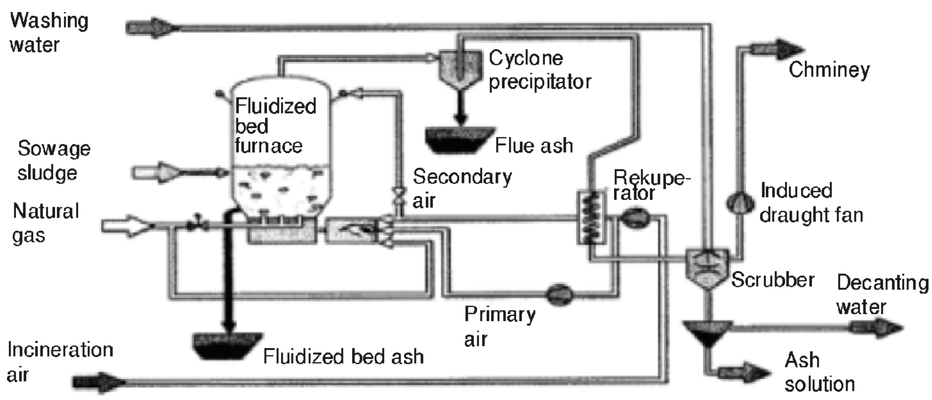

Figure 8. Flow sheet sewage sludge incineration plant Höchst AG, Griesheim (cross sectional area 8 m^2) 18

Case 9 – Industrial sewage sludge incineration plant [18]

In order to reduce NO_x emissions two-stage combustion plant was developed by TU Hamburg Harburg. The first industrial two-stage combustion bubbling FBC incinerator was erected in "Höchst Industrial Park", Frankfurt. The sewage sludge comes from the "Höchst Industrial Park" biological wastewater treatment plant (capacity 50,000 m^3/d). The sludge composition has a wide range; for example, the calorific value lies between 500 and 7000 kJ/kg (relative to original substance). The average composition is similar as in previous case: water 57%, inorganic 20%, organic matter 23%. The industrial sludge incineration plant is a twin-line fluidized bed firing plant, each line consisting of a stationary fluidized bed furnace with two-stage combustion, a heat recovery boiler, an electrostatic precipitator and a two-stage wet scrubber (Fig. 9). Each line has an incineration capacity of 10.4 t/h.

The flue gases issuing from the fluidized bed furnace (about 50,000 m^3/h) are cooled from about 900 °C to 200 °C in a heat recovery boiler. In this operation a steam volume of 20 t/h with a pressure of 16 bar is produced. The steam is used as a heat medium in other industrial plants at the site.

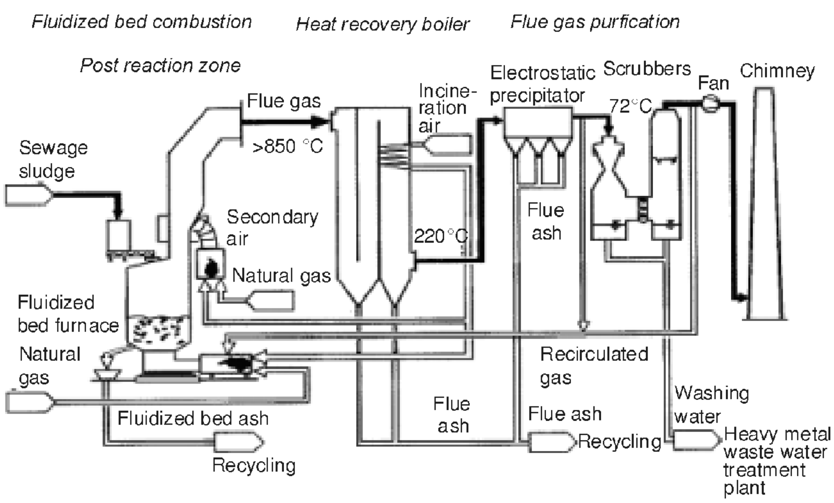

Figure 9. Flow sheet sewage sludge incineration plant "Höchst Industrial Park" (cross sectional area of fluidized bed furnace 16 m²) 18

Particles emission is less than 30 mg/m³. Two-stage wet cleaning follows the electrostatic precipitation process. The first stage is the ventury scrubber, where hydrogen chloride, hydrogen fluoride ash and heavy metals, especially mercury and

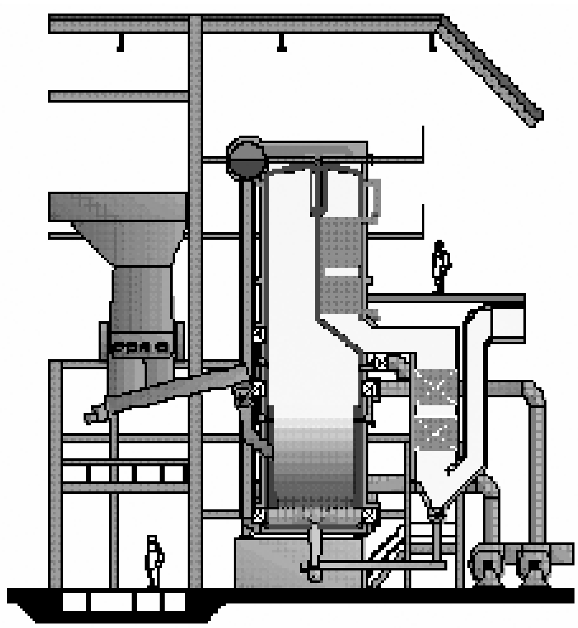

Figure 10. Bubbling FBC, 18 MWt boiler in Avrika, Sweden [19]

cadmium are precipitated. The subsequent stage is the radial flow scrubber, where sodium hydroxide solution with a pH value of about 8 is used to wash out sulfur dioxide. All emissions are under the permitted standards.

Case 10 – Bubbling FBC boiler burning wood biomass [19]

Bubbling FBC boiler in Avrika Sweden is district-heating boiler with 18 MW_{th} fuel effect using wood biomass as fuel (Fig. 10). The Arvika boiler is a membrane walled natural circulation boiler supported from beneath. The boiler produces only district heat, and the steam pressure in the steam drum are maintained by circulating the feed water through district heating heat exchangers. The furnace consists of the fluidizing grid, refractory lined lower part and membrane walled freeboard section. The refractory lining height is about three meters from the grid. Furnace exits to second pass where the economizers are located. The fluidizing grid is a nozzle type of grid, through which part of the combustion air, primary air is blown to the furnace. The cross section of the grid is about 9 m^2. Fuel is a mixture of wood chips, bark, sawdust, recycled wood, with 50% of moisture and heating value 8,3 MJ/kg (wet base). In Arvika the guaranteed NO_x emission level is below 65 mg/MJ with the optimized design.

Conclusions

In spite of the fact that BFBC technology has not found market in electric energy production in competition with the CBFC technology, the new large market can be previewed in distributive energy production, both for heat and electric energy production in industry and district heating. The use of local fuels, biomass and industrial and municipal wastes in distributive energy production make BFBC even more attractive. On the other hand this is technology which can be developed and produced in developing countries.

Literature

1 Oka, S., New Technologies of Combustion in Energetic (in Serbian), in: New Energy Technologies (Ed. M. Djurović), Montenegrin Academy of Sciences and Arts, Special editions, Vol. 40, Section of Natural Sciences, Vol. 22, Podgorica, Yugoslavia, 2000, pp. 35– 72

2 Oka, S., Mesarović M., Distributive Energy Production for Rational Use of Primary Energy Recourses, ENYU 2001, *EEE Energija*, Vol. VI, May 2001, pp. 95–120

3 Oka, S., Modern Technology Development and Critical Processes, Research Topics and Data Base for Bubbling Fluidized Bed Boilers (Invited lecture), International Seminar New Technologies In Heat Power Engineernig at the End of Twentieth Century, Russian Acad. of Sci., Siberian Branch, Novosibirsk, Russia, Sept. 5–10, 1993, pp. 7–32

4 Hupa, M., Bostrom, S., Fluidized Bed Combustion: Prospects and Role, Abo Akademi University, Report 91–7, April 3–5, 1991, Invited presentation on I World Coal Institute Conference *Coal in the Environment*, London

5 ***Ahlstrom Pyroflow, Circulating Fluidized Bed Boilers, Ahlstrom Pyropower K. K., Japan, 1995

6 Oka, S., Advanced Technology Development and Critical Processes and Research Topics for Bubbling FBI Boiler Design, *Thermophysics and Aeromechanics, 2* (1995) 3, pp. 251–266

7 Oka, S., Data Base for Bubbling Fluidized Bed Boiler Design (Invited Lecture), *Proceedings,* International Seminar *New Technique and Technology in Thermal Power Production*, 1995, Ulan Ude, Russia, pp. 24–37

8 Oka, S., Fuel Testing and Influence of Coal Characteristics on Bubbling FBC Boiler Design, Keynote lecture, *Proceedings*, 2nd South-East European Symposium on Fluidized Beds in Energy Production, Chemical and Process Engineering and Ecology, September 24–27, 1998, Ohrid, Macedonia, Vol. 2, pp. 223–242

9 Wheeler, P. A., Patel, N. M., Painter, A., Fluidized Bed Combustion of Municipal Solid Waste, *Proceedings*, 13th International Conference on Fluidized Bed Combustion, 1995, ASME, Vol. 1, pp. 597–608

10 Oka, S., Fluidized Bed Combustion, Fundamentals and Application (in Serbian), Yugoslav Thermal Engineering Society, Belgrade, Yugoslavia 1994

11 *** Bubbling Over – Upgrading to Fluidized Bed Technology, Foster Wheeler: Power Plant Technology, Operation&Maintenance, August/September 1998

12 Backman, A., Operation Experience and Ash Management at Vastermalmsverket, Falun, *Proceedings*,14th International Fluidized Bed Combustion Conference, Vancouver, Canada, 1997, Vol. 1, pp. 519–527

13 Douglas, M. A., Morrison, S. M., The Design of an Advanced BFB Steam Generator for Biomass, *Ibid.,* pp. 151–159

14 Rajavel, M., Muthukrishnan, M., Banerjee, M., Natarajan, R., Combustion of Sponge Iron Plant Wastes-Char and Fly Ash in FBC Boilers, *Ibid*., pp. 801–806

15 Albreht, J., Schelhass, K. P., Investigation in NO_x – Formation at Combustion of Sewage Sludge in a Commercial Scale Bubbling Fluidized Bed, *Ibid*., pp. 997–1005

16 Murphy, M. L., Design and Performance Requirements for a Fluidized Bed Boiler Firing Municipal Refuse Derived Fuel in Ravenna, Italy, *Proceedings on CD,* 15th International Fluidized Bed Combustion Conference, Savannah, Georgia, USA, May 16–19, 1999, Paper FBC99-0128

17 Wu, S., Sellakumar, K. M., Chelian, P. K., Bleice, Ch., Shaw, I., Test Study of Salty Paper Mill Waste in a Bubbling Fluidized Bed Combustor, *Ibid*., Paper FBC99-0157

19 Ludwig, P., Stamer, F., Reduction in NO_x Emissions from an Industrial Sewage Sludge Incineration Plant By Employing Primary Measures in a Fluidized Bed Furnace, *Ibid*., Paper FBC99-0053

20 Hillebrand, E., Hulkkonen, S., Fabritius, M., Keinonen, M., Effective NO_x Reduction with Air Staging, Experiences from a Biomass BFB, *Proceedings on CD*, 16th International Fluidized Bed Combustion Conference, Reno, Nevada, USA, May 13–16, 2001, Paper FBC01-0049

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