THE ECOTUBE SYSTEM : A PRIMARY TECHNIQUE TO REDUCE NO_x EMISSION IN WtE PLANT

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ABSTRACT

The Ecotube system is a primary technique to reduce NO_x emission, based on pressurised air injection through tubes extending inside the first pass of the furnace. This equipment has been tested on an Energy from Waste plant operated by VE during a six month trial period. Different configurations and settings have been tested, proving that it is possible to decrease the NO_x concentration below 200 mg/Nm^3, representing a 45 % reduction efficiency, while keeping the CO level below 10 mg/Nm^3, without adding any reactant but air. Some tests have also been carried out injecting ammonia through the Ecotubes. In this case, NO_x emission levels below 100 mg/Nm^3 have been achieved.

INTRODUCTION

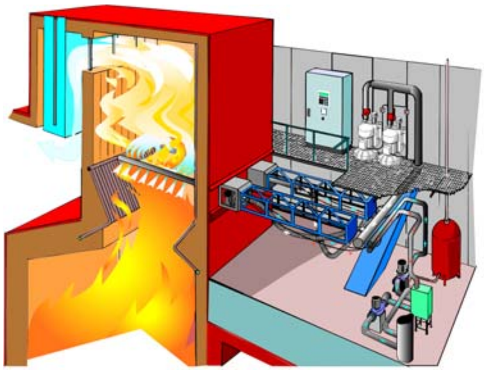
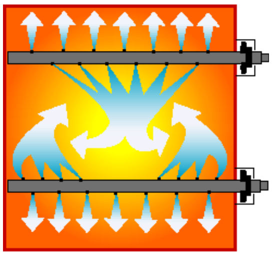
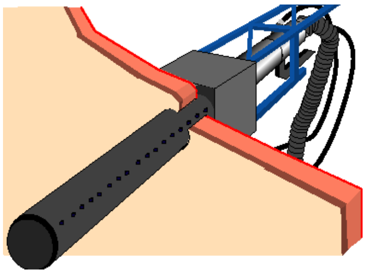
The new European Incineration Directive will impose on all Energy from Waste plants a NO_x maximum concentration in flue gas of 200 mg/Nm^3. This challenging threshold, to be met by 2006, will require NOx control equipment retrofits on nearly all the existing plants.
NO_x emissions can be reduced either by primary or secondary methods. The first category includes all the techniques consisting of optimising combustion conditions. This can be achieved by re-circulating flue gas, staging the combustion, or decreasing the excess air. However, difficulties in obtaining the optimal mix often result in incomplete combustion and CO peaks.

The Ecotube system is a new primary technique, that allows for decreased NO_x concentrations without increasing CO levels, by creating a zone of turbulence in the upper furnace. The process consists of injecting pressurized air through tubes in the first pass of the boiler. This system has been installed and tested on the Tyseley Waste Disposal plant, near Birmingham (UK). This article will present the results obtained during this testing period.

TECHNOLOGY OVERVIEW

The Ecotube system consists of one or more liquid cooled and automatically retractable tubes equipped with rows of nozzles along the length, used to inject pressurised air in the first section of the boiler. This resulting turbulence homogenises the flue gas and the temperature. The amount of air injected via the Ecotubes is quite low and represents about 5 to 10 % of the total amount of combustion air. Thanks to the turbulence created, it is easy to decrease the amount of primary, and more consequently of secondary air injected. By staging the combustion this way and by improving the flue gas mixing in the first pass, the NO_x concentration is lowered without affecting the CO level. Conventional performances obtained by this system are:

- NO_x reduction from 30 to 70 %
- CO still below 10 mg/Nm^3 (for average values)

The Ecotubes are equipped with 2-3 rows of nozzles, quickly changeable for different combinations.

Fig 1 : Description of the technology

This technology has been tested on the Tyseley Waste Disposal plant from June 2002 to February 2003. This plant is a 2 streams SteinMuller grate unit, each one treating 23.5 tph of Municipal Solid Waste (MSW).The energy recovery is made using a boiler producing 67tph of superheated steam 40 bars/400°C. No NO_x treatment methods have been previously installed on this unit. To reach the local limitation, that is to say 350 mg/Nm^3, additional air is injected through the last part of the grate to cool the fire and to reduce NO_x production. This additional air is called by-pass air. The total amount of air injected is divided into 3 parts:

- Primary air : 35,000 Nm^3/h
- Secondary air : 20,000 Nm^3/h
- By-pass air : 8,000 Nm^3/h

The oxygen set point in the first pass of the boiler is fixed at 6.5% and fluctuates from 5 to 8 %.

Operating the plant this way enables it to reach NOx emission levels neighbouring 340 mg/Nm^3, instead of the 450 mg/Nm^3 previously obtained without the by-pass air system.

At the end of June 2002, 2 Ecotubes had been installed on the 1st line, in the post-combustion chamber of the boiler, 3 meters from the roof of the 1st pass, that is 12 meters above the grate. The location of the tubes is represented in the figure 2.

This installation was not a fully automated system as it was only designed for temporary testing purposes. Additionally, a fan and a pump were installed to provide the pressurized air delivered through the tubes, and the water necessary for the cooling system. Each tube was provided with 2 rows of 21 nozzles.

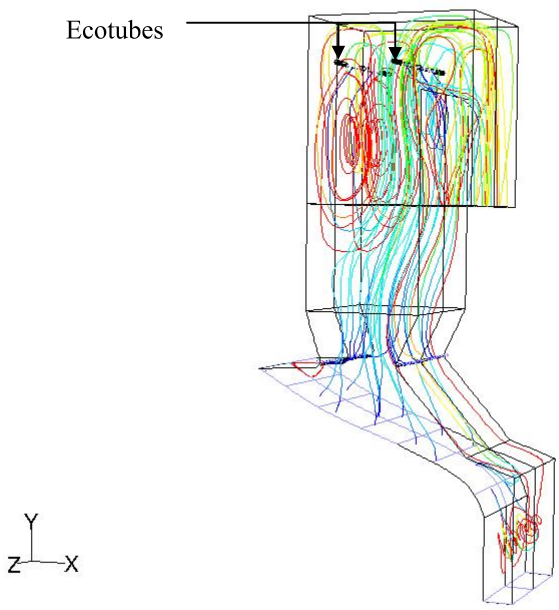


Figure 2 : Ecotube location in the first pass

TEST OVERVIEW

Different parameters have been changed during the test period. First, on the Ecotubes itself, the nozzles diameters were changed between 19, 25 and 33 mm. The lances could be axially rotated as to change the direction of the air jets and the air flow pressure could also be controlled for both tubes simultaneously. With this type of equipment, it is also possible to inject chemical reagents in addition to the air delivered through the nozzles. Tests with ammonia injection have been carried out during the test period.

Concerning the furnace operation parameters, several tests have been carried out, with different primary and secondary air injection as well as various O_2 contents. Tests have also been performed to compare configurations with and without by-pass air.

Two types of testing procedures were carried out: short period test and long period test. The short period tests were carried out for 5 to 8 hours. These tests were done to optimise the process and to find the best setting. A long period test was then conducted when an optimised configuration had been found. This configuration was then tested for 72 hours, to obtain more relevant data on a longer period.

Several parameters have been observed during the tests. First, concerning the plant operation parameters, the following data has been observed and recorded: steam production, quantity of primary, secondary air, temperatures in the furnace and in the boiler… Concerning emissions, continuous measurements have been carried out for NO_x, CO, O_2. Dioxins and Furans have also been measured using an extractive method complying with the NF EN 1948 norm. Bottom ash quality has also been analysed complying with the French norm NF X 31 210. Finally, the fly ash composition and production were measured during the 72 hours tests.

RESULTS

The results will be presented in three parts. First, tests carried out with the by-pass air on will be discussed, then the tests carried out with by-pass air off, and finally the ammonia injection tests results will be described.

Tests using by-pass air on

Nine different configurations for the Ecotubes have been tested with the by-pass air on. In general, for all these tests, the secondary air injection has been decreased from 20,000 Nm^3/h to values between 8,000 and 12,000 Nm^3/h. The amount of air through the Ecotubes has also been fixed at 9,000 Nm^3/h. Finally, the dry O_2 set point has been decreased from 6.5% to 5 %. The main configuration variables were the angles of the Ecotubes, and the number and diameter of the nozzles, just keeping a total aperture of the nozzles equivalent to 14,000 to 16,000 mm². The results of these tests are presented in table 1 .

Table 1 : Main emission results concerning tests with by-pass air on

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7	Trial 8	**Trial 9**
Secondary air (Nm^3/h)	12,400	7,700	7,700	7,700	7,700	7,700	7,700	7,700	9,300
NO_x Average 1h before test (mg/Nm^3)	298	420	333	349	383	390	328	340	340
NO_x Average 1h during test (mg/Nm^3)	259	360	218	299	279	229	204	210	**160**
% NO_x variation	-13 %	-14 %	-35 %	-15 %	-27 %	-41 %	-37 %	-38 %	**-53 %**
CO Average 1h before test (mg/Nm^3)	15.1	2.9	4.1	3.9	3.7	4.9	4.1	6	7
CO Average 1h during test (mg/Nm^3)	13.1	2.5	8.3	7.1	6.3	8.2	7.2	8	9
O_2 Average 1h before test (%)(1)	7.1	5.0	6.5	6.3	5.6	6.2	6.4	6.5	6.5
O_2 Average 1h during test (%)(1)	5.3	2.6	5.7	3.8	4.4	3.2	4.8	5.5	5.2

(1) O_2 content measured in the 1st pass of the boiler

The results of these tests show a NO_x reduction between 13 and 53 %. The CO content is maintained at values below 10 mg/Nm^3. The O_2 content is generally 1 % lower with the Ecotubes, corresponding to a flue gas flow 6 % lower. Dioxins measurements were carried out during the first trial. No noticeable impact has been found for this chemical: The value is kept below 0.1 ng ITEQ/Nm^3. Concerning the plant operation parameters, flue gas temperatures are 10°C lower in all the passes of the boiler. This could be due to the lower flue gas velocity, increasing the contact with the water tubes, and therefore favouring the efficiency of the energy recovery. Concerning residues, no impact has been found either on the bottom ash and fly ash composition, or on its leaching characteristics.

If we look more precisely at the results of the tests separately, we can see that several tests nearly reach the 200 mg/Nm^3 (tests 3, 7 & 8), but only test 9 leads to a value lower than 200 mg/Nm^3 whilst conserving reasonable O_2 and CO concentrations inside the furnace. Then, this configuration has been chosen to be tested for 72 h. For this test, the secondary air was fixed at the value of 10,800 Nm^3/h, and the O_2 set-point was fixed at 5 % during daytime, and 5.5 % during the night. Main test emission and operating parameters results are presented in the table 2 and compared to the 72 h before the test.

Table 2 : Results of the 72 h test with configuration 9

	72 h before the test		72 h test			
	Average	Standard deviation	Average	Standard deviation	Daytime	Night
NO_x (mg/Nm^3)	328	48	189	32	182	196
CO (mg/Nm^3)	5	2	9	12	9	9
O_2 (%)[(1)]	6.5	1.3	5.3	1.2	5.1	5.5
Steam production (tph)	66.7	3.0	67.0	1.8		
T 1st pass (°C)	1,004	30	1,018	24		
Prim.+BP. air (Nm^3/h)	83,700	10,100	57,600	7,800		
Secondary air (Nm^3/h)	23,200	3,100	10,800	-		

(1) O_2 content measured in the 1st pass of the boiler

In table 2, the results show that it is possible to maintain the NO_x concentration below 200 mg/Nm^3, especially when the O_2 set-point is 5 %. On the other hand, some fluctuations in CO emissions appear, especially when the Ecotubes are retracted for cleaning every 8 hours. This could have been solved by increasing the secondary air during this short cleaning phase to avoid CO peaks. Concerning operation parameters, the use of Ecotubes favours the stabilisation of the steam production, and other parameters (temperatures…). The only negative point is the flame height with this fitting. Indeed, with these secondary air values, the flame reaches the roof, increasing the damage risk.

To conclude on tests with by-pass air on, it is possible, using the Ecotubes, to reach the future 200 mg/Nm^3 limit. The cleaning phase of the Ecotubes will have to be controlled very precisely when using this configuration to avoid CO peaks. Nevertheless, tests with by-pass air off have to be carried out, because this under-grate air diversion process has been proven to cause severe corrosion during standard operation. Therefore, suppressing the by-pass air should limit the corrosion problems experienced on this plant.

Tests with by-pass air off

When the plant is operated in normal conditions and the by-pass air is turned off, the NOx concentration tends to rise up to 450 mg/Nm^3. For these tests, the plant operation parameters were the same as for the by-pass air on trials for primary and secondary air, and the O_2 set point was 5.5 %. With the by-pass air off, the secondary air has to be increased compared to the by-pass on tests (around 13,000-14,000 Nm^3/h versus 10,000 Nm^3/h for by-pass on test), to compensate for the flames' tendency to become longer and reach higher inside the furnace and to protect the roof from its contact. Table 3 represents the main results of the tests carried out with by-pass air off.

Table 3 : Main emission results obtained during tests with by-pass air off

	Trial 14	Trial 25	Trial 27	Trial 28	Trial 23	Trial 22
Sec. air (Nm^3/h)	12,400	13,100	13,100	13,100	13,900	15,400
NO_x Average 1h during test (mg/Nm^3)	**199**	214	212	214	222	229
Standard deviation	20	33	22	11	31	16
CO Average 1h during test (mg/Nm^3)	**8.0**	8.5	9.4	10.1	6.8	8.1
Standard deviation	0.8	1.2	1.0	0.8	2.4	2.2
O_2 set point	5.5	5.5	5.5	5.5	5.5	5.5
O_2 Average 1h during test (%)(1)	8.3	8.2	7.3	8.1	8.4	8.6
Standard deviation	0.8	2.6	1.1	0.9	0.7	0.5

(1) O_2 content measured at the stack (dry content)

The results show that it is more difficult to reach 200 mg/Nm^3 in the by-pass air off configurations, due to the secondary air level. Only test 14 presents a NO_x level just below 200 mg/Nm^3. Nevertheless, the results are quite interesting, as it represents a 55% reduction in NO_x. As far as the CO levels are concerned, we are still below the 10 mg/Nm^3. As it was for the by-pass on tests, no impact has been found on bottom ash and fly ash quality.

The configuration of test 14 has been chosen to carry out the 72 h test. For this test, secondary air has been fixed to 13,100 Nm^3/h. The results are presented in table 4.

Table 4 : Results of the 72 h test with the configuration 14

	First day		Second day		Third day	
	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation
NO_x (mg/Nm^3)	206	19	219	15	222	19
CO (mg/Nm^3)	8.7	3.8	6.9	1.1	6.1	1.3
O_2 (%)(1)	8.8	0.5	8.8	0.3	8.8	0.5

(1) O_2 content measured at the stack (dry content)

As far as the emission results obtained, it is difficult to reach the 200 mg/Nm^3 with the by-pass air off during the 72 h test. On the other hand, if the CO values are compared to the ones obtained during the 72 h test with the by-pass on (see table 2), these latest CO results are much more steady and remains consistently below the 10 mg/Nm^3. Also, the APC residue production has been decreased from 37 t during 72 h of normal operation to 24 t during the 72 h test with the configuration using the by-pass off, which corresponds to a 35 % reduction, proving that the Ecotubes decrease the fly ash transportation in the boiler.

Tests with ammonia injection

The by-pass off tests showed that it was possible to be very close to 200 mg/Nm^3, with a good and steady CO concentration. In this case, a small injection of ammonia will facilitate the NOx reduction to obtain a steady concentration below 200 mg/Nm^3. A stronger injection should theoretically allow NO_x to decrease below 100 mg/Nm^3. These two configurations have been tested with the Ecotubes, during 30 minute tests. The results are presented in table 5 below. The values called "before and after" correspond to the average value obtained when using the Ecotube without NH_3 injection.

Table 5 : Main emission results concerning ammonia injection tests

	Secondary air (Nm^3/h)	NH_3 injection (kg/h)	Injection through tubes	NO_x before and after test (mg/ Nm^3)	NO_x during test (mg/ Nm^3)	% NO_x variation
Trial (a)	13,100	15.9	1&2	190	108	- 43 %
Trial (b)	13,100	13.3	1&2	182	82	- 55 %
Trial (c)	13,100	9.2	1&2	182	144	- 24 %
Trial (d)	13,100	5.4	1&2	204	170	- 16 %
Trial (e)	15,400	5.7	1	210	170	- 19 %
Trial (f)	15,400	6.0	2	210	185	- 13 %
Trial (g)	15,400	3.5	1&2	218	192	- 12 %
Trial (h)	15,400	8.2	1&2	214	160	- 25 %
Trial (i)	15,400	14.4	1&2	201	122	- 39 %
Trial (j)	17,800	13.9	1&2	240	144	- 40 %
Trial (k)	20,000	11.1	1&2	232	151	- 35 %

Main results of these tests are listed below:
- Injecting a small quantity of ammonia through the Ecotubes decreases the emissions about 10 to 20 %, reaching easily the 200 mg/ Nm^3 (cf. trials c, d, g, h)
- There is no influence of the type of injection (through tube 1 and/or 2) (cf. trials d, e, f)
- The consequence of injecting bigger amounts of ammonia is a reduction of up to 50 %, reaching 100 mg/ Nm^3 (cf. trials a,b)

Unfortunately, and due to the equipment used, it was not possible to have ammonia flow rates larger than 16 kg/h. During all these tests, it was found that on average, to obtain a 10 mg $DeNO_x$, it was necessary to inject 0.073kg NH_3/ton of waste incinerated. Another way to think of this is that for treating one molecule of NO_x, 3 molecules of NH_3 must be injected. Out of these three molecules, only one will be active, the two others will be decomposed by heat.

CONCLUSIONS

The main conclusions of this test period is that, using air injection through Ecotube, it is possible to reduce NO_x emissions by around 50 %, without major impact on CO and dioxins emissions, or bottom and fly ash quality. Other consequences have been found out, such as a more stable combustion (i.e. more stable operating parameters), and a smaller production of fly ash. It has also been proven that it was very easy to obtain emissions around 200-220 mg/Nm^3 for NO_x, but it was more difficult to remain stable below 200 mg/Nm^3, as to comply with the new EU legislation. This goal can be reached by injecting a small amount of ammonia, like in a SNCR $DeNO_x$ system. The perspectives we have on the Tyseley plant with these Ecotubes are now to install them below their actual position, to improve the efficiency of the system. The localisation optimisation will be further improved by using CFD calculations produced within the CREED facilities.

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