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RESEARCH ARTICLE

DESIGN OF AIR DISTRIBUTER FOR PROPER BURNING OF FUEL IN FURNACE FOR HIGH TEMPERATURE AND LOW NO_X EMISSION

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ABSTRACT

Energy inputs and its environmental effects are critical to a thermal process. The increased use of fossil fuel based energy resources has become increasingly important, particularly in developed countries and increasingly in the developing countries. So there is need to use the existing source of energy in most efficient way. The complete burning of fuel is very important for uniform distribution of heat energy and less NOx formation. Numerical study has done to design an air distributor in a regenerative burner for proper mixing of air and fuel. Different configurations of air distributor were analyzed with respect to control of flame temperature, low NOx formation and less pressure development inside furnace. An air distributor unit with its holes of size 4mm in diameter, distributed at an angle of 15 degree was found best in regard of low pressure and low NOx formation which were calculated at the outlet of furnace.

INTRODUCTION

NOx emission is an issue that needs to be considered for boilers (Purvis *et al.*, 2000; www.kxcad.net/ansys; www.kxcad.net/ansys/index.htm; Salzmann and Nussbaumer, 2001) as nitrogen oxides resulting from the combustion of any fossil fuels or biomass fuels contribute to the formation of acid rain and photochemical smogs, which are significant causes of air pollution. The formation of NOx in combustion processes is now well understood, which proceeds predominantly through three routes: thermal-NOx, prompt-NOx and fuel-NOx. Timely and proper mixing of air with fuel is very important to get high temperature and low NOx formation. In this regard, continuous air staging is a NOx emission control strategy that is now commonly used (e.g. (www.eon-uk.com/generation/ratcliffe.aspx)). Air staging introduces the combustion air into the combustion furnace throughout its length, creating a fuel-rich zone or pockets in the primary combustion zone and leading to less intensive primary combustion flame. Air staging reduces NOx formation mainly by two mechanisms: (1) air staging allows deprivation of oxygen, and less mixing of fuel and air in the primary combustion zone, inhibiting the conversion of fuel-N to NOx and hence reducing fuel-NOx and (2) air staging results in a cooler primary combustion flame and hence less thermal-NOx.

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Regenerative furnaces are considered good in regard to recover heat from exhaust gases, so reducing consumption of fuel. Air is entered openly into the furnace which cause improper mixing of air with the incoming fuel. This leads to the formation of thermal NOx by creating zones of high temperature. Also some percentage of air goes out without burning. Due to this, design of an air distributor is important to overcome this problem. Design of new burners is mostly based on the long-time experience. Moreover, burners are tested at testing facilities before putting into operation. However this approach is limited by economic constraints (costly prototype manufacture and individual test) as well as technical one (parameters of testing facility). Thus new alternatives of partial or complete substitution of physical burner testing are being investigated with support of up-to date computational tools. Art of computational methods for the fluid flow prediction including chemical reactions and heat transfer, make complex burner simulation possible (Thierry Poinsot, *et al*., 2005). On the other hand these computational methods are not reliable. Therefore good knowledge of their strengths and weakness is required (www.kxcad.net/ansys; www.kxcad.net/ansys/index.htm). This article reports modeling of an experimental regenerative burner installed with air distributers. The purpose of this study is to design and select a proper air distributor unit within furnace for complete burning of fuel to get high temperature and low NOx. The air distributor has been designed as a low NOx by introducing combustion air staged-wise along the length of furnace. The geometry of air- distributers is modified with respect to amount of NOx emission.

Continuous staged air combustion (COSTAIR)

The COSTAIR combustion concept has been developed for application in boilers. The main principle is a continuous staging of the combustion air in order to suppress the thermal NOx. Its operation is stable and free of pulsation over a wide operating range (air ratio up to 5). NOx emission values are <10 ppm (15%O_2) and CO emission are <5 ppm (5%O_2) under atmospheric conditions (Al-Halbouni, 1998; Giese *et al.*, 2000). With air distributor based on COSTAIR concept in regenerative burner, following objectives were aimed to get.

1. Using axial tube as air distributor with numerous holes on its periphery which increase mixing rate inside the furnace and consequently a uniform temperature distribution throughout the furnace length.
2. To reduce fuel consumption and consequently CO_2 emissions.
3. To increase of the stability of the combustion process in a wide range of excess air ratio.
4. To suppress the high pollutant emissions by reducing the flame temperature.

Description of furnace and air distributors

In regenerative furnace, the entrance of air into the furnace is altering after specific intervals during combustion process. This has done to recover the heat from flue gases by ceramic filter in its way. One end which acts as inlet also act as outlet in another time interval when direction of air is changed with the help of 4-way valve system. The absorbed heat by ceramic filter is then given to incoming air for preheating purpose (fig.1). At the both entrance ends of furnace, air distributor units were designed with different configurations (fig.1). As shown in the figure, this system has a pair of axial tubes acting as air distributors.

Fig. 1. Regenerative burner and testing air-distributors

Both of these tubes are placed axially in front of each other. The combustion air flows through the inner annulus of these tubes and then enter through the circular openings into the furnace. The total amount of combustion air can be controlled by 4-way valve. Here the main objective of simulated work is to show a comparative difference between existing one (without furnace) and modified one (with air distributor) with respect to proper mixing of air and fuel for low NOx production, uniform temperature distribution and finally find out an appropriate design of an air-distributor. This made simplification for modeling that main parts of system (furnace, fuel nozzle and air-distributor) are modeled to optimize the air-distributor configuration. A two side arrangement for air distributors inside the furnace is shown in figure 2.

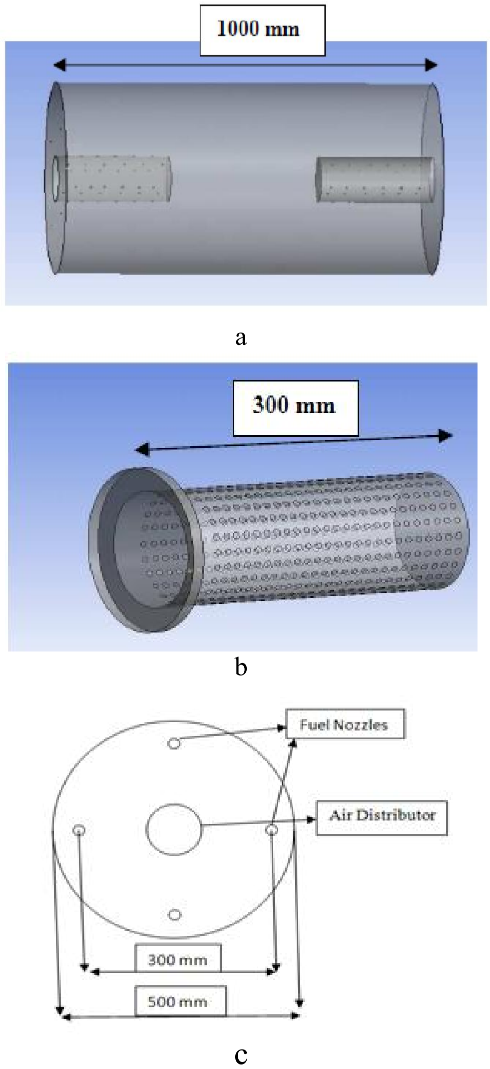


Fig. 2. Configuration of test furnace (a) Furnace geometry with air distributers units (b) Air distributor (c) cross sectional view for the arrangement of fuel and air inlets and flue gas outlet

There is need to select an optimum air distributor which estimates the minimum pressure development inside furnace along with minimum NOx production. In this arrangement of air distributors, flue gases would have to pass through the openings of distributor acting as outlet (at least 50% of the incoming air pass out), so it can cause a strong turbulence at the side acting as outlet. That is why only the furnace having air distributors is modeled as shown in figure 2. To provide a base for experimental and commercial developments for this concept of air distributors, a numerical analysis has done.

Simulation detail

Computational model is set up in ANSYS-CFX software. For simplification following assumptions are introduced to the model: Firstly, the whole of the set-up is not modeled. This simplification uses an assumption that only those parts which cause air distribution in furnace will have effect on mixing properties and pressure development. Secondly, geometry simplification concerns the inspection of holes in the chamber, which are neglected as well as annular volume filled with cooling water. It is modeled as constant temperature wall boundary condition. The surface of computational mesh is displayed in figure 3.

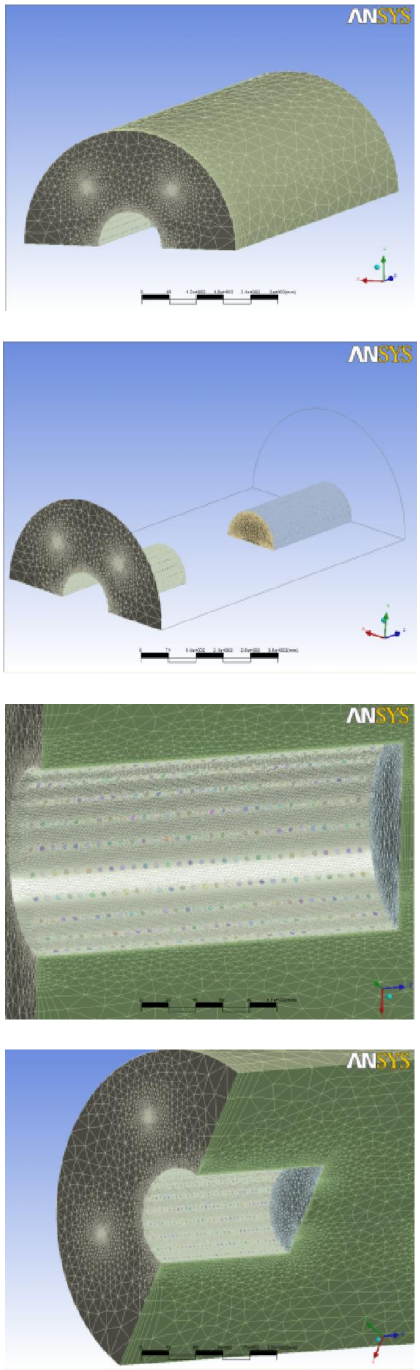


Fig. 3. Computational meshing of the model

Tetrahedral mesh elements are applied around more complicated features such as fuel nozzles and air opening while hex/wedge element elsewhere (www.kxcad.net/ ansys; www.kxcad.net/ansys/index.htm). Detail of them lies in table 1.

Table 1. Model properties and settings of the simulations

Properties	value and settings
Number of elements	1961542
Grid type	3D, tetrahedral, unstructured
Turbulence model	k-ε standard
Discretization	Second-order upwind

Following boundary conditions are set,

Fuel Inlet: The fuel (methane) is injected through the 4 nozzles with a velocity of 40m/s. The volume fraction is 1 for methane.

Air Inlet: The air is injected through the distributor tube holes with a velocity of 10 m/s. The volume fraction is N2 (79), O2 (21).

Outlet (Average Static Pressure): The static pressure is allowed to locally vary on the outlet boundary such that the average pressure is constrained in a specified manner. In all cases, the flow direction at the outlet is an implicit result of the computation. In this case we used the 0 [pa] value relative pressure.

Wall: Outer walls are adiabatic walls and are defined using a no slip boundary condition.

Symmetry: Calculations for half model geometry require symmetry conditions at the symmetry plane. It will use to reduce the computational time and ultimately decrease CPU used memory space.

In order to identify optimum arrangement of the air openings in terms of minimum pressure accruing inside the furnace, six (3 diameters × 2 angles) different arrangement of holes on air distributor unit were introduced (fig. 4 and table 2).

Table 2. Alternatives of air-distributor to be analyzed

Diameter	Degree	Number of openings
2 mm	15	720 (24 × 30)
	30	360 (12 × 30)
3 mm	15	720 (24 × 30)
	30	360 (12 × 30)
4 mm	15	720 (24 × 30)
	30	360 (12 × 30)

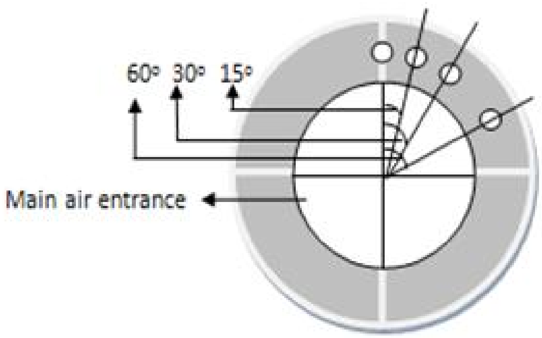


Fig. 4. Distribution of air openings of air-distributor at three angles

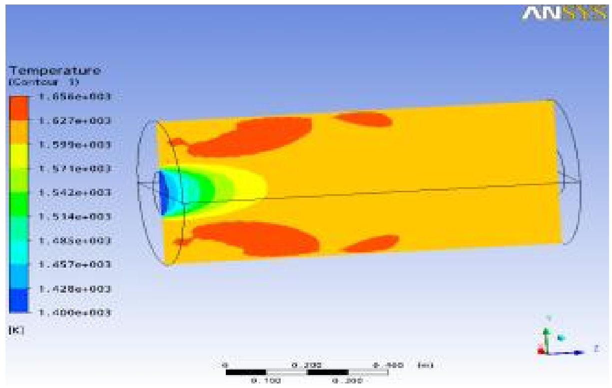
Rates of chemical reaction are calculated using well-known eddy-dissipation model of Magnussen and Hjertager (Al-Halbouni, 1998), which relates the rate of reactions to the local turbulence properties (representing intensity of turbulent mixing). This model is best applied as the chemical reaction rate is fast relative to the transport processes in the flow and also that fuel and oxidant be available in the control volume for combustion to occur. There is no kinetic control of the reaction process. Thus, ignition and processes where chemical kinetics may limit reaction rate may be poorly predicted. The specified chemical time scale may need to be adjusting in order to achieve best results for specific problem. For methane-air combustion, good starting points are 1.37e-4 [s] when applying Kolmogorov time scale, or 5e-4 [s] when applying to the mixing time scale and this is applied as Kolmogorov time scale tends to be more aggressive and lead to global extinction of flame (www.kxcad.net/ansys; www.kxcad.net/ansys/index.htm). The complete set of six alternatives of different positions of the air openings was calculated. After an acceptable level of convergence, computation of NOx formation took place based on the obtained results. As the fact that fuel does not contain any chemically bounded nitrogen, all of the NOx produced is accounted by the two following formation mechanism (Giese *et al*., 2000):

- Thermal (Zeldovich) mechanism and
- Promt mechanism

RESULTS AND DISCUSSION

Fig.5 shows the temperature distribution in both regenerative burners with air distributor and without air distributor. When the fresh air was preheated to 1300 K, the combustion intensity was seen to have increased a lot. Not only the maximum flame temperature had increased from 1600 K to 1700 K, but the averaged furnace temperature also reached a high level for using methane gas as fuel. With the case of using air distributor, it is clearly visible that zones of high temperature are found less which shows that flame temperature intensity had lowered down and thermal NOx production was small as compared to regenerative burner without air distributor. The difference between the maximum flame temperature and the averaged furnace temperature was the lowest among the two simulation cases, which implies that the temperature distribution in the furnace tends to become more uniform in the highly preheated air by using air distributor.

Graphical representation in axial direction of furnace also show the accuracy of temperature distribution throughout the furnace. It shows a comparative temperature distribution in axial distance for both the furnaces i.e. with and without air distributors. In case of air distributor unit in furnace, the temperature difference between minimum and maximum of its value was only 20 K while that difference was 180 K in second case without air distributor unit. So, it is clearly observed that temperature distribution is more uniform in furnace using air distributor rather than without air distributor. The furnace with air distributor for combustion air provides the best uniformity of temperature distribution. Such an improvement on the uniformity of temperature distribution is one of the important performance requirements.



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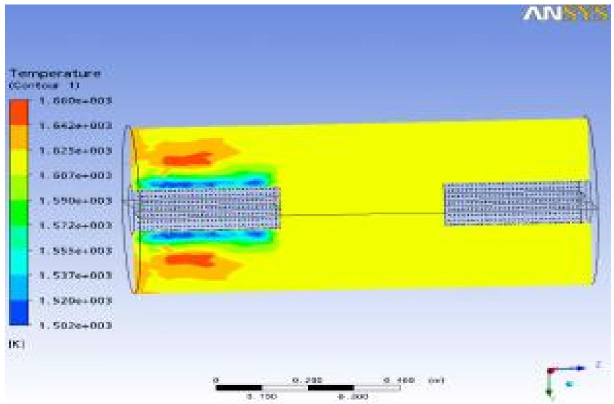

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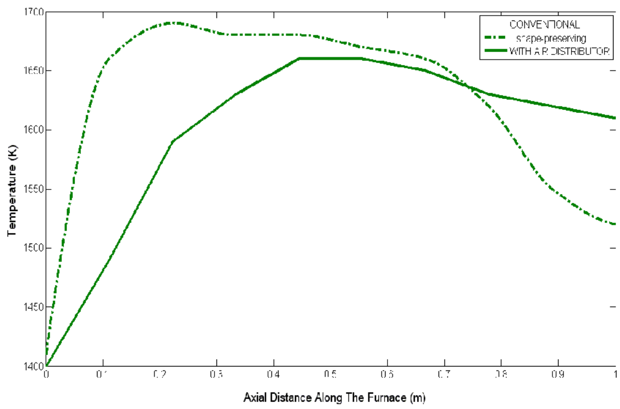
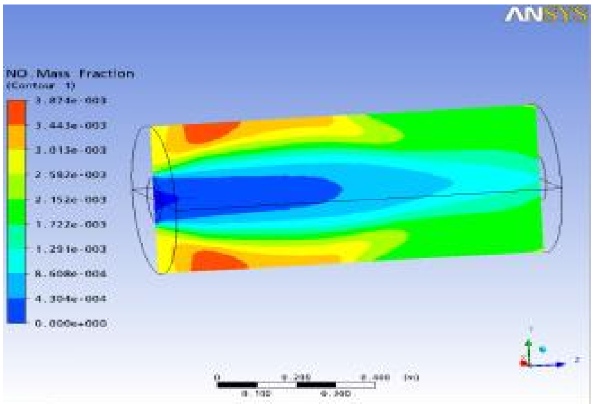


Fig. 5. The profiles of temperature distribution in conventional furnace (a) and furnace with air distributor (b) in axial length of furnace (c) graphical representation of temperature in both cases

Fig.6 shows a comparative difference of combustion behavior in conventional regenerative furnace and modified one with air distributors. In conventional furnace (Fig.6b) NOx formation is more close to inlets while in second case (with air distributors) it is far from it along the furnace due to continuous mixing of air and fuel. The NOx emission during combustion mainly depends on the flame temperature. The high-level flame temperature in the highly preheated air combustion results in the high NO_X emission. Although air is preheated but we can reduce NOx emission by increasing the mixing rate of combustion products by using air distributor inside the furnace. In case of conventional regenerative system, the contours of NO_X emission inside the furnace along the axial direction showed its high concentration in fuel rich region where combustion took place and it had excess amount throughout the furnace. On the other side, furnace with air distributor system showed extremely small amount of NOx at outlet which is under satisfactory limit. Similar results can be seen form graphical representation of NOx distribution inside the furnace along its axial distance. The NOx emission at the furnace middle abruptly increased due to high flame temperature in conventional furnace while such trend was not observed in case with air distributor. It indicates that using air distributor for combustion air increase mixing rate inside the furnace and ultimately suppress the NOX emissions. This can also be proved by the comparison of NOX mass fraction between these two cases at average furnace temperature. It is clearly depicted that stage combustion (using air distributor) has reduced NOX output remarkably.



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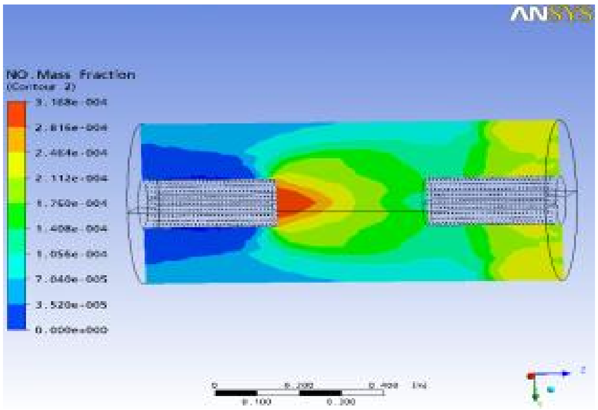

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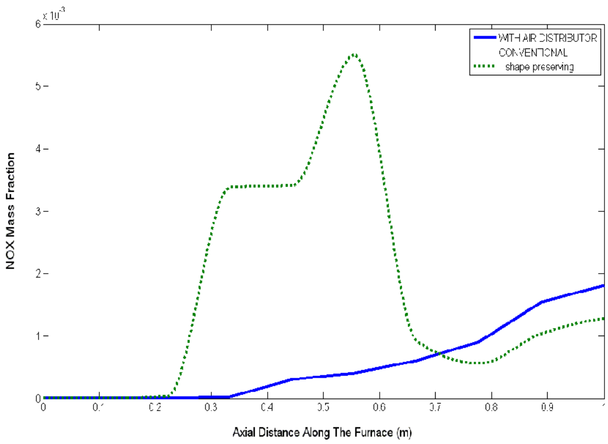
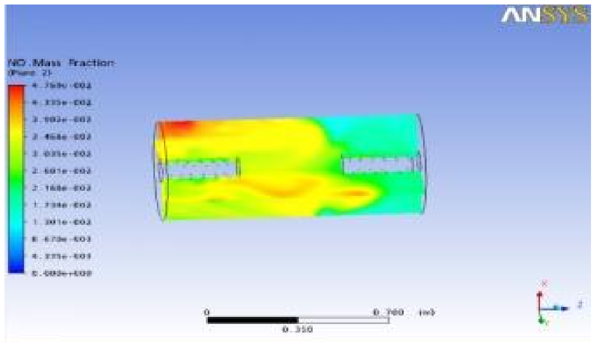
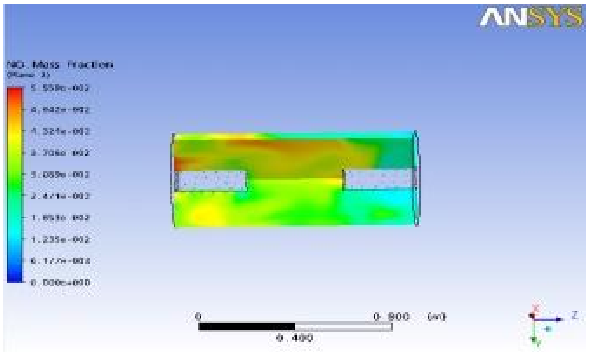


Fig. 6. NOx distribution in conventional furnace (a) and furnace with air distributor (b) graphical representation of NOx distribution in both cases (c)

As the results of temperature and NOx were obtained with different hole sizes of air distributors. Fig.7 shows the NOx distribution inside furnace with different hole sizes of air distributor.





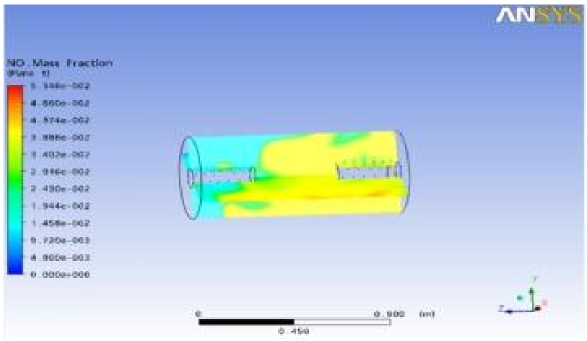


Fig. 7. NOx distribution with 2,3 and 4mm diameter of air opening distributed at 15^0

The numerical results of NOx concentration and pressure at the outlet of furnace obtained with simulations are tabulated in table 3. The optimal diameter for holes of air distributor was found 4mm when distributed at angle of 15 degree. With this configuration lower pressure and low concentration of NOx were calculated.

Table 3. NOx concentrations at outlet and pressure in furnace

Diameter	Degree	Pressure [Pa]	NOx [ppm]
2 mm	15	118	106
	30	170	120
3mm	15	110	98
	30	133	110
4mm	15	80	88
	30	102	98

Oxygen consumption in both systems i.e. using air distributors and without air distributors, shows that oxygen consumed completely in furnace with air distributor. It means that the incoming air was burnt fully after mixing with fuel. On the other hand, in conventional system the circulation region was small so that remaining oxygen amount is large at the outlet point which means that the air is not being completely used and passing out without burning along with the exhaust gases.

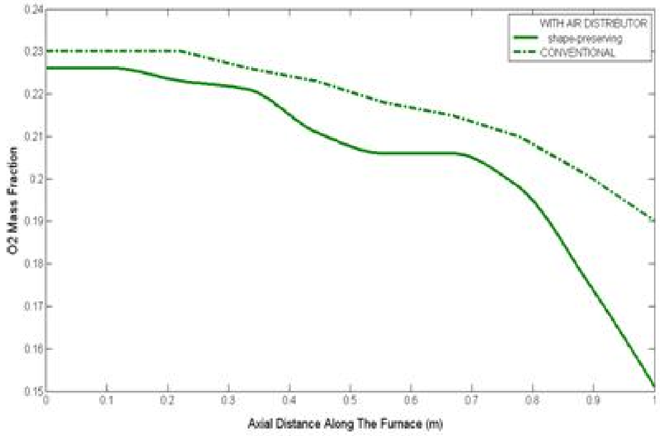


Fig. 8. Oxygen consumption in axial direction of conventional furnace and non conventional furnace

Conclusion

This study reveals the numerical simulation applied for the design of an air distributor within a furnace of regenerative burner for proper mixing of air and fuel. Air distributors with different holes configurations and arrangements were investigated with respect to NOx production and pressure occurrence. It is analyzed that application of air distribution unit in regenerative burning system provides better results in regard to control flame temperature and less NOx formation. The best configuration found for holes were 4mm diameter, distributed at 15 degree angle with respect to minimum NOx production and low pressure development. However, this represents only a first step for experiment, the next step which is under process is to make a set-up for the validation of these results and to provide a base for commercial level.

REFERENCES

Al-Halbouni, The COSTAIR Gas burner: extremely low NOx and CO emission, joint British-French Days, Guernsey, Channel Islands, 1998.

ANSYS CFX, Release 11.0**,** www.kxcad.net/ansys/index.htm

ANSYS Release11.0 Documentation for ANSYS Workbench**,** www.kxcad.net/ansys

Giese, R., A. Al-Halbouni, R. Sontag, The influence of air and fuel impulses on the emission behaviour of the COSTAIR Gas burner, in 5th European Conference on industrial furnaces and boilers, Portugal 2000

Gyung-Min, Advanced low NOx combustion using highly preheated air, Energy Conversion and Management 42(2001) 639-652

Lefebvre, A.H. Gas Turbine Combustion, Taylor & Fracis, 1998, ISBN 1-56032-673-5.

Purvis MRI, Tadulan EL, Tariq AS. NOx control by air staging in a biomass fuelled underfeed stoker. Int J Energy Res 2000;24:917–33.

Salzmann R, Nussbaumer T. Fuel staging for NOx reduction in biomass combustion: experiments and modelling. Energy Fuel 2001;15:575–82.

Thierry Poinsot, D. Veynante Theoretical and Numerical Combustion. R.T. Edwards, 2nd edition, 2005

Veynante, D. Turbulent combustion modeling, Prog. Energ. Comust. 28 (2002) 193-266

www.eon-uk.com/generation/ratcliffe.aspx [accessed 02.10.12].

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