# Performances Analysis And Improvement Of A Twin Fluid Internal Mixing Nozzles For Industrial Burners

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**Abstract**
A parametric study on a twin fluid internal mixing burner is presented, that includes the effect of some construction design improvements, the study of its performance curve with single and twin fluid, feed at different flow rate and temperature. Unfired test, performed with air and water as model fluids, are aimed at understanding the nozzle behaviors in terms of mass flows and volumetric coefficient at different feed pressures and pressure ratio of the two fluids, thus helping in tuning up quickly the following fired test. Fired test, with Heavy Fuel Oil and Steam are aimed at understanding the variations and improvements of combustion efficiency and pollutant emissions, when some specific constructive and operative parameters are changed, like the nozzle internal flow and geometry details, the mass flow rate of steam and fuel, the operative temperature, that is the parameters expected to play a major role [1,2,3] in the fuel atomization and subsequent combustion.

**Research Framework**
The presented activity has been made within the Centro Combustione Ambiente SpA project "BE4GreenS", sponsored by Regione Puglia using European founds. In particular, it is developed in the R&D program related to improving the Sustainability of boiler burners, firing oil.

**Set up: burner, nozzles, cold set-up and fired set-up**
The study evolves from a standard production component used in Heavy Oil Fuel Steam assisted combustion systems with typical [1] fuel mass flow up to 1 kg/s, corresponding to a power of about 38-40 MWth. The gun has a length up to two meters, with two coaxial channels, designed to be easily switched with the fuel either in the inner or outer channel, depending on different design criteria and plant-specific requirements, with minor installation differencies. The gun hosts at its end the distributor plate, clamped by the same nozzle head (Fig 1). The distributor plate geometry controls the two fluids mass flows, thanks to the two ranges of circular metering holes, and stats their mixing by redirecting the individual flows. The nozzle head forms the large internal volume where the two fluid can mix [3] thanks to the long contact time, and hosts the slots through which the mixture (oil, steam, condensed water) is injected into the burning chamber. The

possible combination of the different liquid (Oil, Water) and gaseous fluid (Vapour, Air) in the different channel (Internal, External) used in the present work is indicated by the fluid and channel initial letters, e.g WI means ‘Water Internal’.

**Figure 1**. The standard burner distributor plate (left), clamped by the injector head (right)

The new tested components include geometries where the design parameters are changed one by one; starting from the standard geometry, the new components were designed to study the effects and improvements do to swirled mixing, improved impact mixing, optimized distributor metering geometries, different injection slot angle and aperture. A “cut off” head, machined for clamping only, was used to measure some flow parameters of each tested distributor for the cold tests only.

The “Cold set-up”, a spray rig test facility purposely built for this project, was designed for test with water and air. It includes an injection box (3800×2200×1000mm) for water spray collection and possible use of optical techniques, and some standard equipment for pressurised water and air delivery and measure (air compressor, water pump, pressure transducers, fluid flow measuring devices), like in [2]. Some photos of the water-air spray are reported in Fig 2, a scheme of the set-up in figure 3.


dP = -3. Air=4bar, Water=7bar. | dP = +2. Air=5bar, Water=3bar.

**Figure 2.** Some photos of the standard nozzle, Water Internal (WI) configuration.

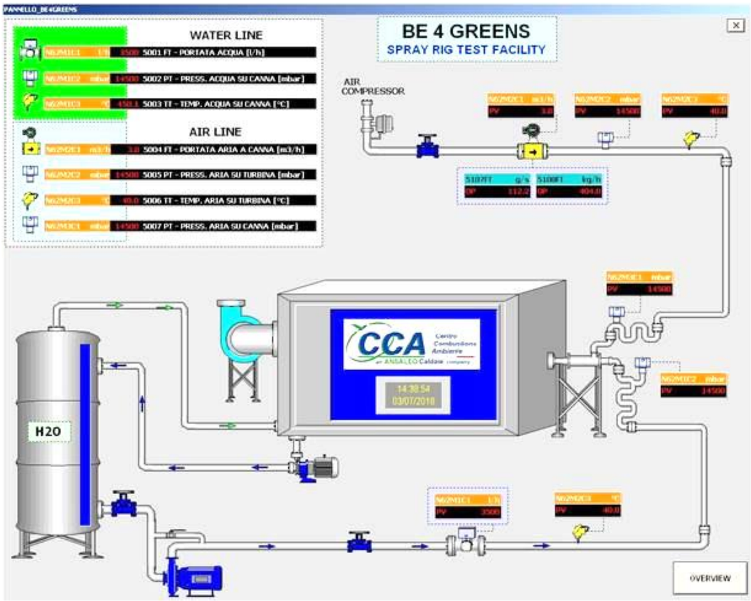



**Figure 3.** Scheme of the cold set-up

The “Fired set-up” is the test facility at Centro Combustione e Ambiente, the AC Boilers owned combustion research center. The main boiler facility is able to operate in full-scale a boiler burner up to 48 MWth fuel heat input with different fuels. Designed for best similarity with a real boiler burner flame, it has dimensions of 12 meters length, 4.5 width and 6.5 height, plus the 2.5 meters hopper.

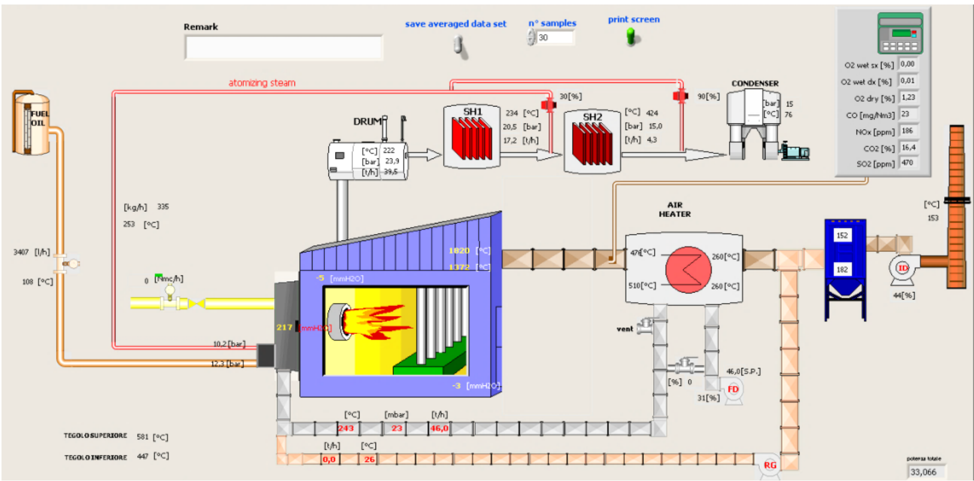



**Figure 4.** The “Fired set-up” scheme

## Cold test results

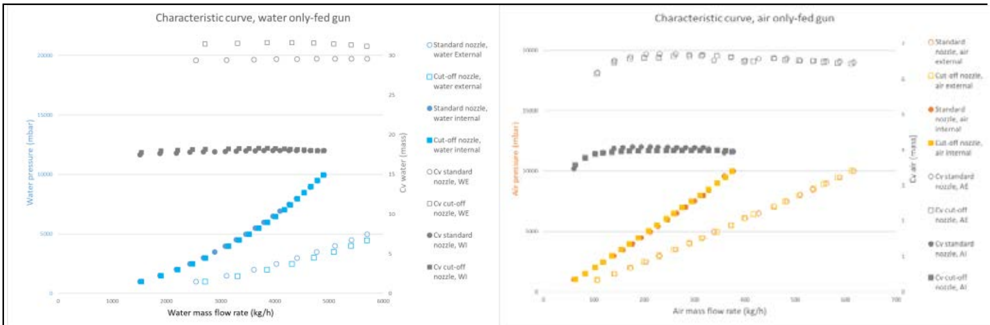
From the cold spray test rig, some performance curves of the nozzles could be obtained.

Figures 5a and 5b shows an example: they reports the results for the standard distributor plate, tested with its standard nozzle head, and with the “cut-off” head, with each single fluid (Water or Air) tested alone, fed through either the internal or external channel. For each combination, the fluid delivery pressure was set at different values, while the mass flow rate was measured (horizontal axis), thus Volumetric Coefficients Cv could be calculated, that in this work are defined as follows, with $\varphi_W$ and $\varphi_A$ rescaling constant factors, used for the adjustment of the order of magnitude in the graphs.

$$C_{v,w} = \varphi_W \cdot \frac{\dot{m}_{water}\,[kg \cdot h^{-1}]}{\sqrt{P_{w,rel}\,[kPa]}} = 0.116 \cdot \frac{\dot{m}_{water}\,[kg \cdot h^{-1}]}{\sqrt{0.1 \cdot P_{w,rel}\,[mbar]}} \qquad [kg \cdot h^{-1} \cdot mbar^{-0{,}5}]$$

$$C_{v,A} = \varphi_a \cdot \frac{\dot{m}_{air}\,[kg \cdot h^{-1}]}{P_{a,abs}\,[kPa]} = 11.6 \cdot \frac{\dot{m}_{air}\,[kg \cdot h^{-1}]}{0.1 \cdot (P_{a,rel} + 1000)\,[mbar]} \qquad [kg \cdot h^{-1} \cdot mbar^{-1}]$$

The results show that the water pressure difference follow a typical parabolic behaviour as a function of its flow rate, so its volumetric coefficient above defined keeps almost constant along the whole tested range. The large difference between the internal and external feed configurations depends mostly on the large difference in the passage areas at the distributor. The cut-off head allow to identify the pressure losses due to the nozzle head, which are negligible compared to the total when the water flows inside, and about 10% of the total when it flows outside.
The air pressure loss is much more linear with its flow rate, typical of a choked flow; its volumetric coefficient is coherently defined and results almost constant except for an initial increase, when choked flow is not yet established.




| **a)** Blue ● = water pressure (left scale).<br>Gray ● = discharge coefficient $C_{V\text{-}W}$ (right) | **b)** Yellow ● = air pressure (left scale)<br>Gray ● = discharge coefficient $C_{V\text{-}A}$ (right) |
|---|---|

**Figure 5.** Single-fluid fed gun, characteristic curves with standard and cut-off nozzle. Round symbol ○ = standard nozzle, square symbol □= cut-off nozzle. Empty symbol ○ = fluid outside, filled symbol ●= fluid inside

The results of a test with both fluids feed at the same time is shown in figure 6. The configuration shown is “Water Internal” (WI, so also Air External), only the volumetric coefficients of the fluid are reported, whose variations from the previous constant values with the fluid alone are due to the presence of the other fluid. The pressures of the two fluid were set to keep constant their difference

$dP=P_{AIR}-P_{WATER}$. The reference value dP=0 means that the two fluid are set at the same inlet pressure, and when the water flow is changed, the air flow changes as a consequence. In this case the nearly constant $C_V$ for both fluids (green symbols of figure 6) mean that also the ratio among the two flow rates keeps constant. Note also the difference from the single fluid configuration: $C_{V\text{-}AIR}$ (compare to AE in Fig 5b) decreases from 6.5 to 5.5, while $C_{V\text{-}WATER}$ (compare to WI in Fig 5a) decreases from 18 to 9, meaning that the air flow reduces the passage available for the liquid at the mixing chamber inlet. When the two pressure are different, also the flow ratio is obviously different, and a large pressure shift at constant dP produces a variation also of the flow rate ratio, reflecting the different behaviours of the two fluid flows seen in figure 5.

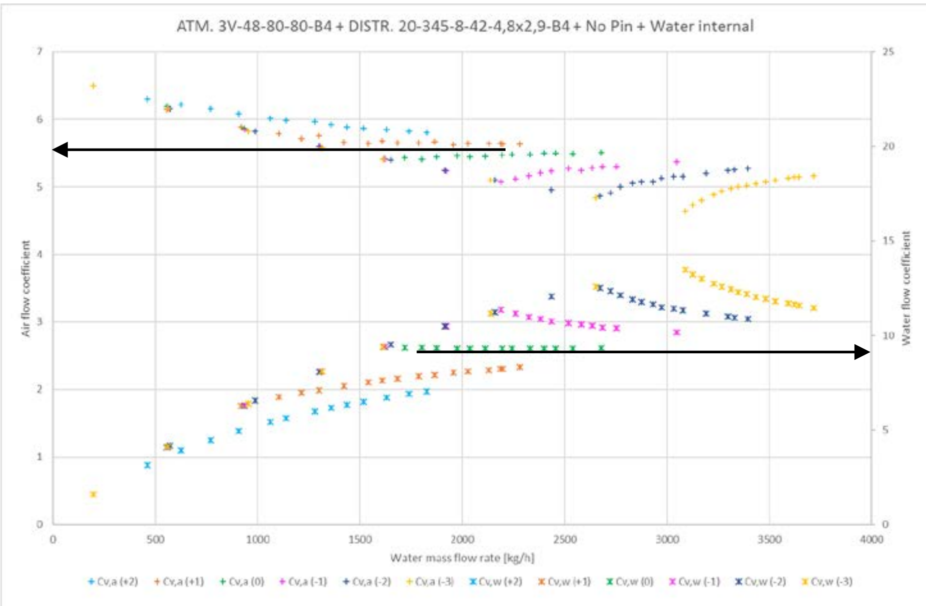



**Figure 6.** Air(+) and water(×) flow coefficients versus water mass flow rate. Water internal WI=AE. Series at different values of $dP = P_{AIR}-P_{WATER}$ from -2 to +3 bar

## Fired tests and results

The fired tests were performed with different set up configurations, obtained by some combination of distributors and nozzle heads, flow internal/external switches, different air-to-fuel ratios (or air excess) measured by the oxygen content in the dry exhaust gasses, different steam-to-fuel ratios, and fuel preheat temperatures. The same batch of HFO was used (density of 989 kg/m3, distillation curve starting at 210°C, kinematic viscosity 337 $mm^2/s$ @50°C, net calorific value 40.5 MJ/kg, Nitrogen content 0.57% w/w), preheated at 100-110°C. In figure 7 are reported some of the most interesting results, that is the NOx and CO emissions reported as a function of the set O2 exhaust gas content, for few hardware configurations. The values are the average of 30 instantaneous acquisitions sampled over 150 seconds of steady working conditions, each test lasting at least 2 hours due to the transient period between successive steady states. Tests start with high air excess, and stop when the CO content shows the abrupt increase usually called smoke point.

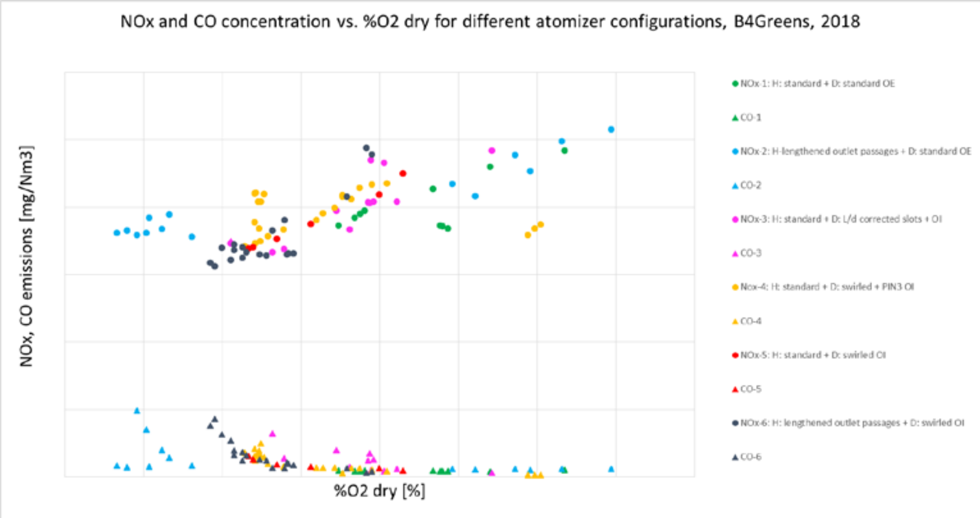



**Figure 7.** Emission performances of the atomizer configurations tested. Y-axis: exhaust mass content of NOx (○) and CO (Δ) per $Nm^3$. X-axis: volumetric content of oxygen in dry exhaust gases. The same color refer to the same hardware asset.

## Conclusions

The parametric study presented allow to identify the design that helps improving the desired system parameter, for example the use of a fuel with high nitrogen content may suggest to use the nozzle that minimizes the NOx production, while a different fuel allow to use the design that minimizes the air excess thus improving the combustion efficiency.

## References

[1] Graziadio, M., *L'atomizzazione dei combustibili nella generazione termica*, Pacini Editore, Italy, 2001.

[2] Barroso, J., Lozano, A., Barreras, F.,Lincheta, E., "Analysis and prediction of the spray produced by an internal mixing chamber twin-fluid nozzle", *Fuel Processing Technology*, 128: 1-9, 2014.

[3] Zaremba, M., Weiß, L., Maly, M.,Jedelsky, J., "Low-pressure twin-fluid atomization: Effect of mixing process on spray formation", *International Journal of Multiphase Flow*, 89: 277-289, 2017.