Studies of heat transfer and furnace temperature uniformity during combustion of oil and wood using oxygen enrichment technology

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ABSTRACT

In many combustion applications a switch from fossil to renewable fuels, e.g. from fuel oil to wood powder, may result in a reduction of production capacity in the boiler, furnace or kiln. Oxygen enrichment of the combustion air can be used to improve the thermal efficiency of practical combustors, i.e. reduce heat losses and promote fuel savings. In addition, oxygen enrichment can reduce NO\textsubscript{x} emissions and also facilitate CO\textsubscript{2} scrubbing and capture processes in such systems. In this work, flame characteristics and furnace temperature profiles during oxygen enriched combustion were studied when oxygen was added to the combustor at different enrichment levels by the use of a lance. The experiments were carried out in a pilot-scale furnace fired with (i) wood powder and (ii) heavy fuel oil (no.5). The results show that for the wood flame, the average furnace temperature becomes higher and the furnace temperature profile becomes more flat. Thus, compared to conventional air combustion, there are smaller differences between near-burner and back-end temperatures as oxygen is added to the process. For the oil flame, as oxygen was added to the process, a higher average furnace temperature was observed along with a distinct shift in furnace peak temperature towards the central parts of the furnace, creating a relatively strong temperature gradient towards the back-end of the furnace. Comparing the two flames, the furnace temperature profile of the oxygen enriched wood flame becomes more flat compared to the oxygen enriched oil flame. This is interpreted as an effect of differences in overall fuel reactivity, in which the oil, being a liquid fuel, ignites and burns faster than the solid fuel wood powder. The results found in this work shows that the burner that was used, being designed for conventional air combustion by feeding of air through the primary, secondary and tertiary air vanes, could handle the changes in aerodynamics caused by the reduced air flows. The general results from this work are useful for furnace and kiln applications in which a more controllable flame and process temperature is required, e.g. in a lime kiln where a fuel switch from fossil fuels to biomass is considered.

Keywords: heavy fuel oil, wood powder, oxygen enrichment, heat transfer
1. INTRODUCTION

In many combustion applications a switch from fossil to renewable fuels, e.g. from fuel oil to wood powder, may result in a reduction of production capacity in the boiler, furnace or kiln. Oxygen enrichment of the combustion air can be used to improve the thermal efficiency of practical combustors, i.e. reduce heat losses and promote fuel savings. In addition, oxygen enrichment can reduce NO\textsubscript{x} emissions and also facilitate CO\textsubscript{2} scrubbing and capture processes in such systems.

The use of oxygen as an additive to assist combustion in furnaces has for many years been done by using general enrichment of the combustion air or by oxygen lancing. During the last twenty-five years the development of oxy-fuel burners has been in focus to be able to use the full advantages with this technology. The principal difference between enrichment by lancing and oxy-fuel is the amount of oxygen used and to what extent air is replaced. In enrichment by lancing the oxygen level in the combustion air is increased to maximum 30%. In oxy-fuel burners all air is replaced with industrial oxygen, i.e. oxygen levels in the range 90-100%. Earlier use of oxygen addition technologies had a number of limitations that made it more or less impossible to work with an oxygen amount in the range corresponding to 30-90% oxygen in the combustion air. The limitations are related to the existing equipment and are, for example, increased combustion temperatures and decreased velocities for combustion gases in the furnace. These changes influence local temperatures and heat transfer behaviour which can create overheating of burners and furnace equipment and have a negative influence on NO\textsubscript{x} formation.

Recent development based on experiences from latest oxy-fuel technology and traditional lancing technology makes it possible to use higher levels of oxygen with lancing technologies. It is now possible to use oxygen levels higher than 50% without any negative influence on equipment and emissions. Instead this has resulted in several positive effects to the behaviour and influence of the combustion process and its energy transfer to the production process of the furnace [1]. Such positive effects are (i) improved heat transfer, (ii) better and more even temperature distribution, (iii) higher productivity, (iv) improved material surface quality and (iv) more complete fuel particle burn-out/combustion. This new developed lancing technology can use higher levels of oxygen than traditional enrichment of the combustion air and have up to now been installed in heating furnaces in steel industry. An important reason for choosing this technology is the relatively low investment in new equipment and minimized interference in the existing furnace system allowing a flexible use when necessary from production and quality reasons.

Previous work on oxygen enhanced combustion has mainly been focusing on fossil fuels, such as natural gas and coal, and to some extent also mixtures between coal and biomass. Recent findings on oxygen enriched co-combustion of coal as well as coal and biomass
(oxyfuel as well as direct enrichment) show that particle burnout, radiant heat transfer and NOx emissions is affected by increasing of the oxygen fraction in the comburent (the oxygen carrying media used in the combustion process, either air or enriched air) [2-6]. Limited experiences have been published on oxygen enrichment of pure (solid) biomass fuels, and the objectives of the present work were therefore to determine effects on general flame characteristics, including flame length and heat transfer, and on furnace temperature profile in pulverised wood combustion when oxygen was added to the combustor at different enrichment levels by the use of a lance. To facilitate the interpretation of the findings, combustion trials with heavy fuel oil were also carried out.

2. Experimental

2.1 Fuels

The fuels used in this work were heavy fuel oil (no.5) and wood powder (softwood, stemwood with a minor bark fraction). Fuel composition is given in Table 1. Prior to combustion, the wood fuel was milled into a powder with approximate size distribution of: 100% < 3 mm, 98% < 1 mm, 60% < 0.5 mm and 30% < 0.25 mm.

<table>
<thead>
<tr>
<th>Fuel composition (wt-% DS)</th>
<th>Oil (no.5)</th>
<th>Wood</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture</td>
<td>0</td>
<td>4-5</td>
<td>wt-%</td>
</tr>
<tr>
<td>Ash</td>
<td>0</td>
<td>1.3</td>
<td>wt-% DS</td>
</tr>
<tr>
<td>C</td>
<td>87</td>
<td>52</td>
<td>wt-% DS</td>
</tr>
<tr>
<td>H</td>
<td>12</td>
<td>6</td>
<td>wt-% DS</td>
</tr>
<tr>
<td>S</td>
<td>0.4</td>
<td>&lt;0.02</td>
<td>wt-% DS</td>
</tr>
<tr>
<td>N</td>
<td>0.2</td>
<td>0.1</td>
<td>wt-% DS</td>
</tr>
<tr>
<td>O</td>
<td>0</td>
<td>41</td>
<td>wt-% DS</td>
</tr>
<tr>
<td>Cl</td>
<td>-</td>
<td>&lt;0.01</td>
<td>wt-% DS</td>
</tr>
<tr>
<td>Volatiles</td>
<td>-</td>
<td>81</td>
<td>wt-% DS</td>
</tr>
<tr>
<td>Heat value (LHV)</td>
<td>41</td>
<td>19.5</td>
<td>MJ/kg DS</td>
</tr>
</tbody>
</table>

2.2 Research boiler and operating conditions

The equipment used during the test was an isolated horizontal combustion chamber with a 150 kW swirl stabilized burner. The combustion air was divided between primary-, secondary- and tertiary flow to improve the combustion conditions. The combustion chamber was protected on the inside with ceramic tiles. The cross section area of the furnace was 55×55 cm² and length of the combustion chamber was about 3.3 m. The furnace was equipped with three inspection/measurement windows located at an axial distance of 0.7; 0.95 and 1.8 m from the burner quarl, see Figure 1 for a schematic drawing of the furnace. In this work, the windows will be referred to as position #1, #2 and #3 respectively.

The target thermal input was 100 kWth for both fuels. In practice, due to initial operational problems, mainly with the the immersion heater of the oil feed system, the average thermal input for the oil and wood powder was 110 and 93 kW respectively. The target CO level in the flue gas was <10 ppm.
2.3 Measurement equipment

The furnace temperature was measured by the use of thermocouples mounted in the ceramic brick wall, T1-T3 at axial distances of 0.8, 1.7 and 2.6 m from the burner wall and with thermocouples extending into the flue gas, G1-G4 at axial distances of 0.8, 1.6, 2.5 and 3.1 m from the burner wall, see Figure 1. It should be clear that neither the thermocouples in the brick wall nor the ones in the furnace can measure the real flue gas temperature or the flame temperature. These thermocouples measure a process temperature, which is a function of radiative and convective heat transfer from both the flame and ceramic brick walls.

Two cameras were used to monitor the (visual) characteristics of the flames. One camera was positioned just above the burner with a view in the fuel flow direction, and the other camera at the end of the furnace with a view straight into the burner and flame. Flue gas composition (CO₂, H₂O, CO, NO and SO₂) was measured with a FTIR (Fourier Transform Infrared Spectroscopy) from MKS, see Figure 1.

Radiative and total heat flux measurements were conducted with an ellipsoidal radiative (hemispherical) heat flux probe and a total heat flux probe (Vatell Corporation). The design of the probes gives them a relatively short response, and it typically takes less than one minute to get stable readings.

2.4 Experimental procedure and supply system for oxygen

The total time for each fuel trial was close to 7 hours. For both the oil and wood fuel, the trials were initiated with baseline flames from conventional combustion using air as the comburent. The furnace used in this work is not designed for high temperature applications, and in order not to risk any damage of the furnace insulation it was decided
to reduce the duration of the oxygen level trial to 20 minutes. This implies that each oxygen trial in total lasted about 1 hour. After 6 hours of air combustion, oxygen enriched combustion was initiated. As the oxygen was added through the lance, the burner air was decreased. In the wood combustion trial, the transportation air (0.15 Nm$^3$/h) was left unaltered during the whole trial, whereas the primary, secondary and tertiary air, initially adding up to 1.7 Nm$^3$/h, was decreased evenly and stepwise in proportion to the added amount of oxygen, see Table 2.

The supply system for oxygen was a pressure regulated flow system where the required flow was set by its corresponding pressure based on a calibration curve for the tested nozzle size. A stainless steel lance with correct nozzle size was installed through the test burner in a position at 2 o’clock when looking in the direction of firing, see Figure 2. It was also angled, see schematic drawing in Figure 1, to optimize oxygen entrance into the combustion zone and its influence along furnace length.

The radiation and total heat flux probes were moved to different positions during the trials. The thermocouple temperatures were recorded continuously. On several occasions, the fuel feed was switched off during a couple of minutes in order to record background heat flux.

![Figure 2. View of the burner and oxygen lance.](image)

Table 2. Air flows and total oxygen concentration in comburent.

<table>
<thead>
<tr>
<th>Air flow</th>
<th>Unit</th>
<th>Air (21%)</th>
<th>30%</th>
<th>40%</th>
<th>50%</th>
<th>60%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary+ secondary+ tertiary air</td>
<td>Nm$^3$/h</td>
<td>1.70</td>
<td>2</td>
<td>1</td>
<td>1.4</td>
<td>0.45</td>
</tr>
<tr>
<td>Total air</td>
<td>Nm$^3$/h</td>
<td>1.85</td>
<td>2</td>
<td>1.15</td>
<td>1.4</td>
<td>0.6</td>
</tr>
</tbody>
</table>

For wood, the highest oxygen-to-air substitution rate, i.e. 60 vol-% O$_2$ in the comburent, corresponded to a total air flow of 0.21 Nm$^3$/h (11% of the initial air flow). In the oil trial, the atomization air was kept at 2.4 bars and the air flow was initially set to 2 Nm$^3$/h and stepwise decreased as oxygen was added, ending up with 0.5 Nm$^3$/h at the 50 vol-% O$_2$ in the comburent (9% of the initial air flow), see Table 2. For both fuels, the target O$_2$ content in the flue gas was kept relatively high around 5 vol-%.
3. RESULTS

Due to the different operating and measurement conditions of the oil and wood flame, e.g. 20% higher thermal input for the oil flame, a strict comparison between the two trials cannot be made. Hence, this work mainly focuses on comparisons between the different oxygen level for each flame, and any comparisons made between the two flames/fuels should be made with the above-mentioned fact in mind.

3.1 Emissions

Flue gas composition from the wood and oil flame is given in Table 3 and Table 4. Unless otherwise stated, gas concentrations are given on dry volume basis. The flue gas from wood combustion has a higher share of CO\textsubscript{2} at similar oxygen concentrations in the comburent, ranging from 14.3% (air combustion) to 36.1% for the highest enrichment trial (50 vol-% O\textsubscript{2} in comburent). Corresponding values for the oil were 12.2 and 20.3%. The CO levels during wood combustion were below 10 ppm(v), but in the oil trials, due to problems with the immersion heater, the fuel flow fluctuated from time to time resulting in relatively high CO peaks/levels (1000-5000 ppm(v)), especially during the 40 vol-% O\textsubscript{2} comburent trial. We interpret the high CO levels mainly as a function of an uneven fuel feed and not due to a change in burner aerodynamics or combustion conditions caused by a lower feed rate of combustion air through the primary, secondary and tertiary air vanes. For the wood flame, NO\textsubscript{x} emissions expressed as volume concentration, ppm(v), increases with increasing O\textsubscript{2} concentration of the comburant. However, due to the smaller gas volume of the combustion products during the oxygen trials, the (calculated) NO\textsubscript{x} emission expressed as mg NO\textsubscript{x} per MJ (supplied fuel) is lower than or on similar levels as for the base (air) wood flame.

Table 3. Flue gas composition during combustion of wood, dry gas normalised to 6 vol-% O\textsubscript{2}.

<table>
<thead>
<tr>
<th>O\textsubscript{2} in comburent (vol-%)</th>
<th>CO\textsubscript{2} vol-%</th>
<th>H\textsubscript{2}O vol-%</th>
<th>NO ppm(v)</th>
<th>SO\textsubscript{2} ppm(v)</th>
<th>O\textsubscript{2} vol-%</th>
<th>NO\textsubscript{x} mg/MJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>21%</td>
<td>14.3</td>
<td>7.8</td>
<td>127</td>
<td>0</td>
<td>7.6</td>
<td>95</td>
</tr>
<tr>
<td>30%</td>
<td>18.9</td>
<td>10.7</td>
<td>141</td>
<td>1</td>
<td>7.5</td>
<td>80</td>
</tr>
<tr>
<td>40%</td>
<td>25.7</td>
<td>12.6</td>
<td>219</td>
<td>1</td>
<td>9.1</td>
<td>91</td>
</tr>
<tr>
<td>50%</td>
<td>36.1</td>
<td>13.8</td>
<td>326</td>
<td>0</td>
<td>11.6</td>
<td>96</td>
</tr>
</tbody>
</table>

Table 4. Flue gas composition during combustion of oil, dry gas normalised to 6 vol-% O\textsubscript{2}.

<table>
<thead>
<tr>
<th>O\textsubscript{2} in comburent (vol-%)</th>
<th>CO\textsubscript{2} vol-%</th>
<th>H\textsubscript{2}O vol-%</th>
<th>NO ppm(v)</th>
<th>SO\textsubscript{2} ppm(v)</th>
<th>O\textsubscript{2} vol-%</th>
<th>NO\textsubscript{x} mg/MJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>21%</td>
<td>12.2</td>
<td>9.8</td>
<td>225</td>
<td>162</td>
<td>4.9</td>
<td>157</td>
</tr>
<tr>
<td>30%</td>
<td>14.7</td>
<td>12.3</td>
<td>90</td>
<td>266</td>
<td>3.8</td>
<td>52</td>
</tr>
<tr>
<td>40%</td>
<td>16.8</td>
<td>14.8</td>
<td>56</td>
<td>705</td>
<td>3.2</td>
<td>28</td>
</tr>
<tr>
<td>50%</td>
<td>20.3</td>
<td>16.1</td>
<td>84</td>
<td>401</td>
<td>3.8</td>
<td>35</td>
</tr>
</tbody>
</table>
3.2 Furnace temperature uniformity
The temperature profile in the flue gas is shown in Figure 3-Figure 4. As a support to the analysis, data on the temperature difference in the flue gas is shown for the reference case (air combustion) and the 50 vol-O_2 trial, see Table 5. Due to the short duration of the trials, with no distinct temperature equilibrium establishing in the furnace, only data on flue gas temperatures from the two extremes trials, air combustion and the 50 vol-O_2 trial, are analysed in detail.

When wood was combusted using a comburent with higher O_2 concentration, the average furnace temperature increased and a distinct shift of the temperature peak position was observed, moving the temperature peak further away from the burner. This is clearly seen in Table 5 as the thermocouple G3 recorded an average process temperature being 27°C higher than that around G1. This shift of the temperature peak is also seen in the difference between G1-G4 which is reduced from 129 to only 24°C. Thus, the temperature profile of the furnace become higher in average as well as more flat, i.e. less differences between near burner and back-end temperature, as oxygen is added to the wood flame.

When oil was combusted using a comburent enriched with oxygen, the average furnace temperature increased, and with 50 vol-% O_2 in the comburant, the temperature peak was shifted further away from the burner, resulting in higher temperatures in the middle of the furnace, and also creating a stronger temperature gradient in both the near burner region and at the back-end/furnace outlet. Comparing the temperature difference between the burner region (G1) and the back-end region (G4), it is clear that the temperature difference is at similar levels for air combustion as that in the oxygen enrichment trials. Hence, although the gas temperature peak of the oil flame is shifted closer to the centre of the furnace, a relatively steep temperature gradient is present between the centre of the furnace and the back-end/furnace outlet.

Based on the figures and data in Table 5, it is clear that the temperature profile of both oil and wood was affected by the addition of pure oxygen to the combustor, but it is equally clear that the impact of oxygen on the furnace gas temperature profile was different. The temperature profile of the oxygen enriched wood flame became more flat compared to the oxygen enriched oil flame. We interpret this as an effect of differences in overall fuel reactivity, in which the oil, being a liquid fuel, ignites and burn faster than the solid fuel wood powder. The impact of a higher average furnace temperature during the oil trial, caused by a higher thermal input of oil as well as the more radiant/luminous properties of the (soot rich) oil flame, should also be taken under consideration in such a comparison.

From the temperature data in Figure 3 - Figure 4 as well as in Table 5, it is conceivable that a more controllable process with respect to maximum temperature as well as furnace temperature profile can be achieved by the use of the oxygen enrichment lancing technique.
Figure 3. Temperature profile in the flue gas during combustion of wood.

Figure 4. Temperature profile in the flue gas during combustion of heavy fuel oil.

Table 5. Temperature difference in the flue gas during combustion of oil and wood.

<table>
<thead>
<tr>
<th>Trial</th>
<th>ΔT (°C) during oil combustion</th>
<th>ΔT (°C) during wood combustion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>G1-G2</td>
<td>G1-G3</td>
</tr>
<tr>
<td>21 vol-% O₂</td>
<td>28</td>
<td>122</td>
</tr>
<tr>
<td>50 vol-% O₂</td>
<td>-46</td>
<td>39</td>
</tr>
</tbody>
</table>
3.3 Flame characteristics and heat transfer

The oil flame was more compact and luminous compared to the wood flame. By visual observation of the flame envelope, it was estimated that the total flame length of the base oil and wood flames were 0.5 and 0.9 m, respectively. As oxygen was added, the flame (reaction zone) was slightly enlarged and elongated in the axial direction, and an optically (visually) more clear furnace with less smoke was observed.

Figure 5 - Figure 8 show the average furnace process gas temperature, measured by thermocouples G1 to G4, as well as the net radiant heat flux and gross (total) heat flux measured at position #1, #2 and #3. Net radiant heat flux was calculated by subtracting the background radiation originating from the hot (>1000°C) ceramic brick surfaces in the furnace wall, floor and ceiling. It should be noted that heat flux data presented in this work was recorded during non-stable furnace temperatures, and to facilitate comparisons with the different trials of each fuel, average furnace gas process temperature data is also given in Figure 5 - Figure 8.

In general, for wood and oil, the measured average furnace gas temperature (G1-G4) increased as the oxygen concentration of the comburent was increased. As an effect of this increased furnace process temperature, both the net radiative heat flux and the total heat flux to the furnace walls increased at all measurement positions along the axial direction in the furnace.

The net radiative heat flux for wood powder firing, see Figure 5, shows a relatively moderate increase 0.8 m from the burner (position #1) compared to flux data recorded 1.8 m from the burner (position #3) as oxygen was added to the process. We interpret this as a consequence of the flame being “pushed” further in and spread out more evenly throughout the volume of the furnace by the high velocity (sonic) oxygen flow. This is also reflected in the flatter furnace temperature profile, see section 3.2. The total heat flux from the wood flame, Figure 6, shows similar trends as for the net radiative heat flux, i.e. (i) a general increase can be seen in all position along the axis of the furnace and (ii) the highest increase is observed at the end of the furnace.

The heat flux data from the oil flame shows similar trends as that for the wood flame, i.e. both net radiative flux and total heat flux increase as the oxygen concentration in the comburent is increased. The heat flux from the oil flame also becomes more flat when oxygen is added to the process.
Figure 5. Average furnace process gas temperature and net radiative heat flux for wood powder in measurement position #1 and #3 (axial distance of 0.8 m and 1.8 m from the burner outlet).

Figure 6. Average furnace process gas temperature and gross total heat flux for wood powder in measurement position #1, #2 and #3 (axial distance of 0.8, 0.95 and 1.8 m from burner outlet).
Figure 7. Average furnace process gas temperature and net radiative heat flux for oil in measurement position #1 and #3 (axial distance of 0.8 m and 1.8 m from the burner quartz).

Figure 8. Average furnace process gas temperature and gross total heat flux for oil in measurement position #1 and #2 (axial distance of 0.8 and 1.8 m from the burner quartz).
4. DISCUSSION

Although the CO levels were relatively high during part of the oil trials, our interpretation of the results found in this work is that this burner, designed for air combustion by feeding of air through the primary, secondary and tertiary air vanes, could handle the changes in aerodynamics caused by the reduced air flows. However, the combustion process was also assisted by a change in the overall aerodynamic flow pattern in the furnace. When pure oxygen was introduced to the combustion process as a concentrated jet during lancing, the aerodynamic in the combustion chamber was most likely affected. During ordinary air combustion, the swirling vanes create a rotating flow in the combustion chamber around the centre line of the burner and a near burner recirculation zone. When the air supply through the burner is reduced due to oxygen lancing, the speed of the rotating flow is reduced. Furthermore, since ambient gases are flowing into the jet (entrainment) and due to the coanda effect, the main flow in the combustion chamber may be shifted from the central of the combustion chamber to the wall where the jet is introduced and thereby a larger re-circulating flow is created at the opposite wall. This reversed flow, caused by the oxygen jet from the lance, which in addition to returning hot combustion product back to the near burner region also create a good mixing and dispersion of the fuel particles/droplets.

One application where powder burners are becoming more common is lime kilns in the pulp and paper industry. Conversion from fuel oil and natural gas has been done for a number of kilns, mainly to pet coke in North America [7], and to bark and wood powder in Scandinavia [8]. When firing bark and wood powder there is normally a loss of capacity. As the flame temperature decreases - in line with the results presented here - and the overall temperature profile becomes flatter, there is a need to increase the fuel input and the back-end temperature in order to maintain the front-end temperature in the kiln. Oxygen enrichment will reduce the flue gas flow for a certain fuel input, thus counteracting negative effects of increased velocities and capacity limitations in the flue gas fan. On the other hand, there is an increased risk of creating hot spots in the burner zone, which may lead to refractory damage. One interesting feature with the lancing technique examined in this work is therefore that it can be used to ‘shape’ the flame and temperature profile instead of just increasing the average flame temperature. The operating costs for a lime kiln will increase with oxygen enrichment. Whether oxygen enrichment can still be economically justified depends on the possibility of avoiding capital costs for a new kiln or at least pushing such an investment further into the future.

5. CONCLUSIONS

General flame characteristics and furnace temperature profile during oxygen enriched combustion, where oxygen is added to the combustor at different enrichment levels by the use of a lance, in a pilot-scale furnace fired with (i) wood powder and (ii) heavy fuel oil have been studied, and the work has led to the following conclusions:

- For the wood flame, the average furnace temperature becomes higher and the furnace temperature profile becomes more flat as oxygen is added. For the oil
flame, as oxygen was added to the process, a higher average furnace temperature was observed along with a distinct shift in furnace peak temperature towards the central parts of the furnace, creating a relatively strong temperature gradient.

- Comparing the two flames, the furnace temperature profile of the oxygen enriched wood flame becomes more flat compared to the oxygen enriched oil flame. This is interpreted as an effect of differences in overall fuel reactivity, in which the oil, being a liquid fuel, ignites and burns faster than the solid fuel wood powder.

- The results found in this work shows that the burner that was used, being designed for conventional air combustion by feeding of air through the primary, secondary and tertiary air vanes, could handle the changes in aerodynamics caused by the reduced air flows.

- The results indicate that oxygen injected with the lancing technique can be used as an active tool to influence, control and adjust combustion processes using fuels and burners with different behaviour in terms of ignition stability, flame temperature profile and energy transfer by radiation and convection.

6. REFERENCES

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7. ACKNOWLEDGEMENTS

This work was funded by Alabama River Pulp/Parsons & Whittemore, Fibria, Klabin and the Swedish Energy Agency within the Innventia research cluster “Energy and biofuels” and by AGA AB.