Preheating In Pellet Stoves: Effect in Energy Balance And Emissions.

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Abstract. In this research paper a study of the effectiveness of preheating in small pellet fixed bed stoves is presented. Two different set of experiences, with and without preheated air, were carried out and compared in a pilot 24 kWt pellet plant at the University of Vigo. The influence of preheating specially considering efficiency and emissions has been investigated through the application of statistical analysis on the results. Results show that preheating enhances the operation of the pellet stove specially form the energetic point of view

Keywords

Biomass, pellets, combustion, fixed bed, stoves, statistical analysis

1. Introduction

The Renewable Energy Promotion Plan in Spain 1999-2010 highlights the need for improvement in the domestic equipment [1] (Residential equipment in the power range of 8 to 30 kW). In Spain just over half of the renewable energies corresponded to the use of biomass that is limited to heat applications. The regional distribution of consumption is strongly related to the presence of paper and pulp manufacturing sector, timber and food industries and the household sector. Based on this, half of the national biomass consumption is concentrated in Galicia, Andalucía and Castilla-León.

Pelletising of biomass is a densification process that improves its characteristics as a fuel. Typical characteristics of lignocellulosic pellets are low moisture content (<10% Wet Basis (WB)), high density (>700 $kg \cdot m^{-3}$) and a heating value around 17000 kJ/kg with a diameter between 5 and 12 mm. The previous mentioned specifications make pellets very interesting for ordinary central heating systems.

Comparing to fossil fuels the emissions from the small-scale combustion of bio pellets are still higher regarding CO and NOx .

Table 1: Stove emissions.

Emissions (mg/kWh)	Fuel	Gas	Pellet
CO	10	150	250
NOx	350	150	350

In order to develop future stoves with better characteristics, higher efficiency and lower emissions, an experimental plant was designed to test and analyse the main aspects of pellet combustion in small stoves. Due it has a flexible design different situations can be simulated and tested. A first result of the plant has showed that exhaust gases, regardless of the operational factors, are at relatively high temperatures [2]. Therefore, a way of improvement, in such pellet stoves, could be make use of this energy in the heating of air needed for the combustion.

Two set of test has been developed by means of statistics experiment design techniques. The analysis of the results shows the predicted tendencies comparing the influence of preheating in order to achieve a better efficiency of the general process. Previous studies provide two main factors: amount of pellet and air supply.

2. Experimental

A. Description Of The Pilot Plant

The plant can be described as an open fire stove with updraft combustion [2], where exhaust gases are used to preheat the primary air. Primary air supply air is forced inside the installation by means of a speed-regulated fan, which establishes a measured pressure and a mass flow.

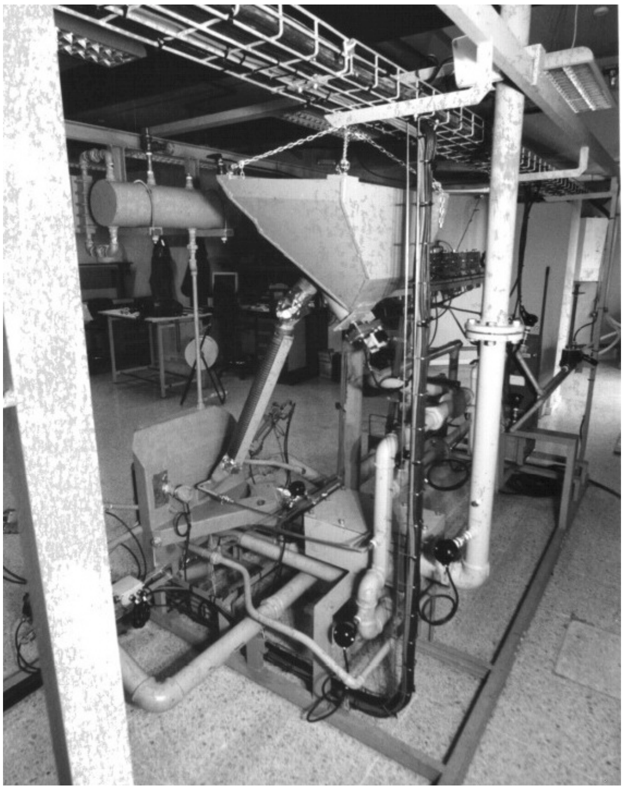

Fig. 1: General View of the Pilot Plant.

This flow is conducted towards the combustion chamber through a control valves which send the fresh air directly to the combustion chamber or through the heat exchanger

Fig. 2: Partial View of the Heat Exchanger.

Exhaust gases: Gas analysis was carried out using a TESTO-350 to measure gas concentrations of the main components involved: O_2, CO, NO, NO_2, SO_2 (the concentration of CO_2 is calculated).

B. Material

The detailed characterisation of the pellet used in both set of experiments (with and without preheter) is described in table 1.

Table 2: pellet properties.

Diameter (mm)	6.6
Length (mm)	10-15
Density[1] ($kg \cdot m^{-3}$)	943.4
Moisture (% WB)	9.5
Low Heating Value (LHV kJ/g	17.0
PROXIMATE ANALYSIS (wt % dry basis)	
Ash (550 ºC)	0.90
ULTIMATE ANALYSIS (wt % dry basis free of ash)	
Carbon	52.0
Hydrogen	5.3
Oxygen[3]	42.0
Nitrogen	0.92
Sulphur	< 0.05

[1]Geometric method. **[2]**Supposed, not experimental data. **[3]**By difference

C. Theoretical basis

Previous studies of our research team showed that relevant factors were, stechiometric ratio n and the pellet supply m_p (gr/s). To contrast the behaviour of the stove considering preheating, several variables has been analysed: Heat in water Q_w (kW), heat in smoke Q_s (kW), CO emissions (ppm dry smoke), NO emissions (ppm dry smoke), O_2 emissions (% dry smoke) and finally, stove η_{st} and combustion efficiency η_c.

In order to study the general behaviour by mean of response surfaces a complete 3^2 factorial experiment was carried. Table 2 gives the different levels of the factors in both the sets of experiments, *without* preheating = *set 2* and *with* preheating = *set 3*.

Table 3: experiment factor levels

m_p (gr/s)	1.0	1.5	2.0
n	1.2	1.6	2.0
Coded level	-1	0	+1

3. RESULTS AND DISCUSSION

A. Preheating: Set 3.

After the realisation of “Set 3”, analysis of the obtained data was carried out. As in previous experiences (“Set 2”) [3], again a clear dependency between some of the studied variables and the two relevant factors (m_p and n) are revealed.

Each variable was individually treated and most of them showed that more than one potential equation was possible. However, the subsequent statistical analysis let us known which was the most appropriate [4,5]. Most of these relationships seemed to be approximately linear, and even a parabolic behaviour could be seen in some cases. This pointed out that the obtained data were appropriate to be assessed by SPSS, in order to find a mathematical and statistical based relationship. Only NO emissions seem to have a weird response.

3.A.1. Heat in water (Q_W)

$Q_W(kW)=10.537 \cdot m_p$

The heat transferred to water depends only on the amount of pellet supplied (m_p).

3.A.2. Heat in smoke (Q_S)

$Q_S(kW)= -8.159 + 5.040 \cdot m_p + 3.117 \cdot n$

Heat in smoke increases linearly with the contribution of both m_p and n, but compared to the stechiometric ratio (n), the m_p factor has a greater contribution.

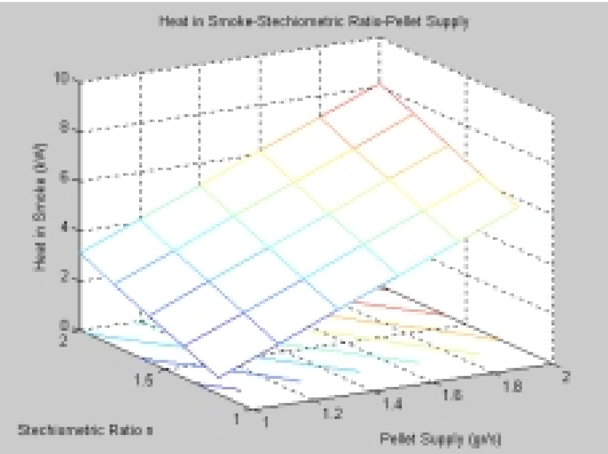

Fig. 3: Heat in smoke (kW) representation.

3.A.3. CO emissions (ppm, dry smoke)

$CO(ppm) = -12442.91 + 46486.011 \cdot 1/n^2$

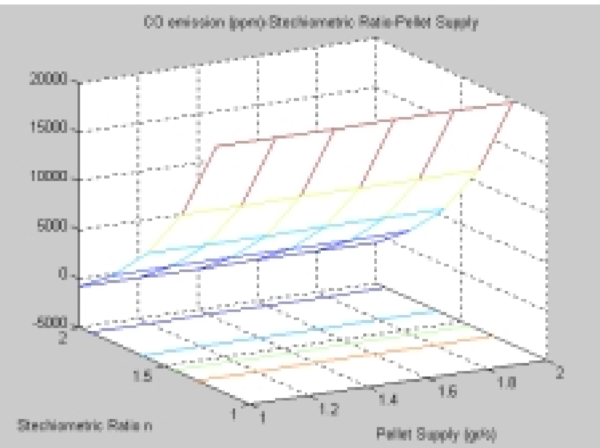

Fig 4.: CO emission (ppm) representation.

The best statistical model analysis results in this expression where the stechiometric ratio (n) is the unique dependent factor. Within the experienced range, an almost exponential response in CO emission is produced when the stechiometric ratio (n) is decreased.

3.A.4 NO emissions (ppm, dry smoke)

The influence of m_p and the stechiometric ratio (n) in NO emissions results in a very complicated and strange equation, according to statistical model analysis. In addition, the expressions does not seem to have physical sense. However, in figure 4 you can see a visual description of the influence of both factors.

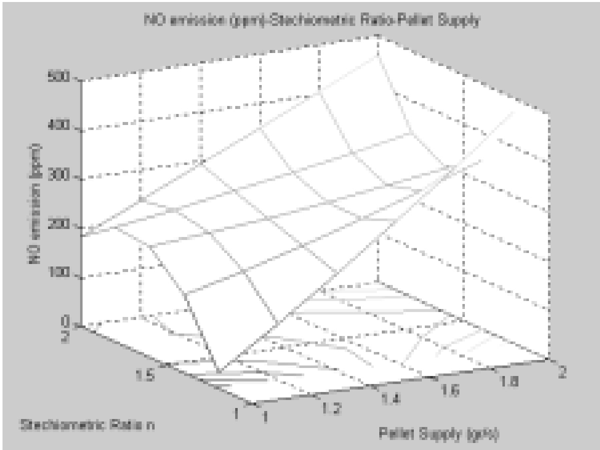

Fig. 5: NO emission (ppm) representation.

3.A.5. O_2 emissions (%, dry smoke)

$O2(\%) = 6.817 \cdot n - 1{,}002 \cdot m_p$

The contribution of the factors m_p and n to the variable (O_2) is quite different: when the amount of pellet (m_p) is increased the O_2 emission is slightly reduced. The stechiometric ratio (n) is how ever the relevant factor.

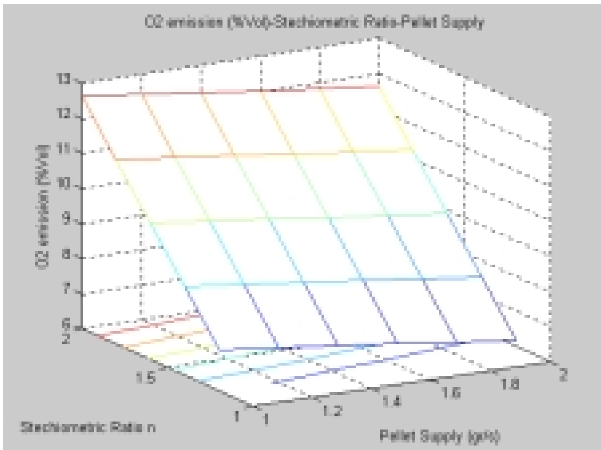

Fig. 6: O_2 emission (%) representation.

3.A.6. Stove efficiency (η_{st})

$\eta_{st} = 0.6198$

Stove efficiency η_{st} , that is the gain in hated water [$Q_w/m_p \cdot LHV$ (WB)], is almost constant value (62%), so that a great amount of energy can not be transferred to the circulating water.

3.A.7. Combustion efficiency (η_C)

$\eta_C = 0.9163 + 0.1834 \cdot n/m_p - 0.4799/m_p$

Combustion efficiency η_C deviate slightly, and mainly because of m_p, from a constant value (92%).

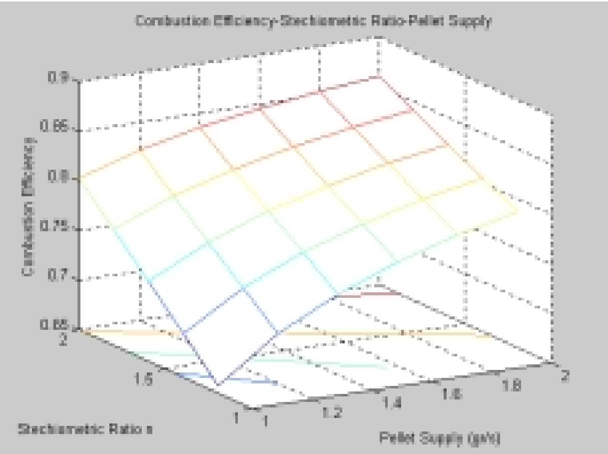

Fig 7: Combustion efficiency representation.

B. Comparing of Set 2 and Set 3: Preheating

3.B.1. Energy Balance

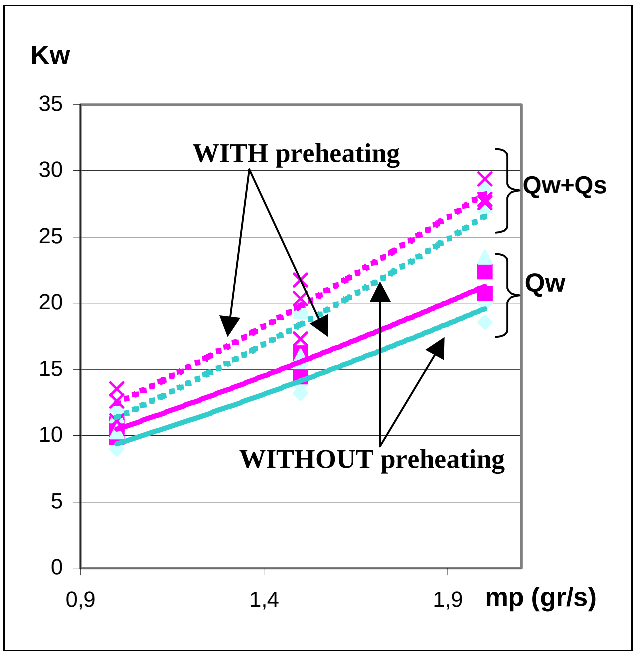

Fig 8: Contrast of energy balance

Preheating of primary air (upper lines of the series) improves to some extent the gain in energy both in water (Q_W) as in the exhaust gases (Q_S). The main factor is in any case m_p and not so much the stechiometric ratio (n).

A similar analysis but taking into consideration efficiencies varying according to the stechiometric ratio shows that preheating improves efficiency but not too much.

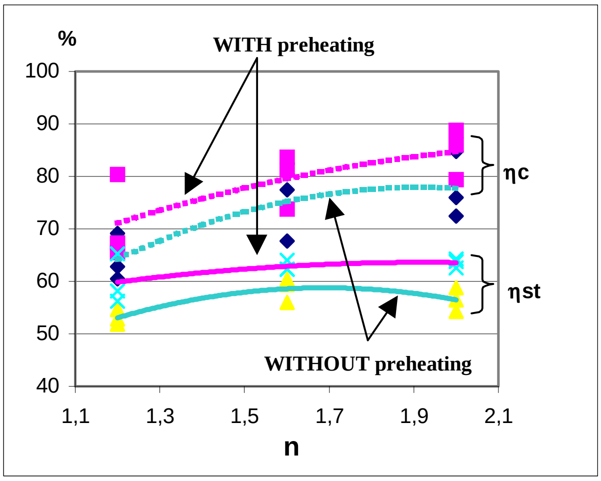

Fig 9: Contrast of efficiency

3.B.1. Emissions

As a general rule emissions of CO and NO are determined by the stechiometric ratio (n). Preheating improves the reduction of emission but changes on the stechiometric ratio has a much greater impact on them.

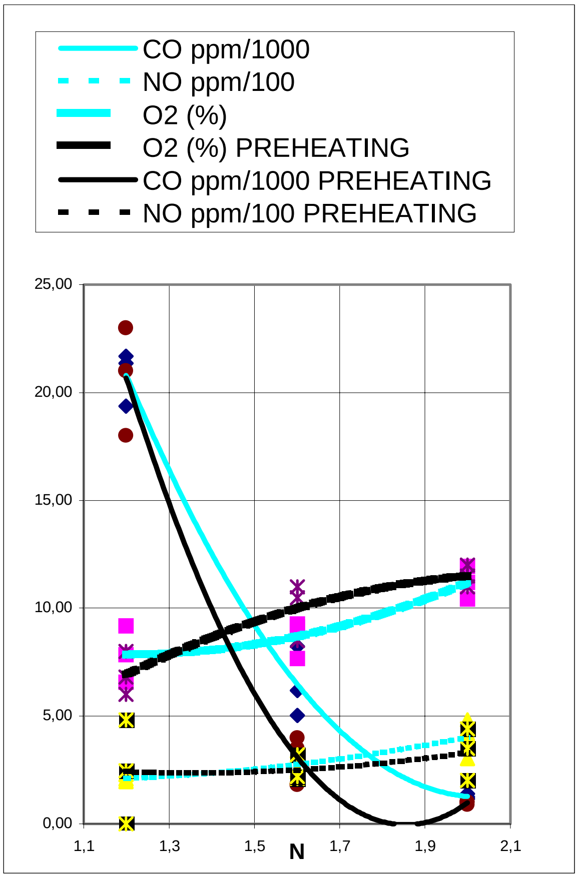

Fig 8: Contrast of emissions

4. Conclusions

- A general characterisation of the behaviour of a pellet-stove plant with preheating of primary air was obtained. A high correlation index R^2 was obtained in the regressions of a bunch of energy and emissions variables
- Critical factors are m_p for energy variables and n for emission variables.
- Preheating of air is easy to achieve and improves the outfit of energy of a small pellet stove although the benefit is not too much. The benefit is about 2 or 3 kW which could be interesting with the plant working with small loads (around 10 kW)
- Preheating of air improves also the reduction of emissions but in a much minor level.
- Preheating is more interesting form an energetically pointy of view than form a environmental point of view.

5. Acknowledgement

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6. References

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