Development of Effervescent Atomisers for Oil-Fired Power Stations

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The following report contains technical background, experimental procedures and results of tests performed on various effervescent atomisers at large scale (5400kg/h of fuel oil). The tests were performed to discover which geometrical configuration resulted in the best spray granulometry at this oil flowrate. This was achieved by testing eight atomisers differing in one geometrical detail at any one time while the other characteristics were maintained constant: number and diameter of exit holes and angle of the spray. The characteristics tested were the volume of the mixing chamber, decreased by the insertion of an extra piece, and the number of orifices for the fluid in the internal nozzle. The internal nozzle contains orifices at its rear (farthest from the exit), at its centre and at its front (nearest to the exit) that were blocked in turn to perform the test.

The best quality sprays were obtained without the mixing chamber insert. The finest spray granulometry was obtained from the atomiser without the insert and with the rear holes of the internal nozzle blocked. Further blocking of the internal nozzle holes worsened the spray quality.

The industrial-scale tests were performed on at the Torrevaldaliga Nord #4 power plant this being the first test for the effervescent atomiser at this scale. The tests were performed comparing the effervescent atomiser with a standard Y-Jet atomiser normally used at the power station. The atomisers were compared regarding their NO_x and CO emissions, amount of atomising steam consumption used and smoke point, all at a load of approximately 620 MWe for the whole boiler.

The results obtained conveyed that the NO_x emissions for the effervescent atomiser were slightly higher than for the Y-Jet atomiser but slightly lower than the Y-Jet for the CO emissions. The effervescent atomiser worked well at a low pressure and saved around 25 % of steam without any substantial variations in the gas emissions compared to the Y-Jet.

1. Introduction

The aim of this activity is to define the most significant parameters effecting the development of 'effervescent' atomisers for high potential burners, characterised by a low atomisation fluid consumption and optimal granulometric characteristics.

An empirical method was used based on the individuation of geometric parameters, of which some were kept constant (number and diameter of nozzle orifices, spray angle), while others were varied according to an organisation matrix (number and position of orifices in the internal nozzle, volume reduction of the nozzle mixing chamber). This method was used to establish which of these parameters were more significant and what the optimum values were.

In the majority of twin fluid atomisers, the atomisation process occurs with the assistance of a high velocity atomisation fluid. Effervescent atomisers are constituted from an atomising fluid distribution system opportunely situated in the mixing chamber where the fluid to be atomised flows.

The atomising fluid enters inside the chamber through a large number of orifices and comes into contact with the fluid to be atomised which flows in an annular area around the atomising fluid distributor. This forms a flow of gas bubbles inside the fluid: the mix exits at a lower pressure, the gas bubbles expand rapidly, the liquid around the bubbles transforms into drops resulting in a fine liquid spray.

2. Experimental Apparatus

The tests were performed on the I.S.A. plant situated at Livorno, ENEL RICERCA at Pisa's station.

2.1 Atomiser Experimental Plant I.S.A.

The plant I.S.A., schematically represented in fig. 1, utilises a simulation oil (AGIP ITE 360) that, at room temperature, has the same physical material properties of combustion oil at 120° C (density 0,89; viscosity 2,5°E; surface tension 36 dyne/cm). In the twin fluid atomiser case the atomising steam is simulated by compressed air.

The heart of the plant is the atomisation chamber, which is comprised from the spray measurement area and an area where the atomised liquid becomes separated from the air, collected and re-circulated. The room operates in depression allowing air to enter into the measurement area impeding recirculation of the finer drops around the nozzle.

The cleaning air is separated from the atomised liquid in an area at the bottom of the chamber. The air is cleaned by an electrostatic filter and is expelled into the atmosphere via a ventilator and chimney. The plant is also equipped with an oil storage tank, an oil supply line and for tests using air assisted atomisers an air supply line.

There is a water heat exchanger and an electric heater to heat the oil to the desired temperature and it is then fed to the atomiser by a high pressure pump. The compressed air originates from a compressor fed tank. Pressures and flow rates of both the simulation oil and the atomising air, are measured during the tests.

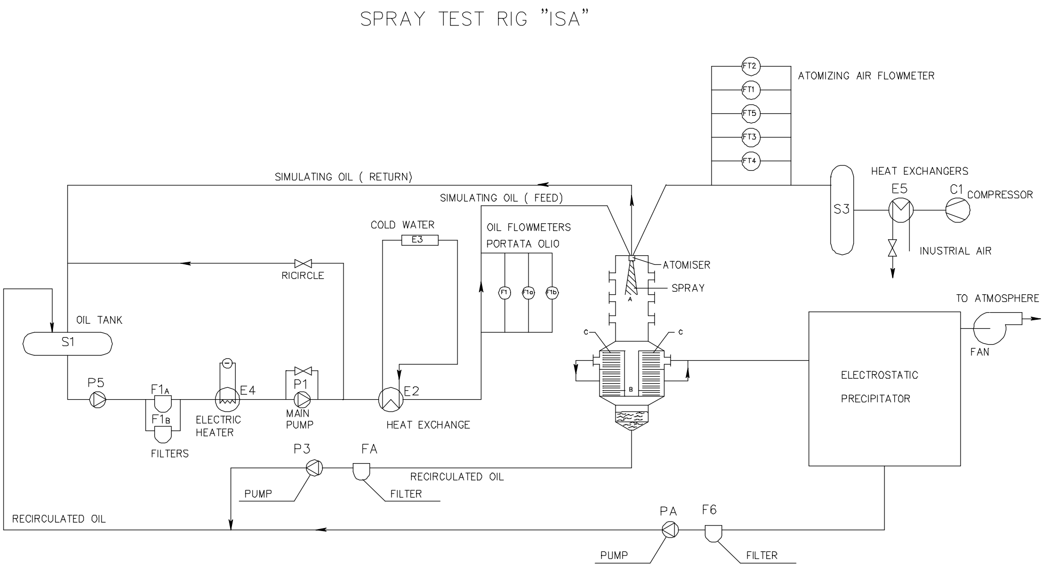

Fig. 1 Spray Test Rig ISA

2.2 Diagnostic apparatus

The quality of the spray is measured using a Malvern Particle Sizer, a piece of non intrusive equipment based upon laser diffraction. This piece of equipment has various field measurement that depend on the receiving lens. In this case a very vast range was used, 11,6-1128 μm, in order to monitor the presence of large diameter drops, that are the most damaging in the combustion process.

The optical measurements are only possible if the density of the drops isare below an appropriate value. In order to satisfy this requirement with the high spray densities encountered, separator tubes were utilised as well as performing the tests on a single cone, closing all the exit holes except one. The exit orifice axis was maintained perpendicular to the laser beam and the distance between the atomiser and the beam was kept constant at 300 mm. The tests are normally performed with the set up shown in Figure 2. The atomiser is positioned in the test area and is moved along the X axis, perpendicular to the spray axis, in order to enable the study of different measurement areas of the spray.

For each area a granulometric distribution is measured from which the Dv0.5, the D32, the volumetric concentration and the % of drops > 300 μm are obtained and displayed graphically with respect to the distance from the X axis.

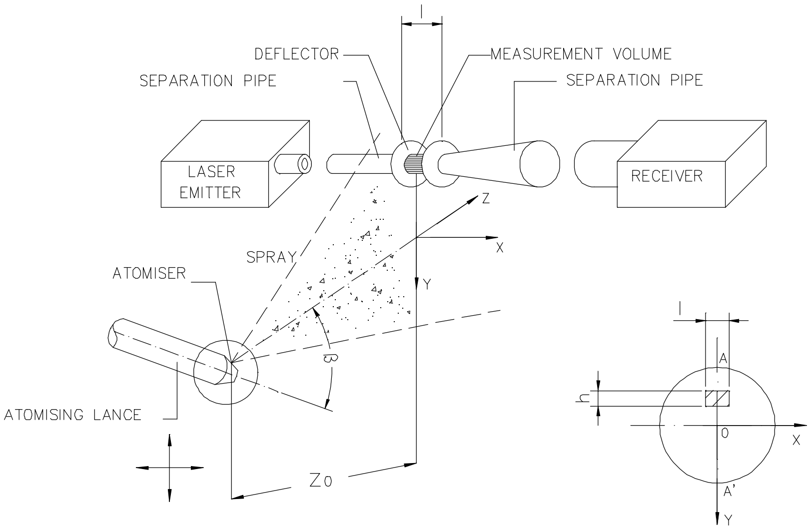

Fig. 2 Relative position of the spray and the laser beam

2.3 Granulometric Characterisation

The aims of the granulometric characterisation tests were to measure the typical drop sizes. The mean volumetric diameter, Dv0.5, the volumetric concentration, and the percentage of drops lager than 300 μm were measured. The test were performed on a single hole so it was possible to mount a deflector on the nozzle so as to isolate a single spray, deviating the remaining jets out of the measurement area.

Each atomiser was supplied with a simulation oil flow rate of 5400 Kg/h and three air atomisation pressures of 6, 8 and 10 ate.

3. The Effervescent Atomisers

The atomisers used in the experimental tests are of the internal pre-mix type, nominated 'Effervescent'. The effervescent atomisers studied are constructed from two components: an external nozzle and an internal nozzle. In the cold tests certain atomisers were characterised differing from each other in the number of orifices for the atomisation fluid in the internal nozzle and for the mixing chamber dimension. The variation in volume of the mixing chamber was obtained by inserting a metallic ring.

All the atomisers tested have the same outer nozzle. In total, eight atomisers were tested all differing in one geometrical detail between them. For clarity the geometric combinations tested are presented in the table below:

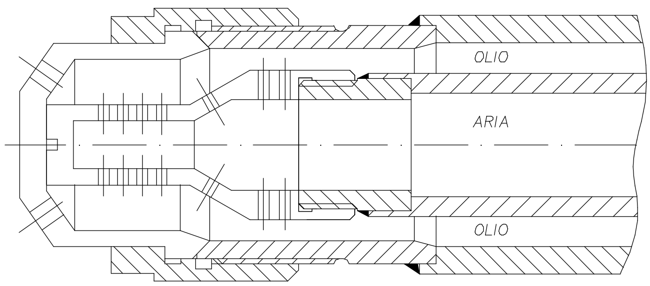

Fig. 3 The effervescent Atomiser (schematic drawing)

4. Analysis of the Results

To facilitate the comprehension of the results obtained, the experiments performed were organised into two units: experiments with standard mixing chamber; experiments with a reduced section i.e. with insert.

4.1 Experiments with Standard Chamber.

The experimental tests performed with the standard chamber dimension were configurations B0, B3, B5 and B7 . They correspond to the following geometries:

- **B0** Atomiser in the standard configuration;
- **B3** rear orifices blocked;
- **B5** rear orifices +central angled orifices blocked;
- **B7** rear orifices +central angled orifices + anterior orifices blocked.

For a better comparison of the data attained with this configuration they were all presented on the same graph. In Figure 4 the trend of the mean diameter Dv0.5 obtained from the various configurations in the function of A/F are reported. In Figure 5 the trend of the percentage number of drops > 300 μm is reported.

The results seem, in part, contradictory and in regarding the mean diameter they indicate that configuration B5 (rear orifices + central orifices closed) give the best results while regarding the percentage of drops > 300 μm the best results are given by the configuration B3 (rear orifices blocked).

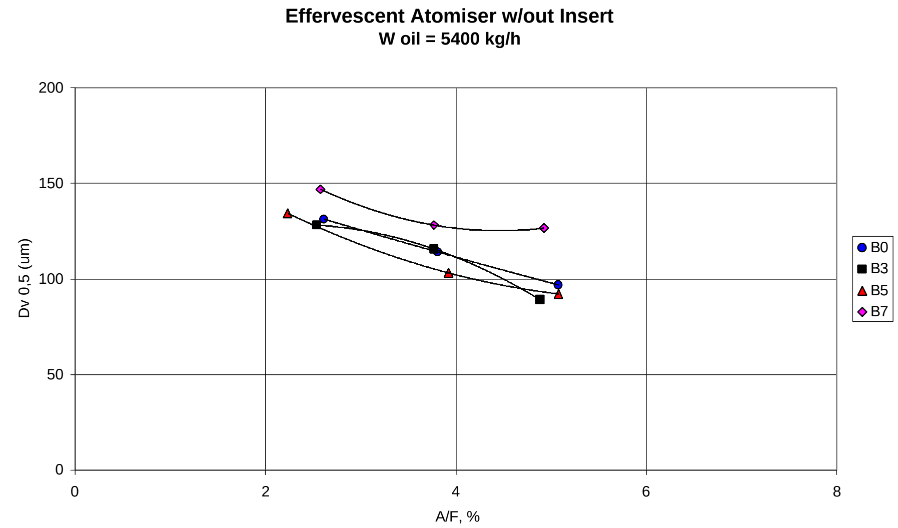

Fig. 4 Mean Volume Diameter vs. Air/Fuel ratio

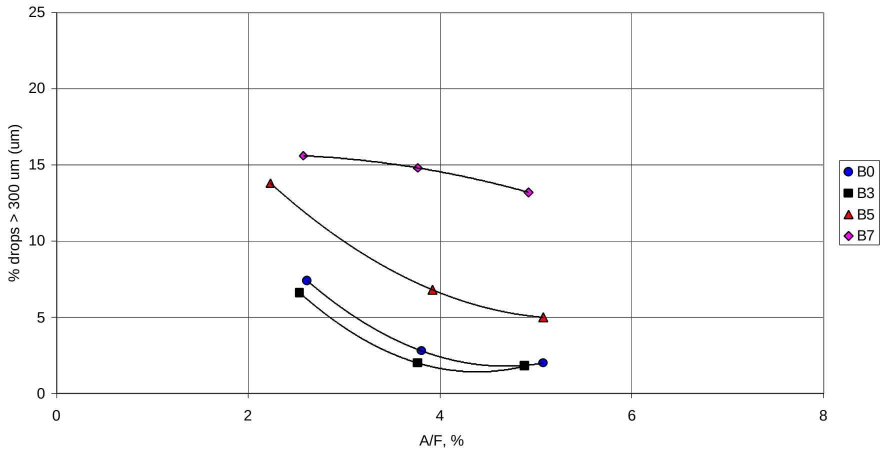

Fig. 5 Percent of drops larger than 300 um vs. Air/Fuel ratio

4.2 Experiments with Insert

The experimental tests performed with the insert were B1, B2, B4 e B6. These correspond to the following geometries:

B1 Atomiser in the standard configuration + insert;
B2 rear orifices blocked + insert
B4 rear orifices +central angled orifices blocked + insert;
B6 rear orifices +central angled orifices + anterior orifices + insert.

In Figure 6 the mean diameter, Dv0.5 trend is reported obtained from the various configurations in the function of A/F. In Figure 7 the trend of the percentage number of drops > 300 μm is reported in the function of A/F. With respect to the standard case described in the previous paragraph, the results obtained with this configuration are more lucid because they show that configuration B2 (rear orifices blocked) gives the best results regarding the mean diameter, Dv0.5, and the percentage of drops >300 μm.

The results are nearly the same for cases B0 and B1 (standard configurations with and without insert) and for cases B2 and B3 (rear orifices closed with and without insert) while they worsen as the other sets of orifices are blocked.

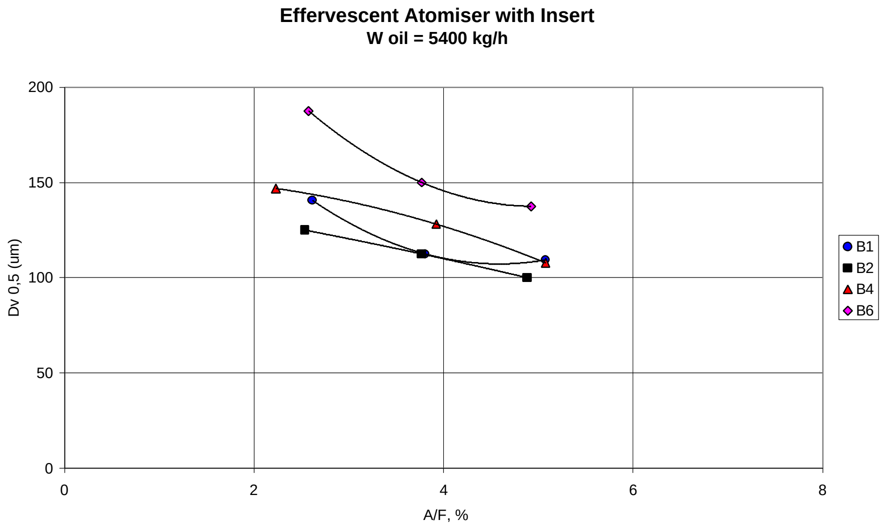

Fig. 6 Mean Volume Diameter vs. Air/Fuel ratio

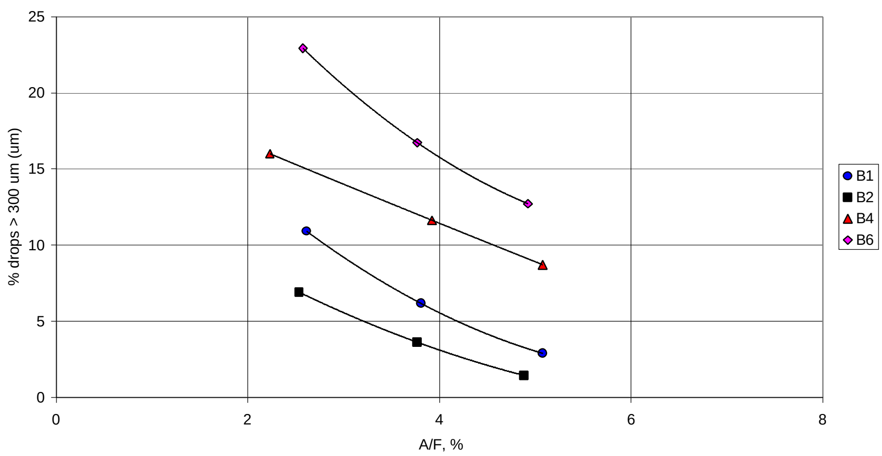

Fig. 7 Percent of drops larger than 300 um vs. Air/Fuel ratio

5. Combustion Tests

During 1997, the intervention of environmental adaptation (IEA) was implemented and optimised on unit #4 of the Enel power plant in Torrevaldaliga Nord (TN). This was successively extended to the other three twin units and unit #4 initiated the 'environmental' commercial process on 01.01.98. The IEA was principally concerned with the transformation of the BOOS combustion system configuration and the installation of a DeNOx plant for catalytic reduction with ammonia from nitrogen oxides. The DeNOx plant is designed to treat a maximum concentration of NOx, at inlet, of 800 mg/Nm3 @3%O2.

The subsequent pressure loss, due to the insertion of the DeNOx in the flue gas circuit, confirmed the impossibility to process the unit at the nominal load of 660 MWe. This occurred due to the insufficient pressure drop available on the air fans. The reference load for the commercial process was, as a result, reduced to 620 MWe.

The 'Effervescent' atomiser, was tested on unit #4 at TN in February 2000, with the principal aim of further improving the management of the combustion process. The atomisers, produced by Produzione/Ricerca, had a 90 °spray angle, the same as the Y-Jet atomiser currently in use on every TN unit. Regarding the effervescent atomiser it was the first industrial scale experience, after the activity on the experimental scale concluded. The two atomisers were compared in terms of NOx, smoke point and atomisation steam consumption, all at a load of 620 MWe.

5.1 Test Description

The test were performed on the standard BOOS configuration, at a load of approximately 620 MWe utilising the DeNOx in order to maintain within the NOx limits of 200 mg/Nm^3 @3% O_2 maintaining the dust and CO concentrations in the chimney below 150 mg/Nm^3@ and 50 mg/Nm^3@ respectively. The experimental activity was performed in two stages:

In the first phase the Y-Jet atomisers, the ones actually in use at all the TN units, were characterised: this was used as reference point to which to compare the characteristics of the new atomiser. At the nominal atomisation steam pressure, the NOx and CO emissions were measured in the flue gas at different concentrations of O_2, until the process conditions with the minimum excess of air were recognised.

In the second phase the effervescent atomisers, designed to operate at low atomisation fluid pressures as to limit the steam consumed, were characterised. However the atomiser's qualities were investigated at pressures ranging from 8 ate and 12 ate. The sensitivity tests to measure the excess O_2 present in the flue gas were performed at a pressure of 8 ate.

5.2 Results

From Fig. 8 it can be seen that the effervescent atomisers result in NOx emissions only slightly higher than those obtained with the Y-Jet atomisers: in particular, medial O_2 levels downstream of the ECO equal to 1.3% result in a change from 640 mg/Nm^3@ to 660 mg/Nm^3@ (values taken upstream of the DeNOx on side B).

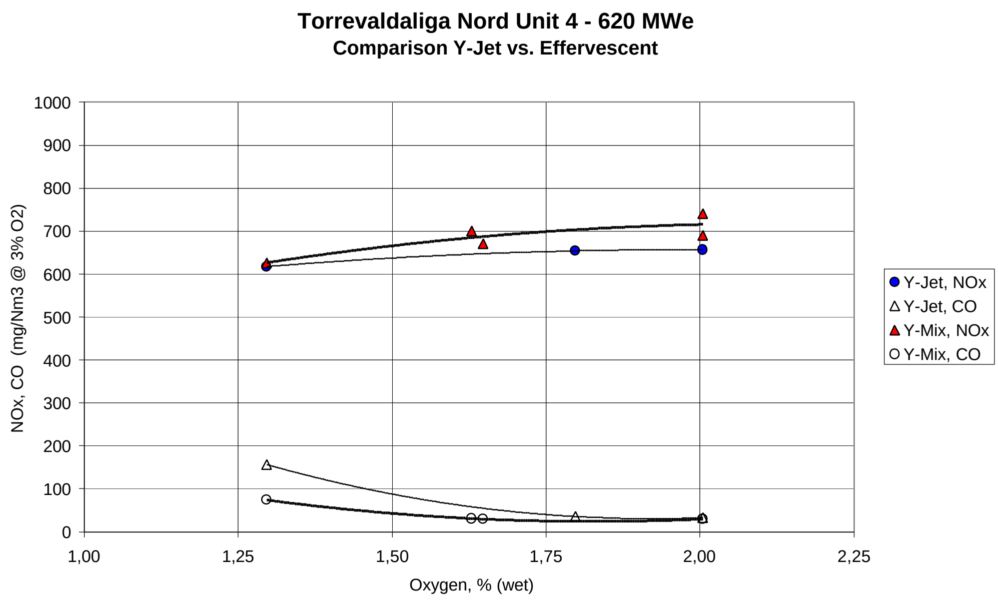

Fig. 8 Comparison between Y-Jet and effervescent atomisers

Additionally with the effervescent atomisers an improvement in the smoke point was observed with an approximate reduction of 0.2% of O_2 (measured downstream of the ECO) at the same CO concentration.

On the basis of the previous results, for the effervescent atomisers, it is recognised that the correct pressure of the atomisation steam to the reference collector is 8 ate, confirming the design objectives for this type of nozzle.

At these conditions a 25% reduction in steam consumption is achieved with respect to the Y-Jet atomisers.

6. Conclusions

The best results were obtained with mixing chamber free from insert and closing the rear set of orifices (configuration B3). Closing of the other orifices lead to an ever increasing worsening of the atomiser's performance.

The utilisation of an insert to reduce the mixing chamber volume did not produce better results in respect to the results obtained with the standard mixing chamber. With the best conditions (configuration B1, rear orifices blocked + insert) the differences are insignificant but become more significant as the other orifices are blocked.

The closing of a lager number of orifices does not appear to cause a decrease in the amount of atomising fluid consumed. The better or worse trend of the parameters seems to only be due to the geometrical distribution of the internal nozzle orifices. The complete data indicate that these atomisers give good results with an A/F ratio > 5%.

The combustion tests, performed on a large industrial Power plant have shown that the effervescent atomisers can be utilised at the atomisation steam pressure to the collector of 8 ate, allowing a steam saving of approximately 1 t/h, without any substantial changes in gaseous emissions at the air excess with respect to the Y-Jet atomisers.

References

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