Influence of heating oil formulation on the combustion and emissions from domestic condensing boilers

C. Esarte, J. Delgado

Repsol Technology Center, Mόstoles (Madrid), Spain

Introduction

The building sector is responsible for 40% of final energy consumption and approximately 30% of the EU greenhouse emissions, being an important source of CO_2 and atmospheric pollutants, which affect the local air quality. Consequently, European authorities are promoting the substitution of old apparatus by modern equipment aiming to increase energy efficiency in buildings and to improve urban air quality. Measures include requirements for high efficiency domestic boilers and encouragement of low emissions (CO, NO_x and particles) equipment installation. [1,2].

Lately, new heating oil boilers have been developed incorporating condensing technology, enabling the recovery of latent heat from water condensation in the exhaust gases, thus increasing energy efficiency. Blue flame burners are also integrated in such equipment optimizing spray pulverization which results in combustion process improvement and emissions reduction. Fuels need to be adapted to the new equipment by diminishing the sulphur content in order to avoid corrosion problems coming from water condensation. Further fuel development may be achieved aiming at reducing fossil fuel consumption and decreasing the formation of pollutants.

In this context, Repsol, as a global energy company concerned about climate change and atmospheric pollutants, has studied the effect of fuel properties and composition on the performance and emissions of domestic heating oil condensing boilers.

Materials and Methods

The present study has been carried out using two commercial heating oil condensing boilers from different manufacturers and similar technical characteristics (Table 1).

Table 1. Technical characteristics of heating oil condensing boilers

Boiler	Model	Heating Output (kW)	Heating Efficiency (%)	Burner
1	Tifell Biofell 30	30	98	Blue flame Modulating
2	Wolf COB-29	29	97	Blue flame 2 Stages

Heating efficiency has been experimentally determined following European Normative EN 304:1994+A2:2004 [3,], whereas the concentrations of O_2, CO, NO, NO_2 and SO_2 in the exhaust gases have been measured by means of a Testo opaticemeter and two Testo combustion and emissions analyzers (Testo 350 XL and Testo 330-2).

The study has been carried out consuming 6 samples of commercial heating oil (CHO), as defined by Spanish regulation [4]; 6 samples of commercial low sulphur diesel oil (LSDO); and

corresponding author: Claudia Esarte, e-mail: claudia.esarte@repsol.com

19 heating oil fuel samples formulated from 14 refinery products. Fuels have been analyzed according to Table 2.

Table 2. Analysis of heating oil formulations

Property	Test Method
Density at 15ºC	ASTM D4052
Distillation curve	ASTM D86
Nitrogen content	ASTM D4629
Sulphur content	ASTM D5453
Carbon and hydrogen content	XRF
FAME content	UNE EN 14078
Aromatics content	UNE EN 12916
HHV&LHV	ASTM D 240
Viscosity at 20ºC and 40ºC	ASTM D445

Results and discussion

Commercial diesel fuel tests

The performance of 6 samples of CHO and 6 samples of commercial LSDO has been studied in the two commercial heating oil condensing boilers previously referred. The results in terms of heating efficiency and combustion emissions are similar for both boilers, since the equipment design and the technology are similar.

Heating efficiency determined following EN 304:1994+A2:2004 [3] does not present significant differences depending on the fuel sample and results are in agreement with the ones certified by manufacturers.

The concentrations of O_2, CO, NO, NO_2, SO_2 and opaticity have been measured in the exhaust gases. CO and opacity are independent of the tested fuel. CO emissions remain under 20 mg/kWh, which is under the toughest level established for CO emissions from domestic boilers [5]. Opacity also shows very low levels, presenting values near zero.SO_2 emissions are directly related to the sulphur content in fuel.

NO_x emissions are dependent on the tested fuel. NO_x emissions from both boilers are similar and lower for LSDO in comparison with CHO. It is remarkable that NO_x emissions from low sulphur diesel oil are bellow or around 70 mg NO_x/kWh, which is the most restrictive limit established for gas boilers (Class 5), which currently set the state of the art regarding NO_x emissions limits [5].

Laboratory pilot heating fuel formulations

Tests using commercial fuel samples reveal an obvious influence of fuel formulation on NO_x emissions from the most advanced domestic heating boilers. NO_x emissions are especially relevant to make gas and oil heating equipment equivalent in terms of emissions of pollutants. Thus, an analysis of the fuel characteristics that present an influence on such emissions has been carried out.

The performance of 19 pilot heating oil fuel samples formulated from 14 refinery products has been analyzed using only Boiler 1, given the similar results obtained for both apparatus in the previous tests. These pilot formulations have been designed targeting the maximization of energy density and minimization of nitrogen content in fuel samples.

As before, the results in terms of heating efficiency and combustion emissions are in agreement with those obtained for CHO and LSDO. Energy efficiency values are in

agreement to the manufacturer certification. CO and opacity are independent of the tested fuel and present low concentrations referred to current limitations. SO_2 emissions are directly related to the sulphur content in fuel samples.
Figure 1 presents NO_x emissions from Boiler 1 consuming refinery products and pilot formulations. As it is seen in such figure, many of the refinery products lead to NO_x emissions levels under or around the most restrictive levels established for gas boilers [5], corresponding to refinery streams with low nitrogen content and low energy density. The highest NO_x emissions are associated to high energy density and high nitrogen content refinery products.NO_x emissions from pilot formulations are around Class 5 since such formulations have been designed aiming such level of emissions, keeping low nitrogen content, while maximizing advantageous properties related to heating oil such high energy density.

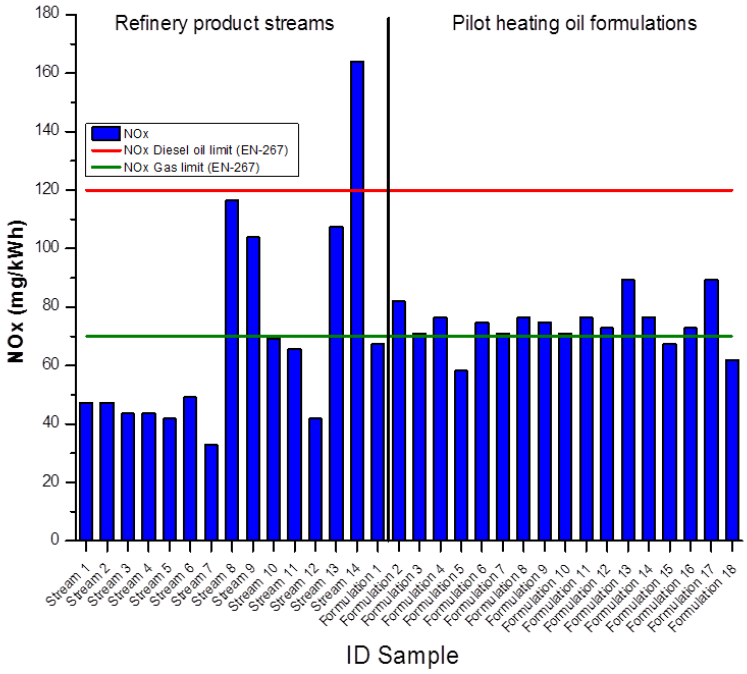

Figure 1. NO_x emissions from Boiler 1 consuming refinery products and pilot heating oil fuel samples.

The analysis of these results leads to conclude that the most appropriate refinery products for low emissions heating oil formulation are those coming from low nitrogen crude oil and/or stream products coming from hydro-treating processes.

NO_x emissions map and specification proposal

NO_x emissions results obtained from this work have been statistically analyzed aiming to identify the most relevant fuel parameters for NO_x formation and to correlate emissions to fuel properties. A multivariable analysis has been performed and a statistically representative prediction model of NO_x emissions as a function of nitrogen content and distillation curve has been inferred and validated from experimental data. Figure 2 shows a NOx emissions maps built from experimental data and the inferred prediction model.

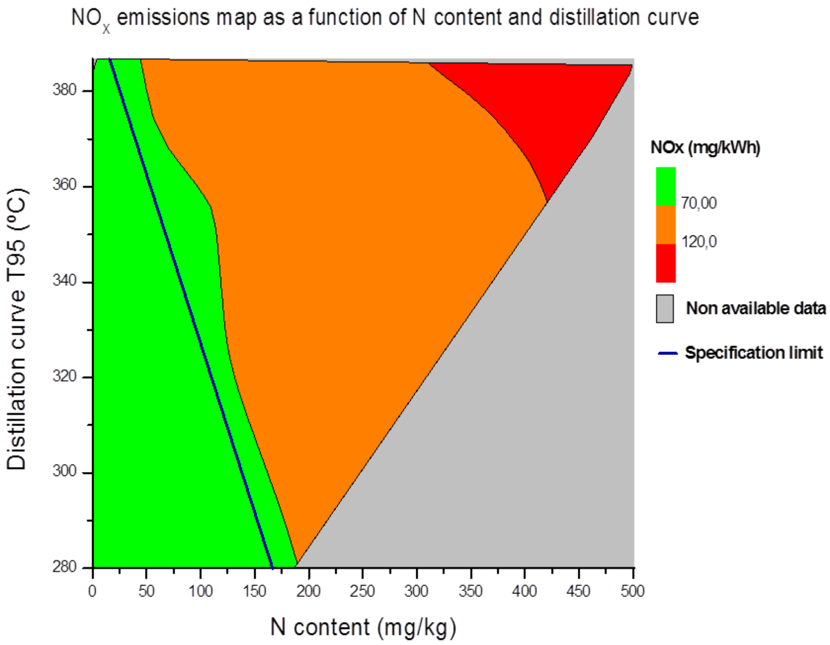

Figure 2. NO_x emissions map as a function of nitrogen content and distillation curve.

In order to guarantee low NO_x emissions, an equati on relating nitrogen content and distillation nitrogen content maybe proposed for the last generation boilers (Equation 1):

$$\frac{(T95-280)}{(165-N)} < 1{,}4082 \qquad \text{(Equation 1)}$$

Conclusions

The present work has led to conclude that fuel properties, specifically distillation curve and nitrogen content, show an influence on pollutant emissions, especially NO_x. With the appropriate fuel, this pollutant may be reduced below the lowest limit required for gas domestic boilers, which until now set the state of the art in terms of NO_x.
Besides, a map of NO_x emissions as a function of fuel properties, useful to predict NO_x emissions from cutting-edge heating oil boilers, has been inferred and validated from experimental data.
Finally, an equation is proposed to guarantee low NO_x emissions.

References

[1] Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency.
[2] Recommendation EU 2016/1318 Guidelines for the promotion of nearly zero-energy buildings.
[3] EN 304:1994+A2:2004. Heating Boilers. Test Code For Heating Boilers For Atomizing Oil Burners.
[4] RD 1088/2010, de 3 de septiembre por el que se modifica del RD 61/2006, de 31 de enero, en lo relativo a las especificaciones técnicas de gasolinas, gasóleos, utilización de biocarburantes y contenido de azufre de los combustibles para uso marítimo.
[5] EN 267:2000+A1:2011. Automatic Forced Draught Burners For Liquid Fuels.