Applied Energy 101 (2013) 357–362

Contents lists available at SciVerse ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Real life performance of domestic pellet boiler technologies as a function of operational loads: A case study of Belgium

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ARTICLE INFO

Article history:
Received 2 August 2011
Received in revised form 6 February 2012
Accepted 7 February 2012
Available online 17 May 2012

Keywords:
Operational loads
Pellet boilers
Wood pellets
Pellet burner
Combustion efficiency

ABSTRACT

Emissions and efficiency of three different wood pellet boiler technologies in real life conditions were compared at two different operational loads. The test consortium comprised of one 15, 20 and 32 kW boilers equipped with bottom feed burner, one 30 kW boiler equipped with top feed burner and one 35 kW boiler equipped with horizontal feed burner. The measurements comprised of carbon monoxide (CO), nitrogen oxide (NO_x), dust and combustion efficiency. All boilers were fuelled with DIN*plus* certified wood pellets.

Emissions and efficiency of each boiler technology varied as a function of operational loads. Magnitude of variations in the emissions and efficiency between nominal load and reduced load was narrow with bottom feed, wider with horizontal feed and was the widest with top feed boiler. At reduced load, top feed boiler had very high CO and dust emissions (5196.0 and 406.4 mg Nm^{-3}, respectively) which were 3.3 and 17.6 times higher, respectively, than at nominal load. Horizontal feed boiler emitted highest NO_x at reduced load (448.5 mg Nm^{-3}), which was 1.7 times higher than at nominal load. At reduced load, combustion efficiency of all bottom and horizontal feed boilers were ±2% of that at nominal load; however, top feed boiler was 17% less efficient.

Keeping in mind minor variations in fuel quality, different burner configurations clearly lead to important differences in emissions and efficiencies at different operational loads. In order to minimize pollutants emission and to achieve high efficiency, reduced load operations of pellet boilers should be avoided, especially in case of top feed boilers considered in the present study.

1. Introduction

This is clear from several studies [1–5] that the use of biomass for energetic purposes brings several environmental benefits. Therefore, the use of biomass for energetic purposes is being promoted in several EU countries via various national/federal and EU policies [6,7]. Residential heating accounts for 30–60% of the total residential energy consumptions in several EU countries [6]. Like in many other EU countries, several homes are heated by small scale biomass heating systems (BHSs) in Belgium. Wallonia is one of the most active regions for BHS in Belgium and the market in this reason is rapidly growing. In this region, 83.5 MW residential heat was generated in 2007 using BHS [6]. At the end of year 2007, approximately nine thousands (8685) BHS were reported in Wallonia region [6].

However, the use of obsolete technologies, bad quality fuel and improper maintenance of these devices may cause bad combustion leading to high pollutants emission. For example in Finland residential biomass heating was reported as one of the major sources of airborne particles, accounting for 25% of the stationary combustion emissions in 2000 [8]. Several other studies have highlighted the emissions of several pollutants such as SO_x, NO_x [9–11], CO, C_xH_y [1,10,11] and dusts [8–15] from small scale biomass heating devices. However, most of them were performed under standard laboratory conditions [10–12,14–17] and at full/nominal load only. However, at reduced load operations, the emissions and efficiency of these devices are totally different [11]. Additionally, in daily life operational conditions many factors such cleaning intervals and practices, draft conditions, quality of installations and modulation range (which completely depends up on the heat demands of the house) may influence emissions and efficiency of these devices. Studies revealing the performance of these devices in real life conditions are rare. Therefore, present study focused up on the concerned matter.

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doi:10.1016/j.apenergy.2012.02.017

Nomenclature

°C	degree celsius	HF	boiler equipped with a horizontal feed burner
BHS	biomass heating system	NO_x	nitrogen oxides
CO	carbon monoxide	DFG	dry flue gas
BF	boiler equipped with a bottom feed burner	wt	weight
TF	boiler equipped with a top feed burner	Dwt/dwt	dry weight

In continuation of our research work to explore the environmental feasibility of residential pellet boilers in Belgium [6,10,11], current study was carried out to evaluate the performance of different residential pellet boilers technologies in real life conditions as a function of different operation loads. Based up on the available technology in Belgium, three different types of pellet boilers were selected i.e. pellet boilers equipped with bottom feed, top feed and horizontal feed burners. Emissions and efficiency of above mentioned three different pellet boiler technologies are compared at two different operational loads i.e. nominal and reduced load (30% of the nominal load).

2. Pellet fuels description

All the boilers tested in the present study were fuelled with commercially available DIN*plus* certified wood pellets in Belgium. Depending up on the supplier (chosen by owner of each boiler), minor differences in the quality of wood pellets are possible. General characteristics of available DIN*plus* certified wood pellets in Belgium are given in Table 1.

3. Experimental set-up

The test consortium comprised of five different commercially available residential pellet boilers. Technologically, three different types of wood pellet boilers were tested i.e. three boilers equipped with bottom feed burner [(BF), one 15 kW, 20 kW and 32 kW each], one 30 kW boiler equipped with top feed burner (TF) and one 35 kW boiler equipped with horizontally feed burner (HF). The tests on the boilers were performed (emissions and efficiency measurements) as they were operating in daily life practices without any interference and these conditions are said in present study as “real life conditions”. Prior to the measurement, operation of each boiler was stabilized for at least 1 h. Test specifications for each setup are described in Table 2. All boilers were equipped with an auto-ignition device and a hot water storage tank of appropriate size.

3.1. Gaseous emission measurements

As soon as the boiler operation was stabilized, gas emissions were continuously measured using HORIBA PG-250 gas analyzers and the values were cross checked with TESTO-350M/XL. Sampling lines were used for continuous monitoring of O_2, CO, CO_2, and NO_x. Sampling durations for each measurement setup are listed in Table 2. The measurement principles of the gas analysers were galvanic oxygen analyzer (O_2), non-dispersive infra-red (CO, CO_2), and chemiluminescence (NO_x) for the HORIBA PG-250, and electrochemical cells for the TESO-350M/XL. The HORIBA PG-250 gas analyser was calibrated with appropriate gas bottles at zero and span points, before and after each measurement. The TESTO-350M/XL instrument has an auto zeroing mechanism which is automatically done once the instrument is restarted. Flue gas and ambient temperature were measured using thermocouple probes (±0.5% measurement accuracy). The carbon dioxide concentration in the flue gas was calculated by following formula:

$$CO_2 = CO_{2max} \times [20.9 - O_2]/20.9$$

where O_2 is the oxygen concentration in the flue gas (%), and CO_{2max} is 20.16%, calculated using the combustion equilibrium equation based on the elemental composition of experimental wood pellets as given in Table 1.

3.2. Dust measurements

Dust was sampled using WÖHLER-Staubmessgerät SM-96 device. The sampling probe was positioned centrally in the flue gas cross section. The sampling tube had a diameter of 8.00 mm that widened to 9.74 mm at the inlet opening of probe. The equipment used for sampling allowed a flue gas volume of 270 ± 27 l to be sampled during a period of 30 min. The fibre glass filters used had a separation capacity of at least 99.95% with 0.3 μm Di-n-Octyl Phthalate smoke particles. The filters were dried for at least 1 h at 105 °C before and after the sampling, to achieve mass consistency and were weighed afterwards with a balance with ±0.1 mg precision.

All measurements (gaseous and particles) were converted and presented at 10 vol.% O_2 content in dry flue gas, with indication of ±absolute error.

3.3. Performance measurements

Thermocouples were used to measure the temperature of flue gas and a micro manometer for measurement of the chimney draught. Pellet consumption rate was determined using a balance with a precision of ±0.02 kg.

Table 1
Quality of experimental pellets (DIN*plus* certified).

Properties	Quality of experimental pellets (DIN*plus* certified)
Diameter (mm)	6.00
Length (mm)	⩽5.00 × d[a]
Apparent density (kg dm^{-3})	1.15
Water content (% wt)	7.14
Ash content (% wt)[b]	0.41
Net calorific value (MJ kg^{-1})[b]	18.00
Sulphur content (% wt)[b]	0.02
Nitrogen content (% wt)[b]	0.10
Chlorine content (% wt)[b]	<0.01
Mechanical durability (% wt)	99.21
Fine content (% wt)	0.34
Carbon (% wt)	49.80
Hydrogen (% wt)	6.30
Oxygen (% wt)	43.80

[a] A maximum of 20% of the majority of the pellets may have a length of up to 7.5 × d.
[b] In anhydrous condition.