EXPERIMENTAL INVESTIGATION OF FUEL OIL ADDITIVES EFFICACY ON REDUCING THE EMISSION OF ATMOSPHERIC POLLUTANTS FROM ULTRA-VISCOUS OILS

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***Abstract**. This paper reports the results of experimental work carried out by IPT in which was investigated the effect of fuel oil additives on the emission rates of particulate material (PM), nitrogen oxides (NO_x), sulphur dioxide (SO_2) and carbon monoxide (CO) and on the "soot index" of flue gases. The experiments were carried out in two test equipments of IPT Combustion Laboratory: a boiler and a vertical furnace. The oil burned during these experiments was typical of that used in boilers and process heaters in Brazilian industries which has abnormally high viscosity, carbon residue, asphaltenes, ash and nitrogen contents. Tests were carried out with and without adding additives to the fuel oil and involved three kinds of compounds manufactured by Shell. The additives were supplied into the oil line by a dosage pump just upstream the burner. The main conclusions are: (1) the use of additives have lead to reduction on emission rate of PM up to about 48 % and on "soot index" in the flue gases of two numbers in a scale of 0 to 9 (2) the utilization of additives didn't change meaningly the emission rates of CO, SO_2 and NO_x. This experimental work was financial supported by Shell Brasil Ltda.*

***Keywords.** Fuel oil additives, heavy oil combustion, atmospheric pollution, particulate material emission.*

1. Introduction

Brazilian fuel oils are very heavy that means high viscosity and furthermore high carbon residue, asphaltene, ash and nitrogen contents. These are classified as types 1 to 9 according to their increasing viscosity and as A or B according to their sulphur content, A for the high (1 to 2.5%) and B for low one (up to 1%). Owing to these properties the pollutant emissions from the combustion of these oils are very high, mainly those of particulate material constituted mostly of unburned carbon. Beyond the improvements in atomization quality and swirling motion provided by the conception of recent burners, the use of combustion additives is being increasingly considered by the users of medium and large boilers for matching the emission limits imposed by regulations.

The users normally do not have enough information about additives because informative material issued by the suppliers is quite poor. On the other hand papers published on technical congresses and journals on this subject are very scarce and generally refer to European or American heavy fuel oils that are much lighter than the Brazilian ones, not allowing simple transposition of the results.

These facts were the main motivation for this work in which was investigated the effect of fuel oil additives on the emission rates of particulate material (PM), nitrogen oxides (NO_x), sulphur dioxide (SO_2) and carbon monoxide (CO) and on the "soot index" of flue gases. The experiments were carried out in two test equipments of IPT Combustion Laboratory (an boiler and an vertical furnace), with and without adding additives to the fuel oil (type 1B) and involved three kinds of compounds manufactured by Shell.

2. Additives

The additives normally commercialized fall into one of the three following classes:

- Class 1: Fuel-handling additives - These additives may in some circumstances contribute to the control of pollutant emission through influence on the physical properties of the fuel or by stabilizing the condition of important fuel-handling elements; for example, maintaining spray nozzle cleanliness. However, such effects are incidental and can be expected to be small in the presence of proper fuel handling and equipment maintenance.

- Class 2: Combustion additives - These additives are specifically intended to affect the combustion process and, hence, may have a direct influence on the pollutants classed as products of incomplete combustion. They are often termed combustion improvers.

- Class 3: Post-flame treatment additives - These additives that operate in the post-flame region include various scavenging agents and pollutant property modifiers, as well as agents which modify the catalytic properties of exposed heat exchanger and breeching surfaces.

The additives manufactured by Shell are mixtures of organic solvents (asphaltene dispersing promoters; class 1) and organic mettalic compounds (combustion catalysts; class 2).

3. Experimental set-up

3.1. Test boiler

Part of the tests was carried out in a small commercial fire tube boiler, having 600 kg/h of nominal steam load (saturated at 12.10^5 Pa), equipped with a steam-atomizing oil burner of 60 kg/h nominal flow rate - Fig. (1a). A platform was installed in the stack boiler where the sampling station for gas composition and PM collecting is located.

3.2. Test furnace

Tests were carried out too in a cylindrical vertical test furnace of 1.45 m internal diameter and 4.0 m height. The furnace steel shell is double plated and divided in twelve sections. Each section, as well as the furnace front end are provided with independent water cooling flows - Fig. (1b). The furnace is coupled to a stack provided with a platform where the sampling station for gas composition and PM collecting is located.

A commercial natural draught oil burner, typical of petrochemical furnaces, equipped with a steam-atomizing device and having 80 kg/h of nominal oil flow rate was used.

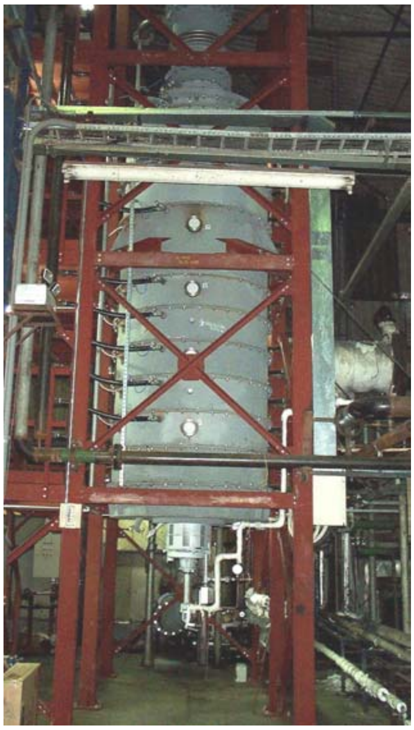

Figure 1. Test boiler (a) and test furnace (b)

3.3. Additivation system

The additives were supplied in to the oil line by a dosage pump just upstream the burner - Fig. (2).

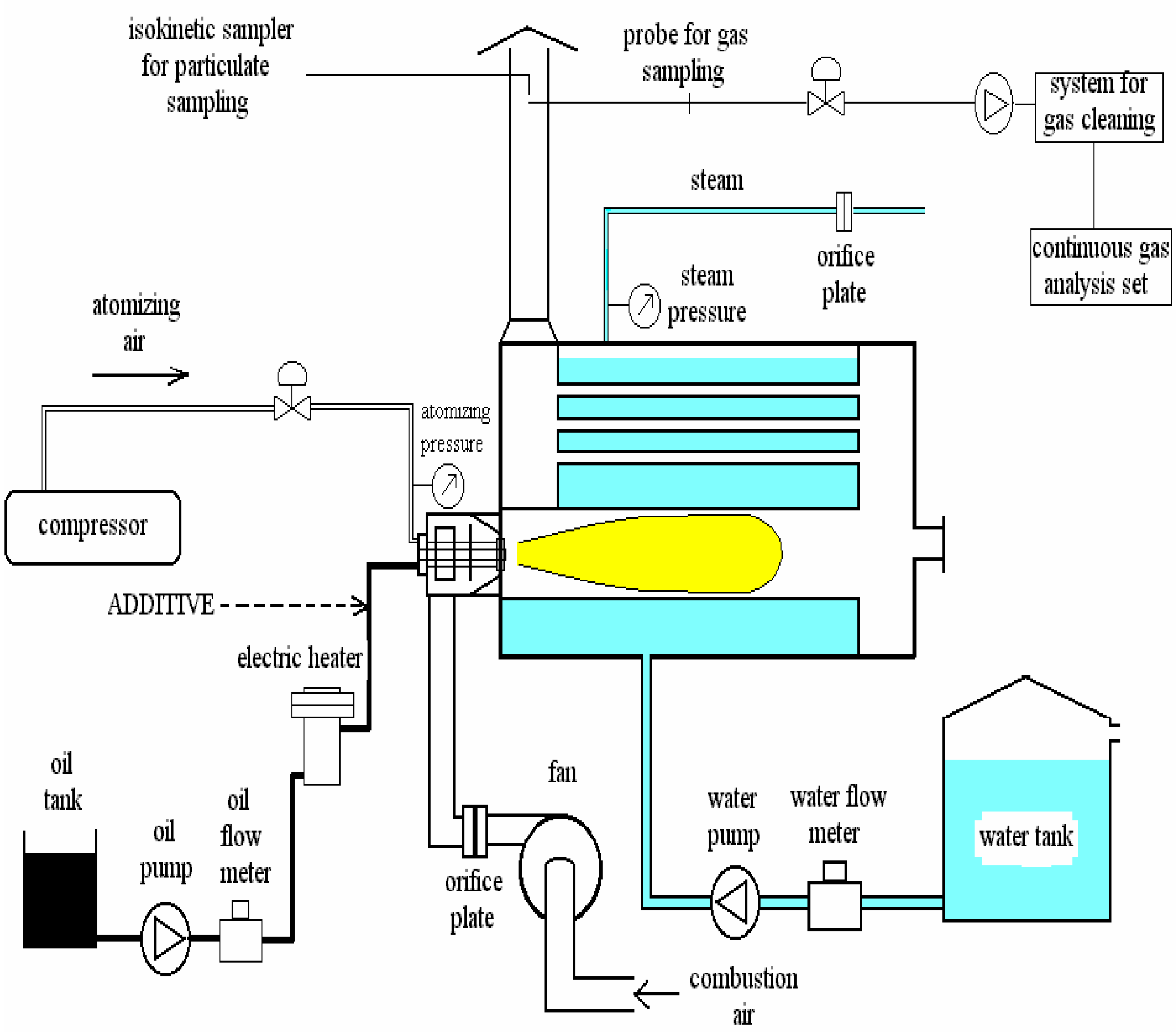

Figure 2. Test boiler schematic drawing (basic flowsheet of the test furnace is similar)

3.4. Instruments

A data acquisition program was provided for monitoring and recording the main operational parameters during the tests. Flow rates, pressures and temperatures were measured with typical instruments - orifice plates, pressure transducers and thermocouples.

Water-cooled probes were inserted into the stack for gas sampling. The gas flux was continuously pumped across a cooling and filtering system and further sent to a continuous gas analysis train.

The continuous gas analysis set was composed of O_2 (paramagnetic), CO, SO_2, CO_2 (infrared) and NO_x (chemiluminescence) analysers. The uncertainty of these measurements is ± 3 %, but not less than 5 ppm.

For particulate sampling an isokinetic sampler, built according to the USEPA method n^o 5, was used. For sampling procedure the same method was followed.

In order to determine the “soot index” of flue gases a “smoke test” device was used. A sampling pump draws off a certain amount of gases and then sucks it through a filter paper disk. The paper, in turn, darkens during this process and thus gives the measure of the soot content of the gases. A "smoke scale" is used to take a reading off the darkened disk. (in a scale of 0 to 9, “0” corresponding to “fully clear” and “9” to “black”).

3.5. Fuel

The fuel oil burned in the tests was supplied in two batches, which properties are shown in Tab. (1).

Table 1. Fuel oil characteristics

Fuel oil	**batch 1**	**batch 2**
Type (Brazilian nomenclature)	1B	1B
Composition (% mass; dry):		
_ carbon	89.4	88.1
_ hydrogen	8.5	9.9
_ nitrogen	1.1	1.0
_ sulphur	1.0	0.9
_ ash	0.08	0.04
_ asphaltenes	7.3	12.0
_ carbon residue (Conradson)	13.5	13.0
High heat value (MJ/kg)	41.6	41.9
Viscosity		
	SSF (s)	cSt
_ at 50 °C	643	1334
_ at 80 °C	60	-
_ at 100 °C	-	63
_ at 150 °C	11	-
Density (g/cm^3):		
_ at 25 °C	1.04	-
_ at 50 °C	1.02	1.01

3.6. Shell additives

Tests were carried out with three fuel oil additives manufactured by Shell, designated here by A1, A2 and A3. According to Shell, there is a small composition difference among the additives.

4. Tests

4.1. Methodology

In order to investigate the effect of fuel oil additives on the emission rates of PM and on the “soot index” of flue gases in different combustion conditions trials were carried out in the test boiler and furnace. In the former, trials were carried out feeding pure (“white test”) and additived oil (additives A1, A2 and A3) to the burner. In the second, where the combustion quality is poor and in consequence the PM emissions are tending upwards, trials were performed with pure oil and oil blended with additives (A1 and A2).

In the boiler tests, the effect of fuel oil additives on the emission rates of NO_x, CO, SO_2 was investigated too.

Additive concentration in the oil for all trials were maintained around 1000 ppm for A1 and A2 and 250 ppm for A3, according to prescribed by Shell. During the boiler trials oil from batch 1 was used and in the vertical furnace trials it was used oil from batch 2. But owing to the close properties of both batches it can be considered that the same oil was used in all trials.

In order to allow the comparison between trials a stability pattern for the test equipments was maintained. The data acquisition program allowed to follow the critical variables by real-time graphics displayed in the computer screen and when necessary adjustments were made into control systems up to a smooth operation had been achieved.

4.2. Boiler trials

4.2.1. Results

Table (2) summarizes the operational conditions during the tests.

The influence of additives over NO_x, CO, SO_2 and PM emissions and over the “soot index” of flue gases is shown in Figs. (3), (4), (5), (6), (7) and (8).

Table 2. Operational conditions of boiler during the tests

Fuel oil flow rate *	35 kg/h	* power volumetric releasing rate = 1600 kW/m^3 ** viscosity = 40 cSt *** air coefficient = 1.07 **Obs.** O_2 concentration variable in the elaboration of the CO x O_2 and NO_x x O_2 curves
Fuel oil temperature in burner inlet **	115 °C	
Combustion and atomizing air temperature	ambient	
Atomizing air / fuel oil mass ratio	0.6	
O_2 content in flue gases ***	1.5 % vol.dry	

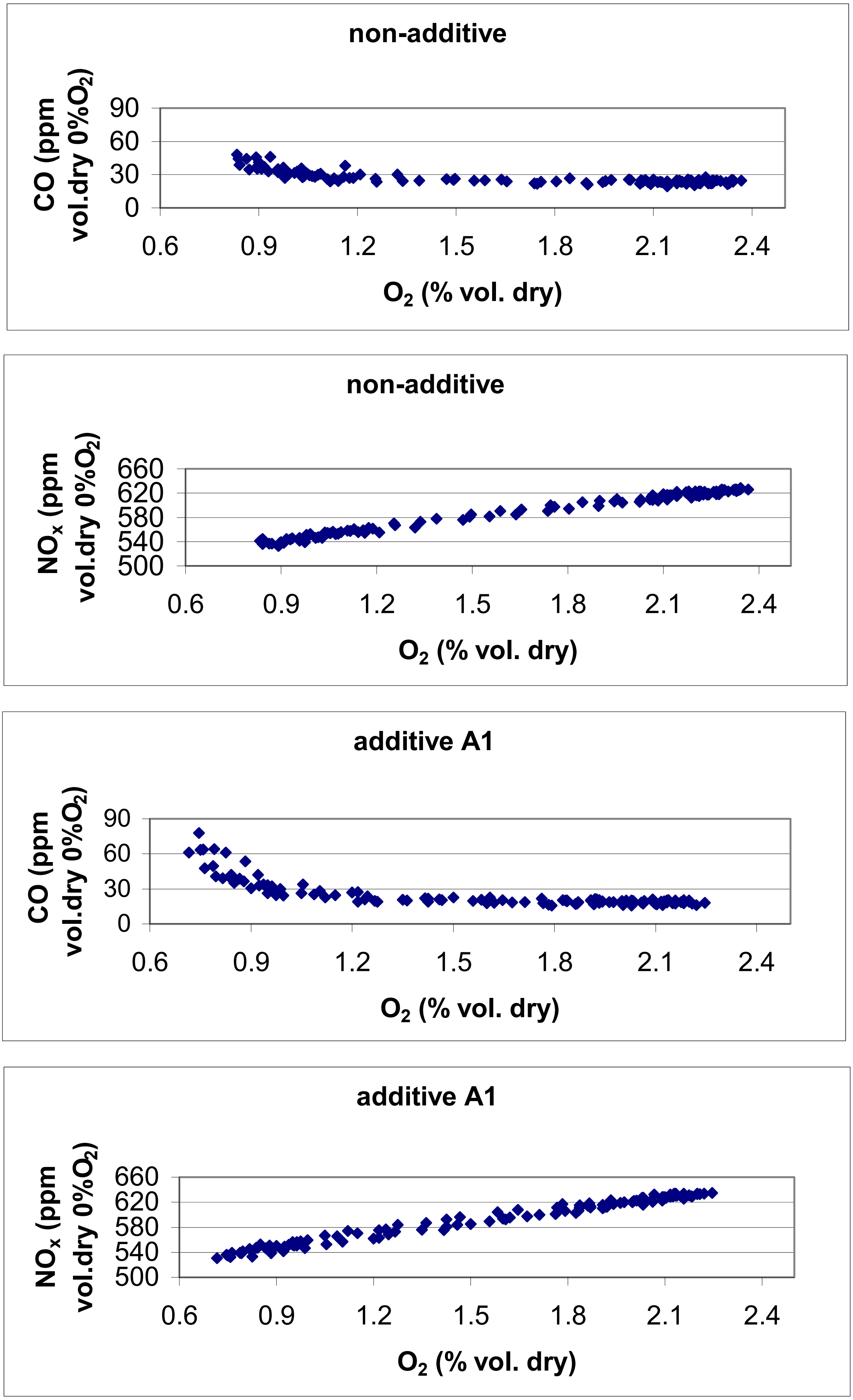

Figure 3. Effect of air excess on CO and NO_x emissions (boiler test)

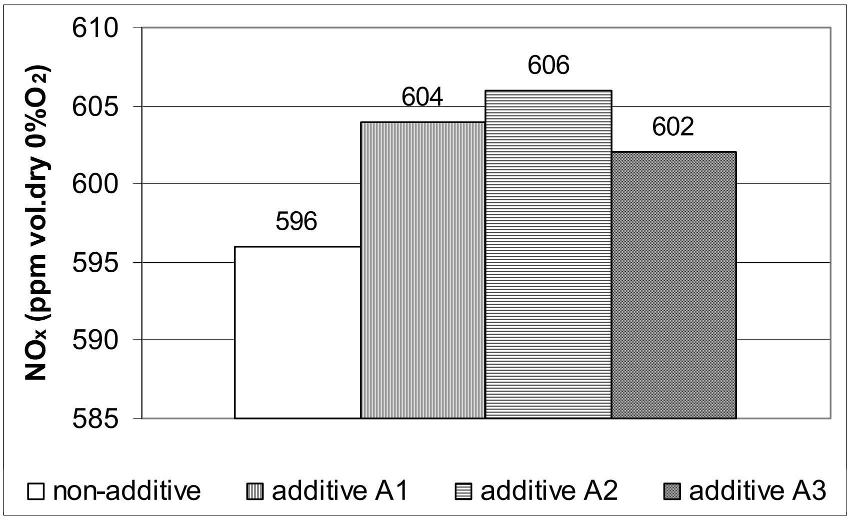

Figure 4. Effect of additives on NO_x emissions (test boiler)

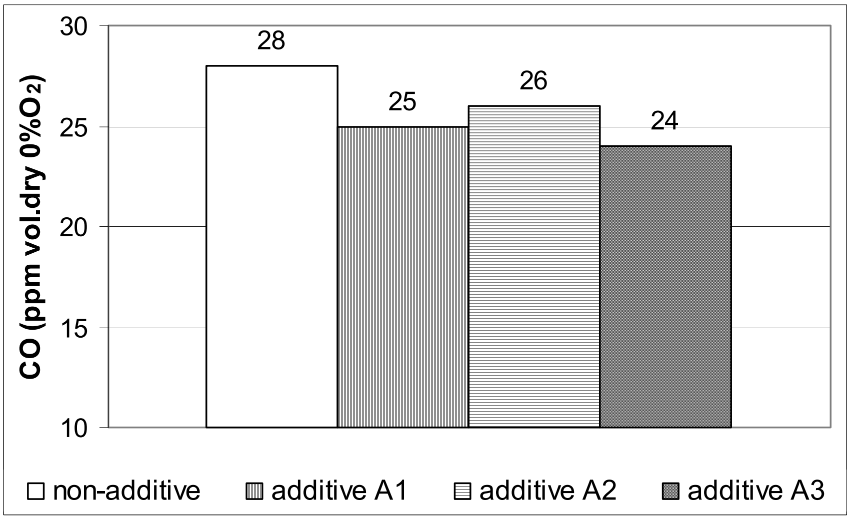

Figure 5. Effect of additives on CO emissions (test boiler)

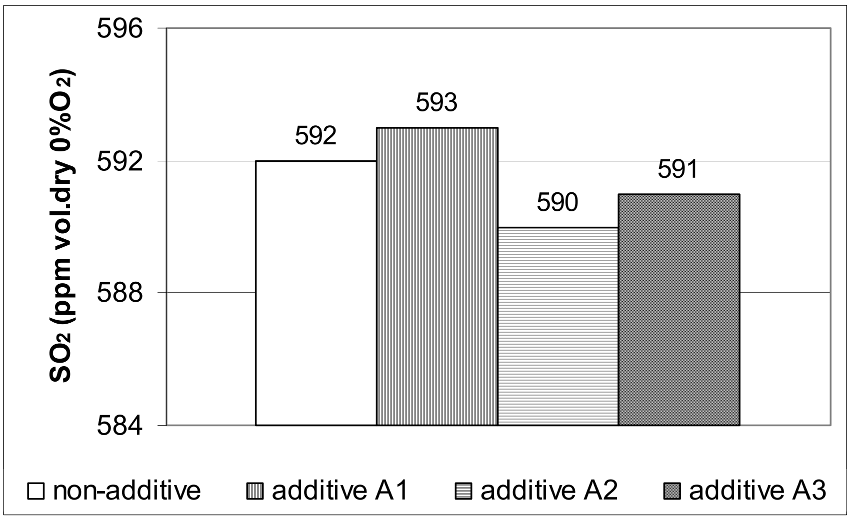

Figure 6. Effect of additives on SO_2 emissions (boiler test)

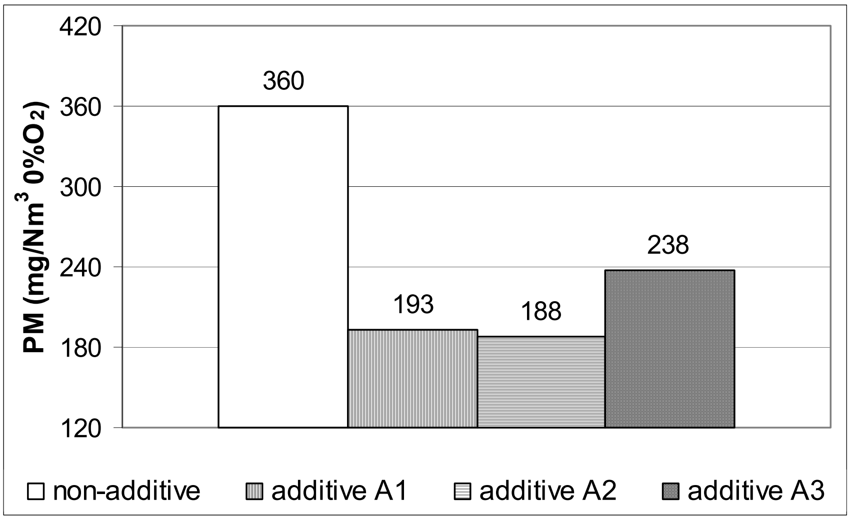

Figure 7. Effect of additives on PM emissions (boiler test)

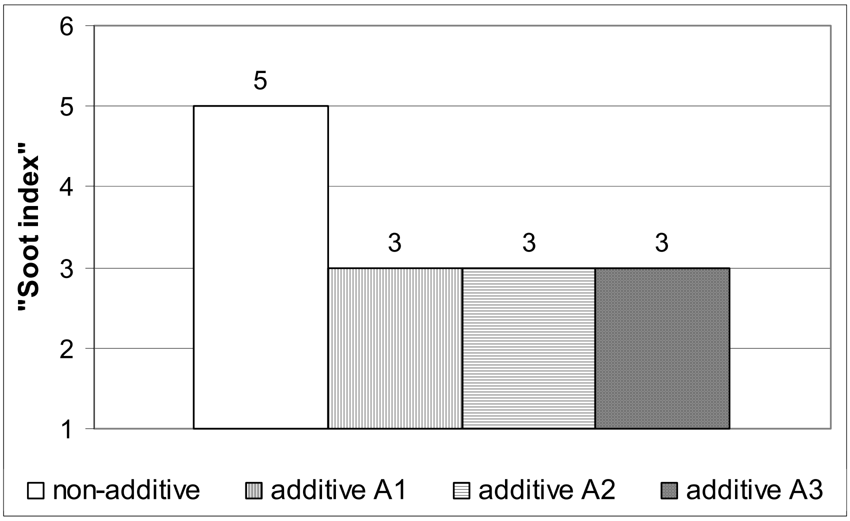

Figure 8. Effect of additives on “soot index” of flue gases (boiler test)

4.2.2. Comments

- In Fig. (3), it can be seen that the NO_x emissions increase with the O_2 concentration in the flue gases and for that values of O_2 content above 1.0% the CO emissions change slightly with the air excess. The curves for CO and NO_x versus O_2 agreed very well with those obtained during field measurements carried out by IPT in large boilers firing fuel oils. It can be seen too that the shapes of the curves practically are not affected by the additive A1 use.

- The NO_x, CO and SO_2 concentrations in the flue gases, for the same operational conditions (air coefficient of 1.07), did not change significantly due to the use of additives.

- The use of additives has dropped the PM concentration in the flue gases. It can be observed a reduction of 46, 48 and 34% from use of additives A1, A2 and A3, respectively, related to the non-additive fuel value.

- The results show that the use of additives decreased the “soot index” of flue gases from “5” to “3”. This small influence agrees with the expected because the gas opacity, which is qualitatively evaluated by the “soot index”, is mainly due to soot particles while the action of additives only should occur over coke particles.

4.3. Vertical furnace trials

4.3.1. Results

Table (3) summarizes the operational conditions during the tests. The influence of additives A1 and A2 over PM emissions and over the "soot index" of flue gases is shown in Fig. (9) and Fig. (10).

Table 3. Operational conditions of furnace during the tests

Fuel oil flow rate *	55 kg/h	* power volumetric releasing rate = 97 kW/m^3 ** viscosity = 40 cSt *** air coefficient = 1.22
Fuel oil temperature in burner inlet **	115 °C	
Combustion air temperature	ambient	
Atomizing steam / fuel oil mass ratio	0.3	
O_2 content in flue gases ***	4.0 % vol.dry	

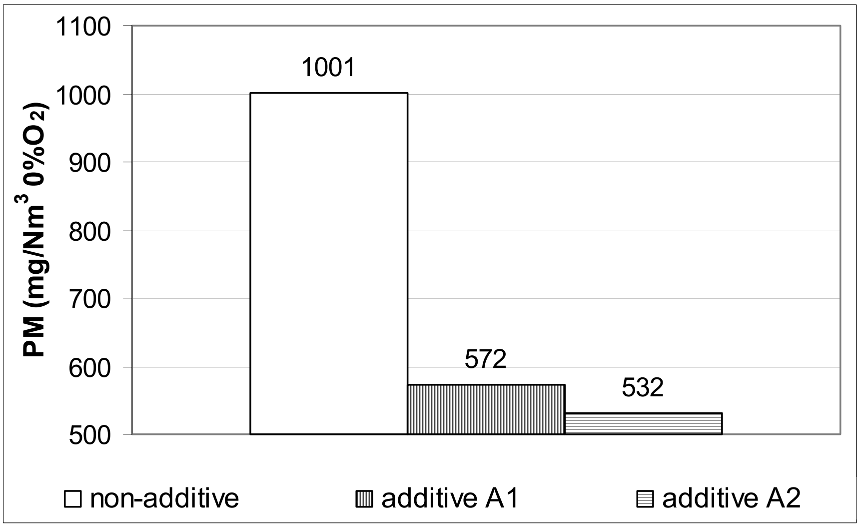

Figure 9. Effect of additives on PM emissions (furnace test)

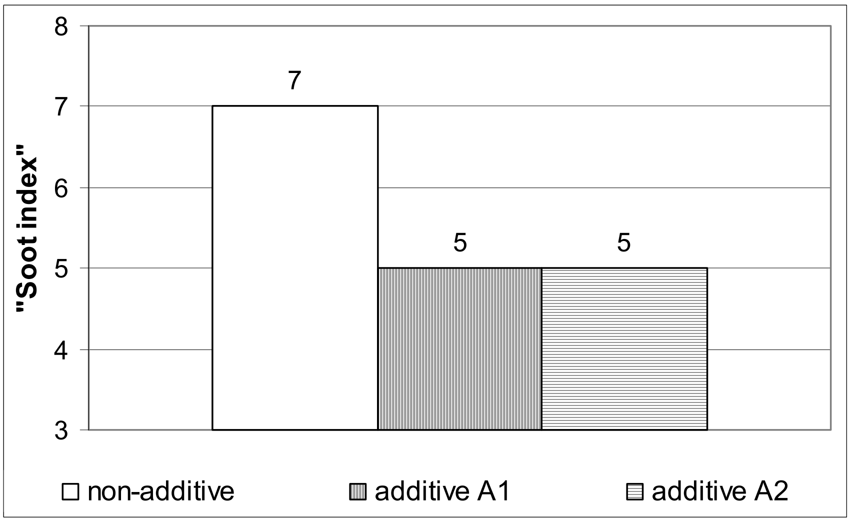

Figure 10. Effect of additives on "soot index" of flue gases (furnace test)

4.3.2. Comments

- The PM content and "soot index" of flue gases in non-additive trials show that combustion quality was worse than tests in the boiler, according to the intended.

- The use of additives has dropped the PM concentration in the flue gases. It can be observed a reduction of 43 and 47% from the use of additives A1 and A2, respectively, related to the non-additive fuel value.

- The results show that the use of additives decreased the "soot index" of flue gases (from "7" to "5").

5. Conclusions

Despite the experiments have not been as extensive as necessary to ensure unequivocal conclusions, the following indications can be drawn:

- The use of additives have lead to reduction on emission rates of PM up to about 48 % (34 % for additive A3) and on "soot index" in the flue gases of two numbers (from "5" to "3", for instance). The utilization of additives didn't change meaningly the emission rates of CO, SO_2 and NO_x.

6. Acknowledgements

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