

## RDF Fluidised Bed Combustor Safety Issues

Alberto TINABURRI<sup>\*1</sup>, Renato BACIOCCHI<sup>\*2</sup>

<sup>\*1</sup> Direzione Centrale per la Prevenzione e la Sicurezza Tecnica, Dipartimento dei Vigili del fuoco, Soccorso Pubblico e della Difesa Civile- Ministero dell'interno, Italia.  
Largo S. Barbara, 2 - Roma

<sup>\*2</sup> Dipartimento di Ingegneria Civile, Università di Roma "Tor Vergata", Roma, Italia

This paper describes the critical issues in the technical assessment of the safety of fluidised bed incineration plants (FBC) fed by refuse derived fuels (RDF) or other solid fuels. These plants are often foreseen as part of an integrated municipal solid waste (MSW) management system, usually downstream MSW pre-treatment plants, where RDF is produced as a fraction having characteristics such that to be fired without any other auxiliary fuel. As for any solid fuel, the furnace is the most critical process unit. Various technologies are available to obtain efficient combustion conditions. FBC safety analysis shall include the entire process flow, considering the potential hazards implied in each section. The aim of the study is to provide a support in the design and evaluation phase of both the operational and technical measures that is possible to adopt, with a detail on fire safety issues. A RDF incineration plant recently started-up represents a case study examined to show the design basis adopted in the protection systems selection and in the process control and in the security assessment.

### 1. Introduction

FBC are used in incineration plants defined in article 3 of Directive 2000/76/EC as any unit and equipment dedicated to the thermal treatment of wastes with or without recovery of the combustion heat generated. Depending on the case, RDF can represent:

- the primary fuel, with auxiliary gaseous or liquid fuel for unit start-up or restart;
- an additional fuel in co-incineration plant;
- a process fuel (for heat generation) as in the cement production industry.

This paper deals with RDF used as main fuel in FBC incineration unit. RDF is prepared from MSW and represents a segregated high calorific fraction of processed MSW, obtained by screening to remove metals and inert fractions and separation of the fine wet putrescible fraction before being pulverized. The medium fraction, mainly consisting of paper, cardboard, wood, plastic and textiles represents the coarse fuel (*c*-RDF), that can be also dried and pelletised into dense RDF (*d*-RDF). *c*-RDF has a fluff appearance while *d*-RDF has a relatively hard external surface and a fibrous core. RDF composition will vary according to the origin of the MSW and the sorting/separation process. CEN has made available in 2003 a Technical Report (CEN/TR 14745) dealing with solid recovered fuels quality. In Italy, the standard UNI 9903 was made available in 2004, concerning RDF characterization. This standard is also cited by the national provisions that extended the possibility to consider "quality" RDF (the so called "CDR-Q") as a renewable fuel, so promoting its use in power generating plants.

## 2. Safety Issues Concerning FBC Plants

### 2.1 Introduction

By virtue of the more consistent ignition source available from the mass of high temperature bed material during normal operation, a FBC system is less susceptible to furnace puffs and flameouts than burner combustion. However during warm-up or in slumped or semi fluidized bed, the unit does not benefit from these mitigating factors.

The safety analysis is conducted dividing the FBC plant in subsystems on the basis of the specific process function performed: RDF reception, storage, on-site pretreatment facilities and feeding equipments; boiler; heat recovery steam generation; power generation; facilities for fluegas clean-up; ancillary units: ash removal, wastewater treatment, chemicals storage and dosing units (e.g., limestone, ammonia).

#### 2.1.1 RDF storage and handling section

The following hazards should be considered in the design of this sub-system:

- abnormally hot, smoldering or burning raw fuel that is ahead of the feed system;
- oxidation reactions inside RDF bulk that can cause spontaneous combustion;
- gases that can be released from the solid fuel, especially if freshly crushed, and can cause the accumulation of flammable or explosive mixtures in bins or enclosed areas.

Waste fuels are more variable in analysis and burning characteristics than conventional fuels. Plant operators shall therefore conduct tests to verify the compliance of the RDF delivered to evaluate its suitability for the intended incineration process (as also required by the article 5 of the directive 2000/76/CE).

#### 2.1.2 RDF feeding system

The RDF unloading, transfer and preparation facilities shall be designed and arranged to size the fuel, remove foreign material and minimize interruption of the fuel supply to the combustor. As a consequence, means for detection of RDF flow interruption and correction shall be provided to ensure a steady flow to the boiler. Foreign substances (e.g., scrap iron) can interrupt the flow to the combustor, damage of jam equipment or become a source of ignition within the fuel-feeding equipment. Therefore RDF-shredder and metal separators shall be designed to minimize the possibility of fires starting inside the equipments, providing sparks detection systems with automatic water extinction.

A bed feed that operates at a lower pressure than the boiler enclosure to which it is connected shall have a lock hopper or other means to prevent backflow of combustion products. Directive 2000/76/CE (article 6) requires that each incineration line shall have and operate an automatic system to prevent waste feed:

- at start-up, until the minimum required temperature (usually 850°C) has been reached;
- whenever the minimum required temperature is not maintained;
- whenever the continuous measurements show that any emission limit is exceeded.

#### 2.1.3 Boiler and heat recovery steam generation

To prevent explosions in FBC systems, the following conditions shall be avoided:

- an interruption of the fuel or air supply or ignition energy to auxiliary burners, sufficient to result in causing momentary loss of flames, followed by restoration and delayed reignition of accumulated combustibles;

- the accumulation of an explosive mixture of fuel and air as a result of RDF entering a bed whose temperature is below its ignition temperature and the subsequent ignition of the accumulation by a spark or other source of ignition;
- insufficient air to all or some bed compartments, causing incomplete combustion and accumulation of combustible material;
- an accumulation of fuel in an idle fluidized bed that is still hot, leading to the distillation of combustible vapors followed by delayed ignition when the bed is fluidized as in a purge sequence.

Incineration plants operating conditions are fixed by article 6 of the Directive 2000/76/EC prescribing that the temperature of the combustion gases shall be raised, after the last injection of combustion air, to a temperature of 850°C (1100°C for wastes with a content of more than 1% of halogenated organic substances, expressed as chlorine) for at least two seconds. It is therefore essential, for the FBC designer, to provide a reliable bed temperature value during the various operating conditions, including start-up, hot restart and low load operation. A system that has been shown to satisfy the requirement consists of a number of thermocouples, roughly proportional to the FBC capacity, positioned in the vertical walls surrounding the bed at elevations below and above the level of the slumped bed. A well penetration of 5 cm from the wall provides a reliable measurement, when bed is fluidized, with limited erosion.

The following issues shall be addressed by system designers and operators in FBC systems in order to minimize the above mentioned hazards:

- potential for unintended accumulations of unburnt RDF in the bed;
- potential for generation of explosion gases if the air supply to a bed is terminated before the RDF fuel in the bed is burned out;
- potential risk of explosion when the air supply is reestablished to a hot bed;
- bed solidification as a result of a tube leak or agglomeration;
- structural load requirements for abnormal accumulations of ash or bed material in the boiler furnace enclosure and the solids return path;
- structural or fire hazards associated with backsifting of bed material.

Backsifting is related to bed material that will sift through the air nozzles at the base of the furnace during low load operation, when the pressure drop across the nozzles is low. This occurs most frequently during start-up and shutdown. Carbon particles contained in the siftings can ignite, as has happened in several plants. Additionally, accumulated material could result in structural overload, improper airflow distribution, or interference with duct burner operation. The following should be considered in the design to minimize backsifting risks:

- an air nozzle system that reduces the potential for sifting;
- start-up and shutdown procedures that minimize the time spent at low airflow;
- means to observe the contents of the windbox and removing any accumulation.

A second issue to be evaluated for safety in case of fire in FBC systems is related to the production of carbon-containing flying ash (char) which can accumulate in dunes on horizontal surfaces in the gas path in the heat recovery and solid separation section. A carbon-rich mass can continue to combust slowly for hours after a plant shutdown and will provide an ignition source if disturbed by increased airflow. Because char carryover is a characteristic of FBC, the system design shall include provisions to minimize char accumulation in the flue gas ductwork and dust collection equipment.

FBC heat recovery steam generation presents peculiar safety problems as the bed contains a large quantity of hot, granular solids and, in some designs, there is also substantial hot refractory. Both the bed and the refractory store large quantities of heat, which causes the behavior of an FBC boiler to differ from that of other fuel combustion systems. An operating FBC boiler continues to produce steam after a fuel supply trip if the air supply continues to operate. The source of heat might not be the fuel remaining in the bed after the fuel supply trip, but, rather, could come from the heat stored in the granular bed material and the refractory. Experience has demonstrated that, although it drops, steam production can continue at above 50% of the full load rating for several minutes after a fuel supply trip. However if the air is stopped and the bed defluidized, the heat removal from the bed becomes very low and steam production drops to less than 10% of full load rating in a matter of seconds.

#### **2.1.4 Solids removal subsystem**

The removal equipment handling hot ash from the boiler and others solids separators in the fluegas clean-up subsystem shall be designed to provide material cooling before material is discharged into ash-handling and storage equipment. Safety interlocks equipped with a device to monitor cooling medium flow and material discharge temperature shall be provided to prevent fires or equipment damage.

#### **2.1.5 Auxiliary burners and burning management system (BMS)**

Article 6 of the Directive 2000/76/EC requires to equip each line of the incineration plant with at least one auxiliary burner that must be switched on automatically when the temperature falls below 850 °C (or 1100 °C as the case may be). It shall also be used during plant start-up and shut-down operations in order to ensure that the above temperature is maintained and as long as unburnt RDF is in the combustion chamber.

Auxiliary burners have usually a relatively high nominal duty (~1 MW), requiring a pilot flame before the ignition of the main flame. With reference to a gaseous fuel feeding, following guidelines should be applied to prevent explosion hazard.

Piping routes and valve locations shall minimize exposure to explosion hazard or high temperature exposure source. As much of the fuel subsystem as is practicable shall be located outside the boiler house. A manual emergency shutoff valve that is accessible in the event of fire in the boiler area shall be provided. For each burner, the minimum requirement shall be two safety shutoff valves with an intermediate valve vent ("double block and vent"). Proof of closure shall be provided for all safety shutoff valves and for all vent valves. Shutoff valves shall be located as close as practicable to the burners, to minimize the volume of fuel downstream of the valve. For units with multiple burners, a header safety shutoff valves and provisions to automatically vent the piping volume between the header safety shutoff valves and any individual burner safety shutoff valves shall also be provided. Provisions shall be made in the gas piping to allow testing for leakage including accurate tightness tests of the header safety shutoff valves and individual safety shutoff valves. Burners shall be switched on from a local control panel and visual observation of conditions at the burner ignition zone and for flame detection equipment is required. Each burner shall be individually supervised, and, on detection of loss of burner flame, the safety shutoff valves for the burner experiencing the loss shall automatically close and shall initiate an alarm to warn the operator of the potential

hazard. Flame detection system may vary depending on the igniters class, requiring the installation of one or two flame detectors (for the main burner flame and/or the igniter flame) for each burner.

### **2.1.6 The combustion control system (CCS)**

The combustion control system (CCS) shall fulfill following objectives:

- equipments shall be provided and operating procedures established to ensure a stable flame condition at each burner and to preclude the possibility of an air-fuel ratio conditions that results in a fuel-rich condition within the furnace;
- provision shall be made for setting minimum and maximum limits on the auxiliary burner fuel and air control subsystems to prevent fuel flow and airflow beyond the stable flame limits of the burner;
- while in the automatic control mode, the control system shall prevent the demand for a fuel-rich mixture.

CCS shall maintain furnace fuel and air input in accordance with demand and the bed temperature within the limits required for continuous stable combustion for the full operating range of the boiler. Controlling the furnace inputs and their relative rates of changes in order to maintain the air-fuel ratio requires the use of gravimetric-type or calibrated volumetric-type RDF feeders and of combustion airflow measurements. Means of providing a calibrated solid fuel flow signal for each feeder shall be part of the CCS to provide indexes of total fuel versus total air. The monitoring of the flue gas percent oxygen and low range combustibles is an acceptable method of controlling the air-fuel ratio. Oxygen analyzers are necessary for use as an operating guide in FBC plant, in order to keep the fuel input calibrated to true air demand for comparison to actual air input. Combustibles analyzers are recommended as an aid in avoiding excess fuel operation, particularly in the case of inadequate bed mixing. However, FBC under certain abnormal operating conditions can accumulate significant quantities of unburnt fuel without an obvious indication of abnormality. Such conditions can occur when the fuel input exceeds the available air for combustion over an extended period of time and is of particular concern where RDF of widely varying heating values and air demand per unit of fuel is fired. In this case, it should be possible for the operator to adjust the required air-fuel ratio.

When changing furnace heat input (load), the airflow and fuel flow shall be changed simultaneously to maintain always an air-rich air-fuel ratio (requirement for air lead and lag control). Setting the fuel flow control on automatic without setting the airflow control on automatic shall be prohibited and this function shall be interlocked. As already outlined, operating procedures (and interlocks) shall be established to heat the bed material to raise the bed temperature to the minimum value required for self-sustaining combustion of the solid fuel and that the bed is in fluidized condition prior to admitting the RDF to the bed. The continuous trend display of critical process variables (including bed temperature) is therefore a key aid to the plant operator.

### **2.1.7 Furnace pressure control systems (FPCS)**

The FPCS shall control the furnace pressure at the desired set point in the combustion chamber, minimizing the risk of furnace pressure excursions in excess of furnace structural capability and of implosion. The boiler enclosure, the air supply system, and

the flue gas removal system shall be designed so that the maximum head capability of the forced draft (FD) fans and induced draft (ID) fans within these systems, with ambient air, does not exceed the design pressure of these systems. On the basis of reported incidents, the maximum negative furnace pressure is determined mainly by the maximum head characteristic of the ID fan. However if worst-case conditions are assumed (e.g., cold air, high head ID fan, FD fan flow shutoff, ID control dampers open with ID fan operating) the furnace cannot be protected only by reasonable structural design. As usual in furnace design, an open flow path from the inlet of the FD fans through the stack shall always be ensured under all operating conditions.

#### **2.1.8 Safety issues concerning the start-up operating sequence**

Sequencing shall follow procedure that allow prepared RDF to be admitted to the FBC only when hot fluidized bed mass and required combustion airflow exist to ignite the fuel as it enters the furnace and to burn it continuously and as completely as possible within the confines of the combustion area. The starting and shutdown operating sequences for FBC are established to preserve the temperature of the bed material and refractory. As a result, the warm-up cycle for cold start-up and hot restart, as well as the shutdown sequence, are different from other conventional units. The basic start-up FBC procedure begins with bed fluidization, the unit purge, the warm-up cycle to heat the bed above the minimum required temperature for RDF feeding to the furnace.

The purge shall interest not only the bed but also all the equipments (e.g., precipitators) containing source of ignition energy for not less than 5 minutes or five volume changes of that component, whichever is greater. After meeting the requirements for average bed temperature, RDF can be fed while maintaining the auxiliary burners in service until the stable ignition of this fuel has been established, as it is possible verifying by watching for a steady increase in bed temperature and a decreasing oxygen level. If RDF has been fed for more than 90 seconds (or a period established by the manufacturer) without an increase in bed temperature, solid fuel feeding shall be discontinued. The firing rate shall be regulated by manipulating the RDF fuel and air supply simultaneously, and reducing the auxiliary burners heat release to maintain the bed temperature at the recommended level and the desired oxygen level in the fluegas.

The on-line combustion control, unless designed also for use during start-up, shall not be placed in automatic service until the following conditions have been accomplished:

- a predetermined minimum main fuel (RDF) input has been exceeded;
- stable bed temperature conditions have been established;
- all manual control loops are operating in manual mode without no error between their set point and process feedback;
- airflow control is on automatic.

#### **2.1.9 Safety management system**

Safety assessment should also include the compliance with the directives concerning the incineration plants (2000/76/EC), the improvements in the safety and health of workers at work (89/391/EEC) and the fitness for the intended use of the installed products (machinery, ATEX, PED directives). Not to mention the VIA and IPPC permitting procedures, this units are also included into the italian implementation of the "Seveso" directive (96/82/EC as modified by 2003/105/EC) as a process listed in the annex A.

The plant operator is required, at least, to assess the potential for major-accident hazards in its risk evaluation and to provide workers with adequate personal protection equipment and training.

### 3. Case Study

#### 3.1 Introduction

The FBC unit is located in Italy, in Tuscany. The RDF fired is produced in a nearby MSW processing plant. Technical data are reported in Table 1.

Table 1. FBC plant technical data

<i>Combustor</i>			
Type	Fluidised bed with internal circulation and watertube walls		
Solid fuel	RDF; biomass		
Capacity	3-5 t/h per line; 2 incineration lines		
<i>Fluegas clean-up facilities</i>			
Type	DeNO <sub>x</sub> SNCR – Dry treatment with lime - Active carbon adsorption – Bag filters – Wet scrubbing with caustic soda		
<i>Steam and Power Generation</i>			
Type	Rankine cycle		
Steam pressure	40 bar	Steam temperature	400°C
Electrical power	5.7 MW		

#### 3.2 Passive protection measures

Fire compartments have been provided for all the specific risk areas determined in the risk assessment, taking into account plant layout constraints. In the boiler house, it has been foreseen the fire protection (R60) of the steel loading structural elements. Emergency routes have been verified according to the prescriptions contained in the Annex III of the Decree 10 march 1998. As a result, it has been necessary to realize smoke-proof type stairs for service of the boiler house.

#### 3.3 Active protection measures

##### 3.3.1 Fixed firefighting systems

The plant is protected by a fixed firefighting system consisting of hydrants and hoses, designed for high risk area (as per national classification). The operator has also the possibility to use foam (produced with on-line premixing system).

In the RDF unloading section an automatic sprinkler system has been installed.

Considering the RDF storage capacity (two silos, 850 m<sup>3</sup> each) and layout (located inside the boiler house, with few meters separation distance), all factors that favor fire propagation and obstacle firefighting operations, additional protection measurements have been required:

- a deluge system has been installed inside each silos. In case of RDF fire, the storage interested by the fire is flooded with water while the other is cooled, to prevent fire propagation. In case of deluge system activation, RDF feeding to the boiler is stopped.

- inside the RDF storage, two infrared sensible video cameras, with remote control, help the operator for early detection of fires initiating inside the RDF bulk.
- to help firefighting operations in case of fully developed fires in RDF storage and handling section, monitors, with remote control option, have been provided to attack the fire at least from two different locations.
- in the storage discharge section, where belt conveyors routes RDF to the boiler, as it is not feasible to realize the closure or compartment in this zone to avoid fire spreading from one silos to another, two water barriers are activated in case of fire detection.

Each RDF conveyor line to the boilers, made by extractors and feeders, bucket elevators, hold-up RDF storage, shredders, metals separators, rotary valves, is protected by cable sensor, a temperature measure through a fiber optics that works as a linear fire detector. Sparks detectors located in the chute above the rotary vane feeder, above the conveyor in the eddie-current separator (ECS) and in the vacuum connection in the ECS will detect spark rates and activate water spray nozzles located along the RDF feeding route to the boiler, according to the specified extinction procedures.

### **3.3.2 Fire detection and fire alarm systems**

All the plant is covered by a fire detection and fire alarm system. Due to the complexity, a specific software is available in control room to monitor the system status and alarms.

### **3.3.3 Gas extinguishing systems**

All electrical apparatus (PCC, MCC, transformers) have been protected by gas extinguishing systems. It has been prescribed to keep in the plant a reservoir of extinguisher agents, multiple of the nominal operating quantity - in this case 25 argon cylinders and 5 carbon dioxide cylinders - permanently connected to the distribution piping in order to facilitate the passage from the operating set to the reservoir set.

### **3.4 Auxiliary burners**

The technical solutions described in previous section 2.1.5 have been adopted. For each burner, a gas leakage detecting systems has also been provided, installed under a hood located above the gas controlling and shutoff valves.

## **4. Conclusions**

A RDF incineration plant recently built and started-up in Italy represents a case study examined to show the design basis adopted in the protection systems selection and in the process control and in the security measures assessment as to represent a guide in the design and technical evaluation of similar process plants.

## **5. References**

1. Ehrlich, S., 1995, Fluidized Bed Combustion, ASME, 729
2. Ehrlich, S., Fire Protection Handbook, NFPA, Quincy, MA, Section 3/Chapter 6
3. Murphy, 1999, Design and Performance Requirements for a Fluidized bed Boiler Firing Municipal Refuse Derived Fuel in Ravenna, Italy, in EPI
4. NFPA 85, 2004, Boiler and combustion System Hazards Code, Quincy, MA