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CASE REPORT

Size-up, monitorization, performance optimization and waste study of a 120 kW in-use wood pellet boiler: A case study

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This work deals with different aspects related to biomass combustion in a medium-size commercial pellet boiler. Firstly, there were evaluated the heating requirements of a bioclimatic building to select an adequate device. Once started up, it was developed a complete monitorization of gaseous emissions and solid wastes aiming to optimize its performance by manually modifying the fuel feeding and air inlet. Thanks to this, fuel consumption decreased a 20% and oxidizing air inlet was lessened to a 21% excess, what led to a reduction of CO, NO_x and SO_2 emissions to values respectively below 200 ppm and 80 and 30 mg/Nm^3. Thermal yield was enhanced from 78.6 to 94.9%. Chamber and fumes temperatures and thermal rise increased to respectively 160 °C and 20 °C, accomplishing values recommended by boiler's manufacturer. All measures taken, and the results they provided, entailed meaningful environmental and economical improvements.

Introduction

Last decades increase in the world's energy demand, besides the gradual shrinkage of traditional fossil fuels and the concern about global warming had encouraged to seek alternative sustainable energy sources and diversifying the global energy mix [1]. This has been reflected in several national and transnational policies, like the most recent Europe 2020, that aims to reduce the energy consumption of the EU a 20% while increasing the renewable based one a total 20% by the year 2020 [2]. In this context biomass presents some advantages that point it as a reliable alternative to fossil fuels for energy securing. Some of them like its CO_2 neutrality or low S, N and ash content, are related to its nature [3]. It is also a versatile feedstock, with plenty of products and conversion techniques available. In addition to this it commercial production may invigorate rural areas economy [4]. Currently it originates two thirds of the renewable energy in Europe, and is the energy resource with highest consumption growth [5]. A relevant part of the overall biomass fuel is used to supply heat and domestic hot water (DHW) to buildings, being small and medium size grate-fired-chambers the devices most commonly used to that end, thanks to their simplicity, robustness and cost efficiency [6]. Monitoring these equipment is mandatory as their poor performance implies a loss of efficiency and an increase in hazardous emissions [7], making it difficult to achieve the goals put forward by environmental policies [8].

Several works provide results obtained in different biomass fed heating systems. In that way Kraszkiewicz [9] used a 10 kW fixed-grate chamber to test the combustion performance of different woody biomass fuels (black locust and European larch chunk wood, wood pellets and pine and birch sawdust) by analyzing their CO, SO_2 and NO_x emissions. It was concluded that there is required a secondary air inlet and its continuous electronic setting to assure the depletion of hazardous emissions.

Carbone et al. [10] proved the key importance of fuel/oxidizing agent mix to reduce gaseous emissions and fly ashes in a domestic fixed bed biomass stove.

Fournel et al. [11] studied the O_2, CO_2, NO and SO_2 gaseous emissions of four seasonal energy crops (willow, miscanthus, switchgrass and reed canary grass) when burnt in a 29 kW boiler.

Forbes et al. [12] studied the maximum output, energy yield, NO_x, CO and C_xH_y emissions and quantity of ash produced during

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combustion of seven farm wastes in a 120 kW chamber, and compared them with a commercial pellet brand.

Chaney et al. [13] developed a CFD model for a 50 kW biomass boiler to optimize its combustion performance and reduce NO_x emissions by modifying the primary/secondary air supply and the orientation, height, direction and number of secondary inlets.

This work focuses on enhancing the combustion performance of a 120 kW domestic pellet boiler that was previously sized up to cover the heating requirements of the building where it is installed. To that aim its primary, secondary, tertiary air inlets and fuel feeding rate were systematically varied basing on results obtained from temperature, gaseous emissions, wastes, outlet power and energy yield analysis. This led to minimize its harmful effects and operative costs, with no influence on the obtained power and yield.

In addition to this, data regarding boiler constructive details, fuel, waste properties and experimental results from each test are provided, as this work also aims to serve as a suitable tool for future model and simulation process developing.

Material and methods

The combustion reaction

The combustion process has 4 co-existing stages with different extents depending on the operational conditions. Drying (≈100 °C), or period during which external moisture is released, pyrolysis (250–500 °C) or thermal degradation of organic matter in absence of oxidizing agent, gasification (700–1100 °C) or partial thermal oxidation in an environment poor in oxidizing agent, and finally combustion itself (250–800 °C). This comprises a series of chemical reactions in which main elements that compound organic matter (C, H, N and S) are oxidized providing an important amount of energy as heat.

In case of adequate conditions (enough temperature, relative air excess, turbulence and residence time) complete conversion can be achieved being produced CO_2 and steam, but also SO_2, NO_x (90% NO, 10% NO_2 and negligible amounts of N_2O) and other minority compounds like C_xH_y [14]. The reaction can be summarized as:

$$C_xH_yO_z(s) + aO_2(g) \rightarrow bCO_2(g) + cH_2O(g) \quad (1)$$

where $a = x - y/4 - z/2$, $b = x$, and $c = y/2$, and a, b, c are positive numbers.

$$S + O_2 \rightarrow SO_2 \quad (2)$$

$$N + (x/2)O_2 \rightarrow NO_x \quad (3)$$

If reaction is not complete, partial oxidation is reached taking place a wide range of unexpected reactions and products, being the high presence of CO, instead of CO_2 its main indicator.

About technology, several combustion devices are available in the market being the grill fixed bed the most common for domestic purposes [15] whilst fluidized bed reactors are most commonly used at industrial ones [16]. Entrained flow reactors are also quite well known nowadays [17].

More detailed information about the combustion reaction can be consulted in specialized monographies [18].

Precedents, context and protocol

Fig. 1 shows the core of the plant start up, where A represents the building's energy requirements obtained from previous balances and calculations, and the options, like the selection of commercial items (boiler and silo according to manufacturers and suppliers). Information regarding ancillary items is obtained from bibliographical review. B represents the operative results obtained in the experimental section and those to be considered by their $R + D + i$ general interest.

Data provided both by previous design calculations and obtained during the experimental process are interlinked (Fig. 3) and the information they provide is implemented in the process described in this work as in Fig. 4.

The container demonstrator building

Heating requirements: energy balance

The first stage of the project was to size up the heating requirements of a container-demonstrator building located in San Pedro de Anes (Asturias, Spain). It belongs to the Barredo Foundation and is currently in use by the enterprise Tunnel Safe Testing (TST). This is a 1300 m^2 three-plant-bioclimatic-building that contains different living spaces (cafeteria, offices, teaching area, meeting rooms, toilets, locker rooms and store).

Sanitary hot water (SHW) should be provided by solar–thermal energy panels located on the building's roof. Nevertheless since Spanish law requires a primary energy source to support periods of time with low radiation, the energy required for SHW (Q_{SHW}) must also be considered in the balance.

Hence, overall heating-power requirements of the building (Q) were estimated as [19]:

$$Q = Q_T + Q_V + Q_{SHW} \quad (4)$$

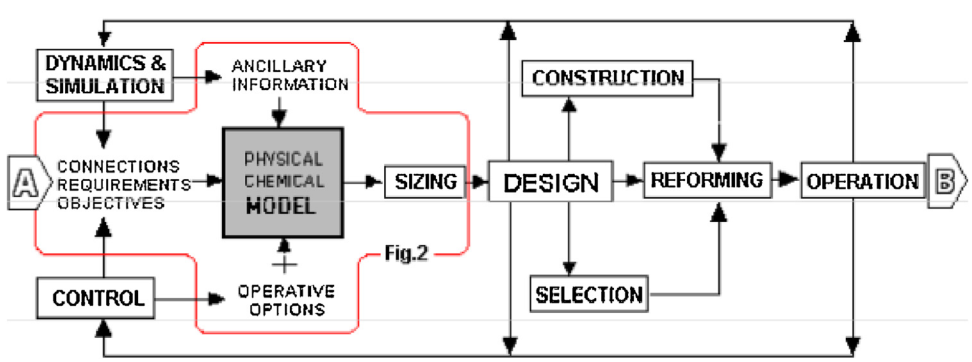

FIG. 1
Logical flow-sheet of the performance optimization procedure. On the other hand, Fig. 2 shows a graphical description of the design equation. Information provided by analytical operations is transferred to the experiment plant as design and control actions.