Optimization of a reheat in an incineration plant for the reduction of emissions pollutants. Application of over fire air technique

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***Abstract*—This paper deals with an experimental and theoretical analysis of the impact of the Over Fire Air (OFA) staged combustion technique for the formation of pollutants in an incineration plant located in Augusta (Sicily-Italy) for industrial wastes. For this purpose it has been implemented a mathematical model of the reheat by using a CFD (Computational Fluid Dynamic) commercial platform. The CFD model was calibrated and validated using the results obtained from experimental field tests. It aimed at characterizing totally and carefully the plant working principles and evaluating the impact of this technique on the pollutants emissions with special attention to nitrogen oxides. The comparison between numerical results and experimental tests leaded to evaluate the efficiency and accuracy of the implemented mathematical model as well as the consequent advantages by the application of this technique on pollutants emissions at the chimney. Moreover, the CFD model allowed to highlight the formation and destruction paths of NOx by varying the mixture ratio between primary zone and OFA zone.**

***Index Terms*—3D Flexible modeling, Computational dynamic analysis, misalignmen, bearings, lubrication film.**

I. Introduction

The management of urban or industrial solid wastes, with the increase of the produced quantities and the reduction of equipped landfills, is becoming more and more a serious problem in both Italy and Europe [1], [2], [3]. In order to remedy to these difficulties there were studied several action strategies such as recycling, waste-to-energy, etc [4], [5], [6].

As a matter of fact, production energy systems in general and especially from waste can be seen in function of many aspects such as their influence on environmental balances [7], [8], [9], [10], [11], their positive effect on energy [12], [13] and economical national balance, their contribution to the reduction of an unproductive placement in landfill and the compatibility with political directives and sustainable environmental concept [14], [15], [16]. An aspect of particular interest refers to solid wastes combustion processes [17], [18]. Incineration plants has to be able to allow high energy performances and an efficient production and use of energy. Moreover, this technology is one of the few that allow a positive economical balance because of its possible energy recovery. For all these reasons, incineration plants with energy recovery should be correctly integrated in a wastes global management system, designed with the aim at optimizing environmental, social and economical benefits. The combustion of the most energetic part of the waste may represent the best solution as long as the necessary measures to minimize human health and environmental risks [19], [20], [21].

The diffusion of incineration plants has leaded to an increasing worry of public opinion for the possible consequent repercussions of their operation to air quality an therefore to health of population spread around the plant site. As a consequence of this, European community and National governments have issued several directives, laws and regulations more and more restrictive for pollutants emissions limits.

The compliance of plants to these new obligations required the implementation and development of suitable technologies [22], [23], [24], so the smokes depuration section has become one of the most important components in modern systems. In this field the impact of OVER FIRE AIR (OFA) technique on emissions and management of an incineration plant for industrial wastes was analyzed both theoretically and experimentally. It was implemented a mathematical model of the reheat of this plant with a Computational Fluid Dynamics (CFD) commercial software [25], [26], [27], in order to study and analyze the pollutants formation in the combustion zone and optimize the management of the plant for pollutants emissions. Moreover, it was analyzed some experimental data in order to characterize the impact of this technique to the incinerator operation and validate the numerical models used in the simulations.

II. THE INCINERATION PLANT

The considered incineration disposal plant is part of the category of semi-pyrolytic ovens with controlled combustion [28], [29], [30]. It was ideated for general purposes determined above all by the treated materials composition and, given its versatility, is destined to be used for several solid wastes. A correct operation of mixing is necessary because of the heterogeneity, for composition and state of aggregation, of the different types of wastes. In this case, this type of oven presents a characteristic which distinguishes it substantially to the traditional ovens, that is a main rotating combustion chamber. This involves several benefits:

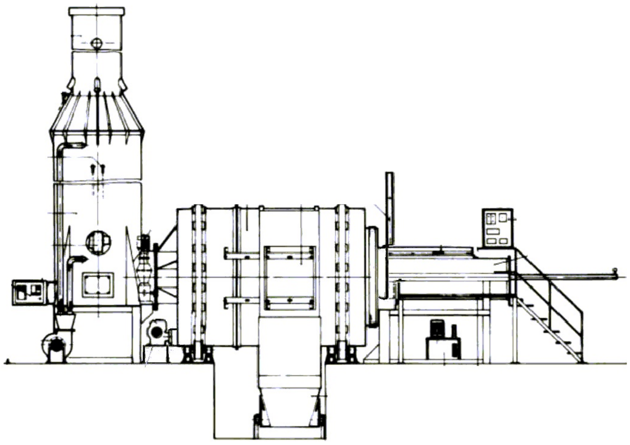

Fig. 1. Plant layout

- A Rapid and complete loading operation and a rational placement of materials inside it are facilitated, that because the liquid and semi-liquid material amalgamate with solid liquid allowing to the a process of homogenization avoiding the formation of preferential zones;
- A significant acceleration of incineration process;
- The produced pyrolysis gases, spreading inside the wastes mass cause an uniform warming regularizing in this way the decomposition process;
- A rapid and rational evacuation of wastes without any manual intervention and with a reduced dust leak.

Therefore the rotation allows to remedy to the main lacks of static pyrolytic ovens where, the combustion of flammable material with a high humidity needs long time and the unloading of hashes is performed manually by the operator. The incinerator is basically made up of a rotating main combustion chamber followed by a fixed combustion chamber [31]. The plant layout also includes a loading automatic system and a unloading ashes system. In Fig.1 and Fig. 2 there are represented respectively a plant scheme and some photos of itself.

The disposal capacity for the three ovens present in the plant is approximately 4,000 Mg/year. The treated yearly quantity of material are reported in the graph of Figure 3, while the volumes of produced ashes are shown in Figure 4.

Fig. 2. Primary chamber, mechanical loader and reheat.

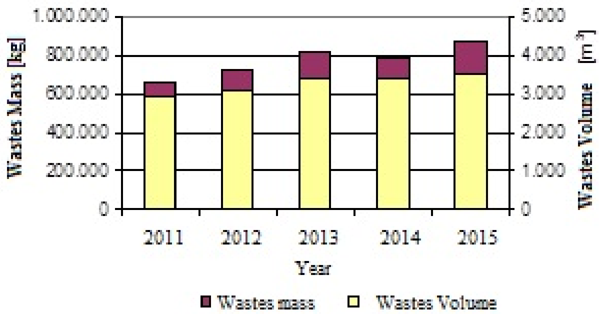

Fig. 3. Amount of wastes for 5 years.

III. OFA COMBUSTION TECHNIQUE

The technique Over Fire Air (OFA) is the most popular commercial application of two-stage combustion [32], [33], [34]. This technique consists to generate two zones inside the combustion chamber: a reducing primary zone where, thanks to the principal incinerator, a combustive part of air (primary air) and the fuel are injected, and a secondary zone where thanks to an appropriate insertion system (OFA ports) the necessary secondary air is blown into to complete the combustion. Fig. 5 shows a functional scheme of staged combustion applied to the reheat.

The effectiveness of this technique depends on the level of penetration and mixing of the secondary air with the products of combustion of the primary zone. The mayor problem with OFA concerns about the high production of unburned hydrocarbons [35], [36] resulting from the reduced value of metering in the primary zone and to their next incomplete elimination because of an imperfect mixing in the secondary zone. For this reason it is not possible to exceed with the reduction of the metering level; it has to be chosen properly to get a compromise between NOx abatement and the production of solid and gaseous unburned products. The choice to apply this primary technique of NOx reduction is due to the particular geometry of reheat chamber of the plant which is provided by two rows of nozzles placed above the flame.

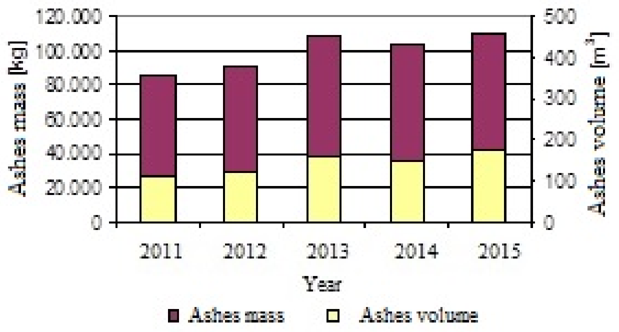

Fig. 4. Amount of ashes for 5 years.

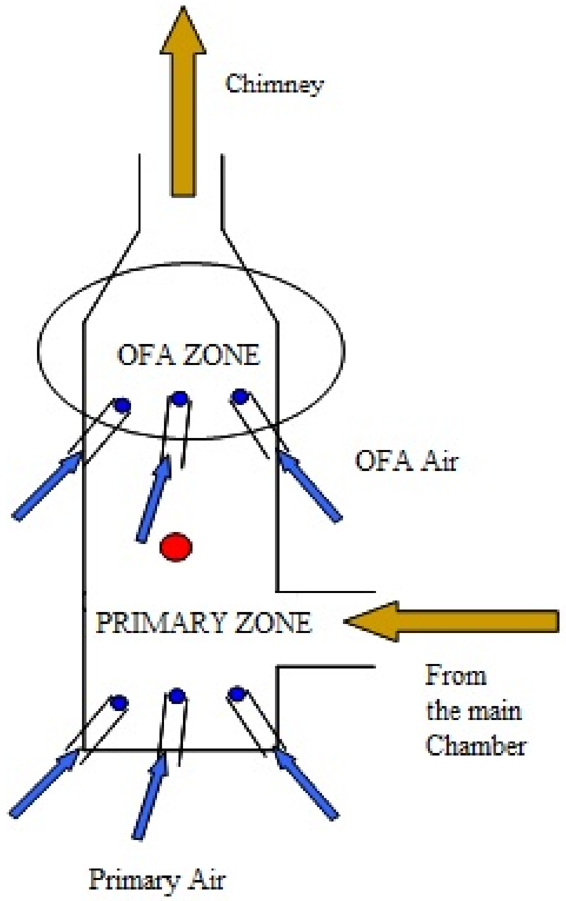

Fig. 5. Principle scheme of OFA technique at the reheat.

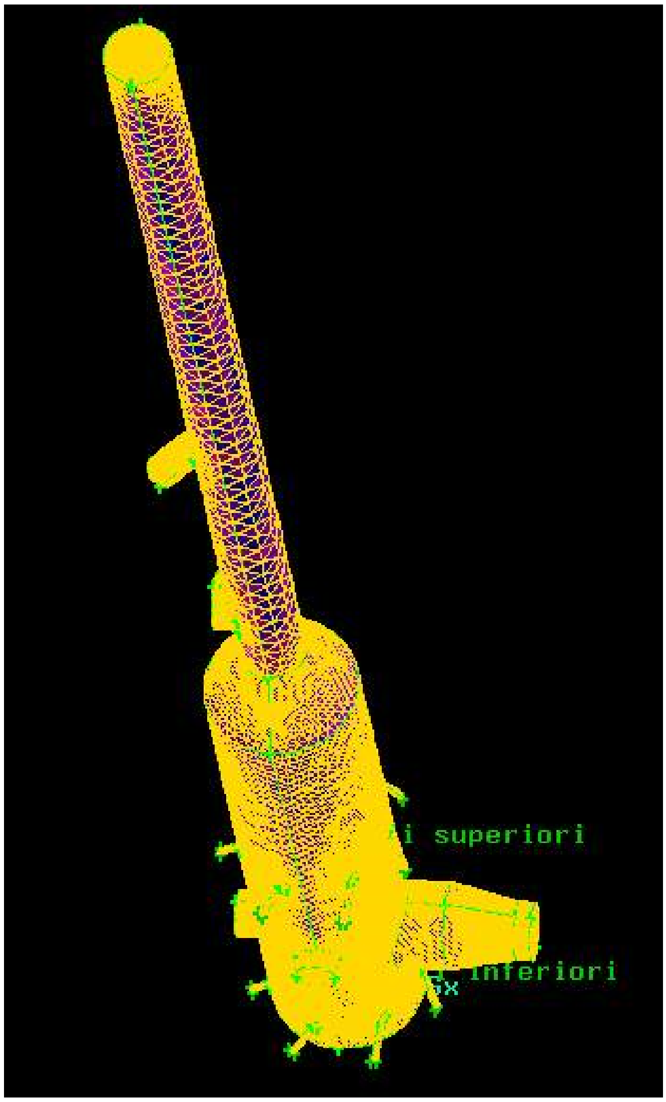

Fig. 6. 3D mesh volume sight.

IV. MATHEMATICAL MODEL

The activity carried out to implement the mathematical model of reheat, in order to optimize the operation under the point of view of pollutants emissions in atmosphere, can be divided in the following main phases:

- The graphic survey of reheat chamber;
- The generation of the chamber mesh;
- Boundary conditions definition;
- Verification of consistency of the model.

The first point was performed using a commercial CAD 3D software. The 3D model was made with a set of simple solids; the Boolean operations, necessary to obtain an unique volume, were performed using a proper utility of the software itself (FLUENT). In this environment, it was generated the mesh for the reheat, that represents the spatial discretization of the calculation domain. The simulations were performed using the segregated solver that allows the resolution of equations in a sequential way and therefore with an high calculation efficiency, but above all because this type of solver is adapted well to the study of NO_x formation. In order to model the turbulence in the calculation domain it was chosen the standard $k - \varepsilon$ model that is suitable for standard simulations of turbulent flows in the combustion chamber or in the reheat. In order to validate the mathematical model, the results of

Fig. 7. Experimental and simulated temperature.

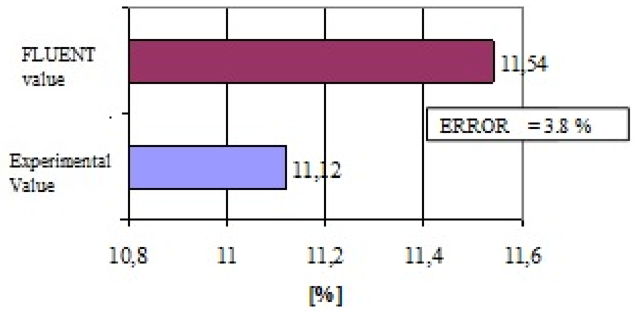

Fig. 8. Air experimental and simulated Mass fraction.

simulations were compared with the experimental data in steady state and with a standard arrangement. The theoretical-experimental comparison is shown in Fig. 7, 8 and 9 reporting the results of simulations and experimental data relating to soot temperatures, oxygen concentrations and the quantities of main pollutants (CO, NO_x, SO_x) emitted from the chimney. According the analysis of graphs the error of simulations to experimental data is relative low (less than 5), and it is possible to state that the mathematical model is able to model correctly the real operation.

V. Application of OFA Technique

Once the reliability and accuracy of the mathematical model were verified it was studied the operation of the plant in OFA asset according both theoretical and experimental point of view. The application of this technique was carried out simply varying the percentage of air in the reheat between the row of the upper nozzles and lower ones leaving unchanged the total mass flow. It is important to underline that there was not make any structural modifications to the plant.

The simulations results in steady state shown that with the increase of air mass flow of the upper nozzles respect to lower ones there is a decrease of NO_x. this confirms the goodness of the application of this technique of emissions reduction. It is also important to observe that the variation of NO_x is accompanied with a reduction of temperature of smokes at the chimney (Fig. 10). This temperature has to be set above

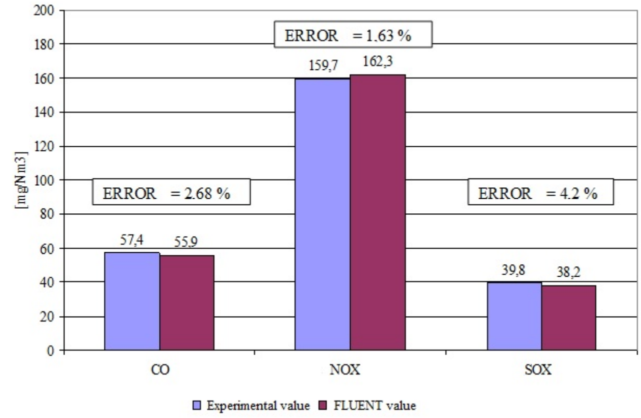

Fig. 9. Experimental amount of CO, NO_x and SO_x.

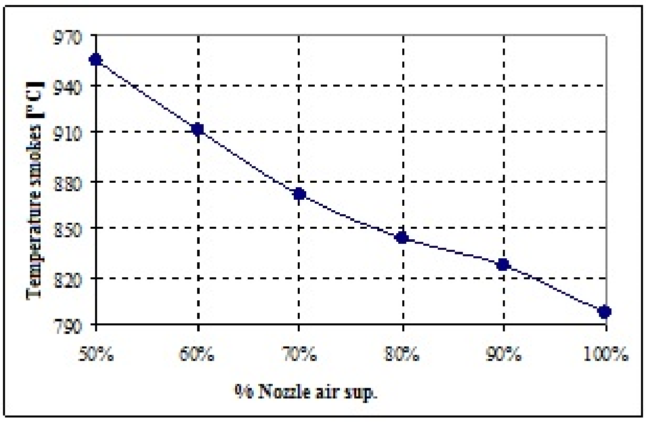

Fig. 10. Temperature variation with percentage of air at upper and lower nozzles.

850° C for law. According the graph in Figure 10 it is clear that it is not possible to use an air percentage upper than 70% in respect to the total mass flow. Therefore, an experimental campaign was conduced with different mass flow percentage (50, 60 and 70%) in respect to the air total mass flow.

The results of experimental tests demonstrated that the application of OFA technique is good remedy for the reduction of NOx emissions by the incinerator plant. These tests also further confirmed the effectiveness of the mathematical model and the reliability of CFD in the application of fluid dynamics. As a matter of this fact the results of simulations differ marginally from real data. The errors occur because of the imperfect homogeneity of the oven and the necessary approximations in the mathematical model.

In Fig. 12 and 13 the trends of the mass fractions are reported for all cases. There are also illustrated the obtained values in simulations. In these graphs it was also reported the percentage error occurred. According the analysis of results its important to observe a good reduction of NO_x (around 15%) while there was a light increase of SOx emissions (around 9%). The increase of SOx is not very important for the plant management, above all for the very low produced mass flow

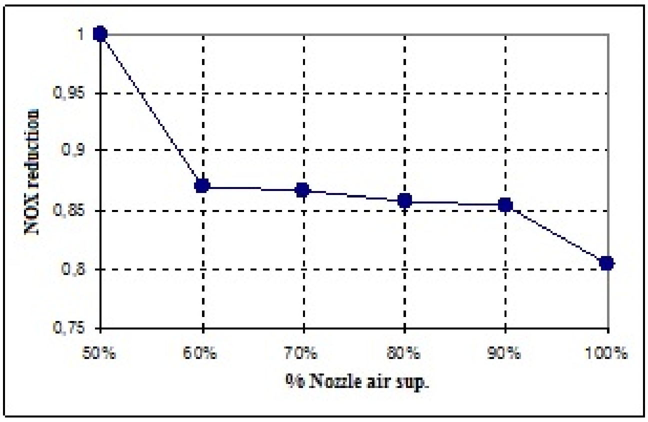

Fig. 11. NOx emissions variation with the percentage of air at upper and lower nozzles.

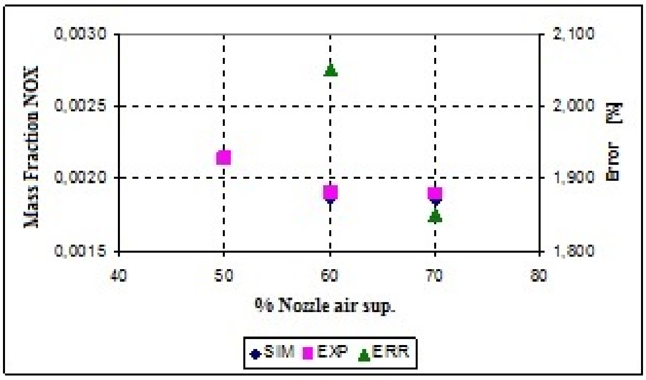

Fig. 12. Trend of mass fraction of NOx at varying the percentage of air at upper nozzles.

fractions and also because the plant is equipped with a system of post treatment of these compounds.

VI. CONCLUSIONS

The present work was carried out according a wider research activity finalized to the application and optimization of combustion techniques, primary and secondary, for the reduction of pollutants formation during the combustion process. The main scope of this research was the implementation and optimization of the combustion Over Fire Air technique in the reheat of an incineration plant, in order to obtain a reduction of NOx emitted at the chimney during the termodestruction cycle. A mathematical model of this component of the plant was implemented using a CFD commercial code. The comparison between simulations results and experimental data shows an effectiveness and accurate prediction of the model that can be used to study the formation of pollutants in the primary and secondary combustion zones. The comparison can be considerate acceptable. The errors (maximum 3-4 %) can be attributed to the approximations of the model itself. The analysis of results shows clearly a reduction of NOX concentrations at the chimney of about 18-19 % that is lowed to 18 % because of the restrictions imposed by law (a minimum

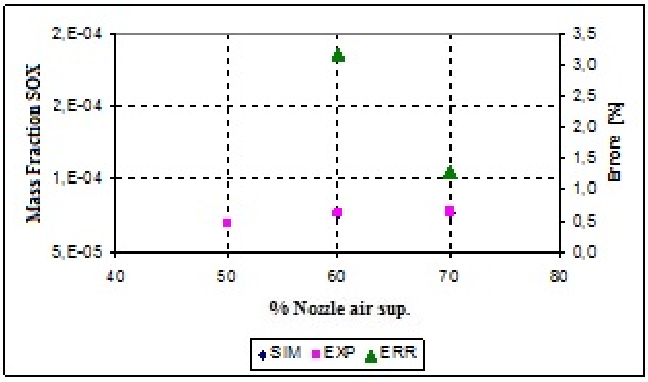

Fig. 13. Trend of mass fraction of SOx at varying the percentage of air at upper nozzles.

temperature of gases at chimney of $850°C$). According the results obtained from experimental tests it was observed that NOX concentration may suffer a real decay of around 15%. With this reduction it is possible to leave expensive techniques of cleaning smokes, with the consequent efficient reduction of plant costs. In conclusion it is possible to declare that the used calculation tool allows to project and optimize the industrial plants according to the process and environmental points of view.

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