Enhancing the *Performance* of Kiln Burners

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RELATE THE FINDINGS OF AN INVESTIGATION INTO THE PERFORMANCE OF KILN BURNER HEADS.

Introduction

Burner designs for modern clinker kilns must fulfil several requirements, including operational flexibility, high durability, low energy consumption, easy tuning, low emissions, and fuel flexibility. The evaluation of many of these features is straightforward.

Generally, the design of a new burner involves the calculation of:

- Flame impulse.
- Turbulence index.
- Primary air ratio.
- Swirl number.

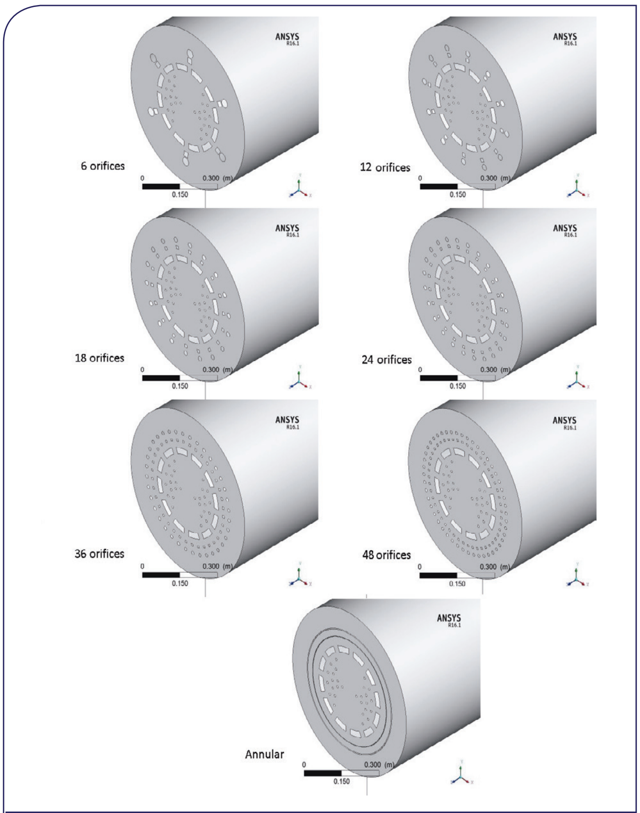

Figure 1. The seven different burner head configurations studied.

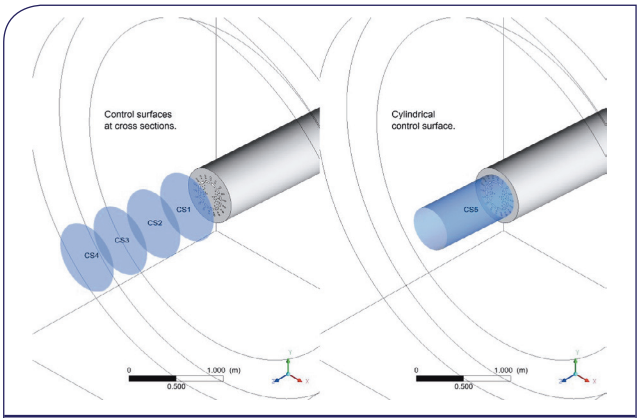

Figure 2. Control surfaces employed in the analysis of secondary air entrainment into the fuel region.

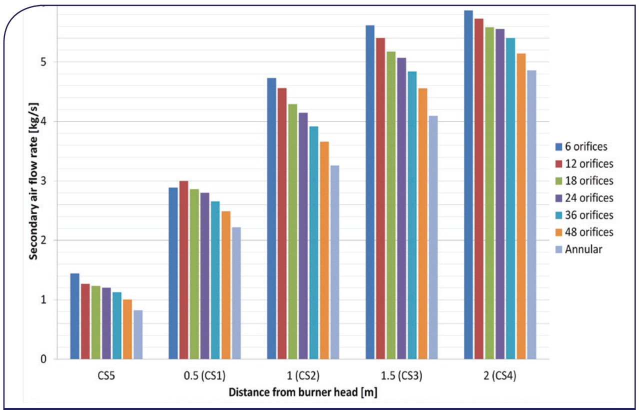

Figure 3. Flow rate of secondary air through control surfaces.

These indices provide essential information regarding efficient fuel combustion and are also used at Dynamis as part of the development of equipment suitable for multiple applications. However, none of them address the geometric aspects, which are also important if the overall performance is to be enhanced. Therefore, relying on these indices alone to evaluate a burner might lead to a lack of information on the process once combustion is governed by far more complex phenomena.

Dynamis has recently adopted a more complete methodology to evaluate and compare burner designs in order to develop its new generation of burners: the D-Flame. This is the result of many years of experience in the field, a specialised technical body, and customer feedback. The new D-Flame burner is the product of a complete analysis of factors crucial to burners' performance enhancement, such as the one addressed here: secondary air entrainment into the fuel injection region.

The influence of burner head geometry

For the same primary and secondary air flow rates, and consequently the same swirl, turbulence and impulse indices, tests with different designs for the external and tangential primary air were carried out to verify how the geometry of the burner head might improve not only the burner's performance, but also the whole kiln operation.

Figure 1 shows the seven different head designs simulated at Dynamis. The boundary conditions and the mathematical models used are the same in all cases studied.

Dynamis believes that the higher the entrainment of secondary air into the fuel injection region, the better the overall performance will be. The importance of this has also been highlighted in other articles.[1]

To measure the calculated secondary air entrainment into the fuel region, several control surfaces, shown in Figure 2, were used to evaluate the results obtained with CFD calculations.

On the left hand side of Figure 2, four control surfaces are presented at different cross-sections from the burner head (CS1, CS2, CS3 and CS4) located, respectively, 0.5 m, 1 m, 1.5 m and 2 m away from it.

The cylindrical surface (CS5), pictured on the right hand side of Figure 2, is 1 m long and 0.5 m in diameter, and comprised the external primary air channel.

Figure 3 shows the measurement of secondary air entrainment calculated on these control surfaces (CS1 to CS5) for all geometric designs considered. It can be seen that the fewer nozzles there were on the head for the external and tangential primary air, the higher the value of secondary air flow rate through control surfaces CS1 to CS4, with surface CS1 being the only exception, 0.5 m away from the burner head for the configuration of six holes. For the cyclindrical surface (C5), only the flux entering into the fuel injection region was considered, once the flux coming out of it could be related to expansion due to the combustion of coal and, therefore, should not be taken into account in such analysis.

Evidence supporting that there is an improvement of secondary air entrainment into the fuel region for a head with fewer nozzles is seen in Figure 4. The coal particle tracks calculated are coloured by the char mass fraction of coal, with red indicating the range in which particles are volatile free. The black plume is, therefore, shorter for configurations with fewer nozzles for primary external and tangential air on the burner head.

The temperature profile along the kiln length for all cases studied seemed, at first glance, to be similar for all configurations, with the exception of the annular case, which showed an unstable profile. However, a closer look, as shown in Figure 5, revealed a cooler region near the burner head (indicated by the darkest shade of blue) as the number of nozzles was raised. This is again an indication that the hot secondary air entrainment was greater in head configurations with fewer nozzles.

Further evidence indicating a greater entrainment of secondary air into the fuel injection region can be seen through the temperature of the burner head.

By assumption, the burner head was adiabatic, so the temperature gradients were solely due to the entrainment of hot secondary air in this region. For the annular configuration, the external primary air created a barrier, isolating the central region of the burner head, and preventing secondary air getting mixed with the fuel in the first few metres. The gaps between the fuel injection channels are also significant in allowing the hot secondary air flow to reach the internal region of the burner.

Figure 6 shows the radial velocity near the burner head. Only the negative values of this variable were considered, since the aim was to identify which configuration allowed more secondary air into the fuel injection region. In this case, it seems that the head with six openings is not as symmetrical as the other configurations. This might suggest that there is some degree of instability with this head design. Looking at the designs with 12, 18 and 24 holes, it can be noticed that the radial velocity reaches its peak around the external primary air injection. For the other three cases – annular, 36 and 48 holes – the values for the radial velocity are 33 – 50% smaller around this region.

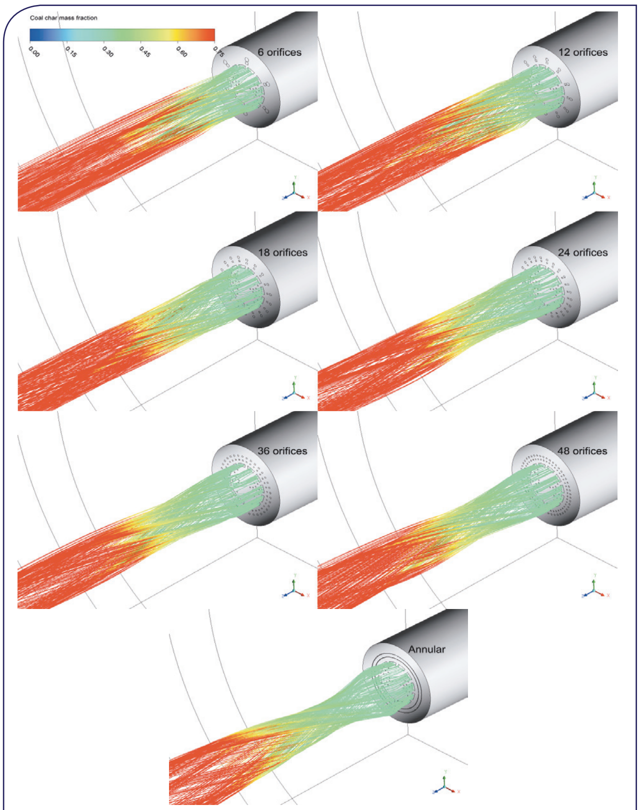

Figure 4. Fuel particle tracks for all head configurations studied – isometric view.

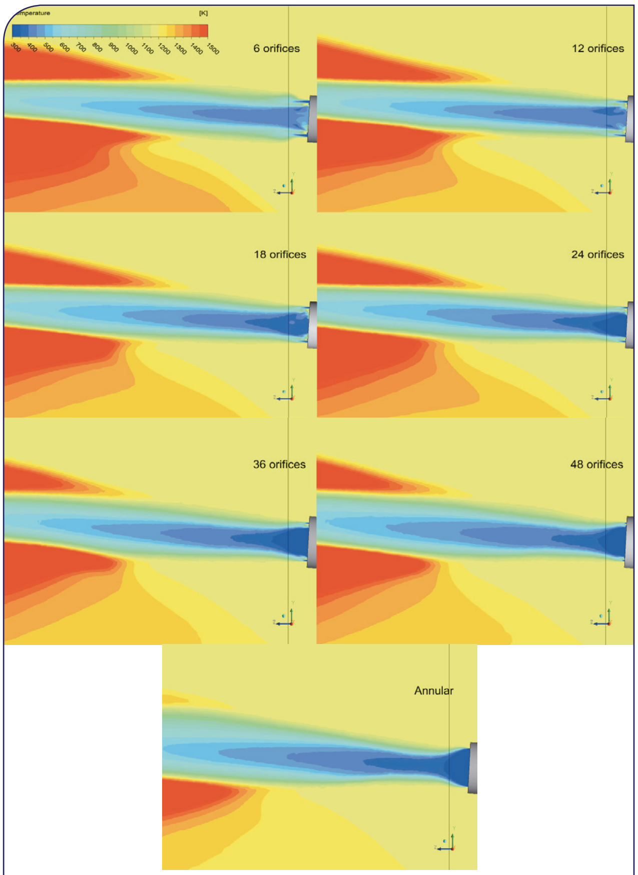

Figure 5. Temperature profile in the burner region for all head configurations studied.

Last but not least, a correlation was set between a new dimensionless geometrical index proposed by Dynamis, as defined below, and the flux of secondary air entrainment into the fuel injection region per opening interval. The proposed geometrical index is defined by:

Where *d* is the distance between nozzles, *Dh* is the external primary air orifice hydraulic diameter, *R* is the distance from the centre of the head to

$$I_g = C\frac{dD_h}{RD_{h\_eq}}.$$

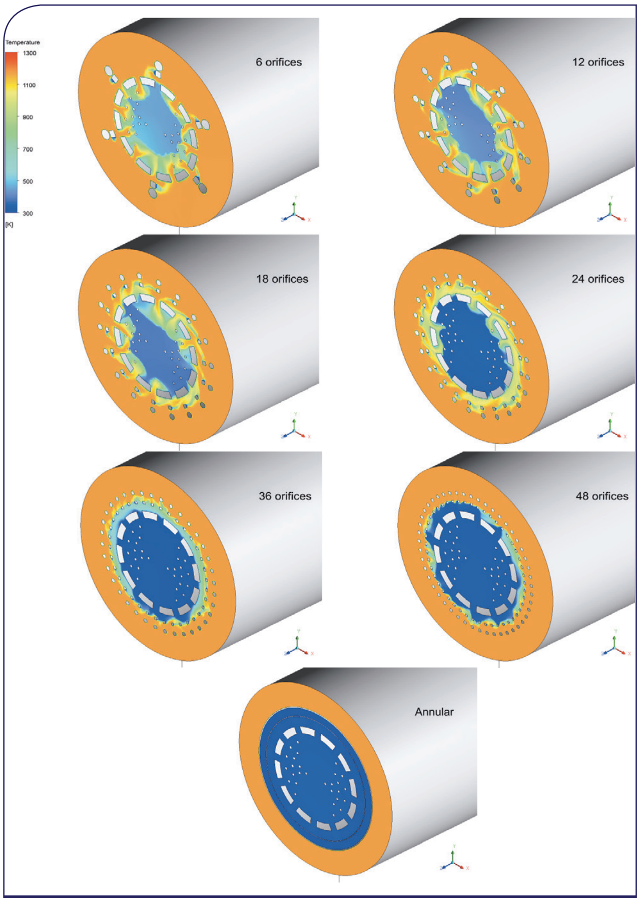

Figure 6. Temperature of the burner head.

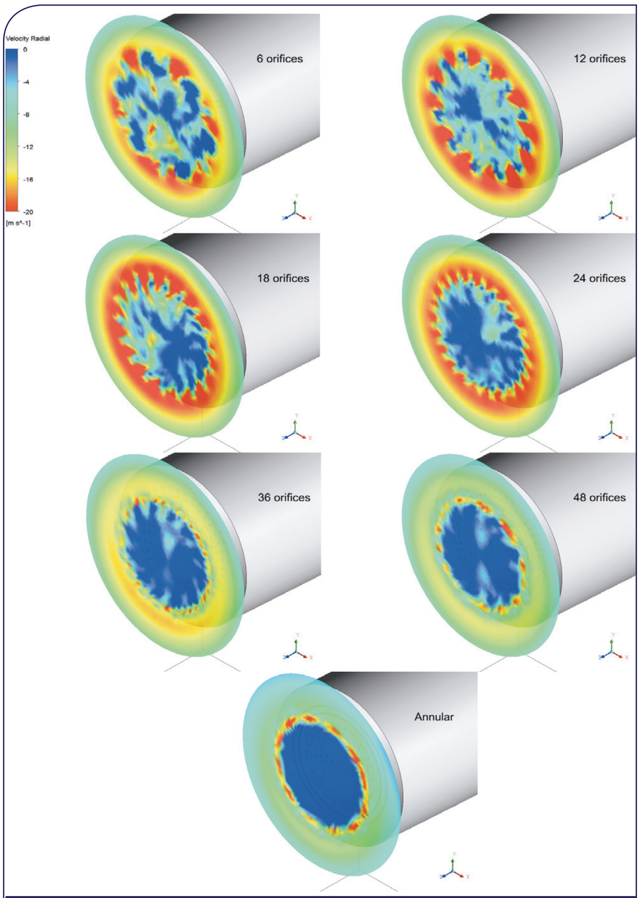

Figure 7. Radial velocity near the burner head.

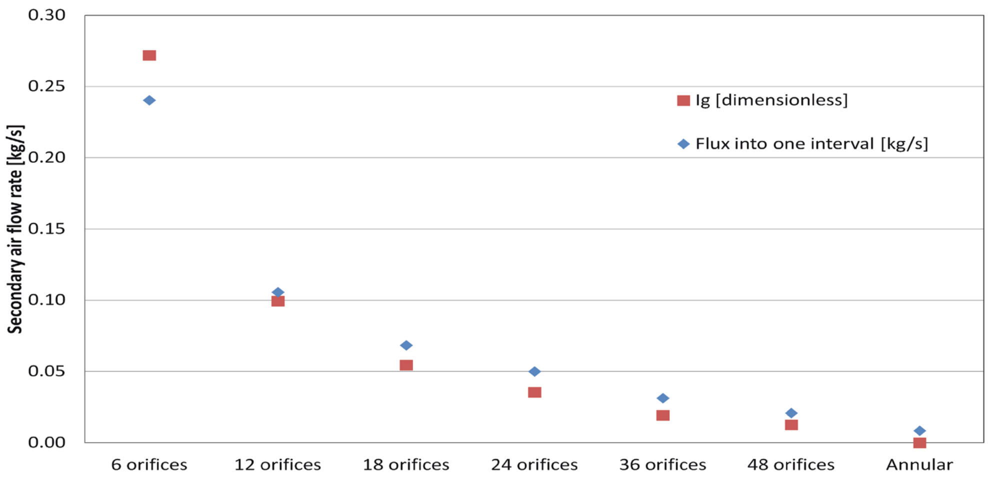

Figure 8. Comparison of dimensionless index Ig (red squares) and average flow rate of secondary air into one interval between nozzles (blue diamonds).

the centre of the external primary air orifice, *Dh_eq* is the equivalent annular hydraulic diameter of external primary air, and *C* is a constant.

Figure 8 presents the index I_g and the calculated fluxes for the secondary air in all cases studied.

Conclusion

The key purpose of a burner is to enable the use of fuel by creating the conditions for proper reaction rates as efficiently as possible. This is achieved by the injection of primary air through the burner channels. Rather than being a reactant in the combustion, primary air is mostly related to the entrainment of secondary air in the fuel stream, the formation of recirculation zones and the increase of turbulence levels to improve mixing.

Regarding the secondary air entrainment, burner head geometry makes a huge contribution to its optimisation, as has been indicated by the study presented in this article. It is essentially a local phenomenon that can only be entirely assessed using well-posed CFD (Computational Fluid Dynamics) simulations. The amount of secondary air entrainment is considered by Dynamis to be of great impact on burners' performance.

CFD simulations show that head designs with fewer nozzles tend to raise the suction of secondary air in the first 2 m of the burner head. On the other hand, there are physical aspects that cannot be ignored if a small number of nozzles are employed. The most important is that the cooling of the burner head could be highly affected, causing overheating and consequently wearing out.

It was also noticed that even though the head design with six holes for the primary external and tangential air injection had presented higher values of secondary air entrainment in almost all control surfaces evaluated, its performance in the near head region might be compromising, as evidenced by the radial velocity.

Finally, a dimensionless geometrical index correlating the influx of secondary air and the design of the burner head was established.

References

1. FIVES PILLARD, 'Development of a new burner', *World Cement*, Vol. 43, No. 11 (November 2012), pp.87 – 94.