OXICOMBUSTION AS AN ALTERNATIVE TO COMBUSTION WITH SIMPLE AIR

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Using oxygen instead of air in a burning process is at present being widely discussed as an option for the problems of CO_2 emissions. One of the solutions is to maintain the combustion reaction at the same energy level as burning with air, reducing the fuel consumption as well as that of oxygen itself. A thermal simulation was made with natural gas with a 5% excess of oxygen and combustion fuel oil 2A, with an excess of 20%, maintaining fixed values for pressure and combustion temperature. The theoretical results show that it is possible to reduce the consumption of combustion fuel and oxidant by approximately 35%.

Keywords*: Oxicombustion, oxygen, natural gas, combustion oil, reduction of consumption*

1. INTRODUCTION

Global warming constitutes today one of the most difficult challenges for humanity to overcome. 80% of all the energy produced in the world comes from fossil fuels (1) and an increase of 51% in emissions is expected by 2030 (2). Countries of emerging economies such as China, ranked as the second largest in the world, with 4.8Gt of CO_2 emissions in 2004 (18% of global emissions) due to the wide use of thermoelectric plants (60% of the energy in China comes from the use of coal) (3), constituting a source of serious concern due to the lack of control of these emissions.

Thus it is necessary to have new regulations which aim at reducing green-house gases as the Kyoto protocol, these regulations provoke development of new technologies which focus on the reduction of these gases (4). The emission of green-house gases from energy plants can be reduced by the use of alternative energy sources or renewable energy sources.

These sources have been gaining ground in the last few years, but until they can generate significant quantities of energy, the present demand must be satisfied by the use of fossil fuels but in systems/manners that use better their heating power and reduce effectively their harmful effects (5).

One of the most promising alternatives is the capturing and storing of the CO_2 in the fossil fuel burning process avoid the release into the atmosphere. However, this burning process when done with air generates CO_2 in low concentrations making it difficult to capture (the process has a low yield and has high energy requirements). The presence of NO_x and SO_x is also a problem in this process of carbon capturing. (1) These problems can be got around using an oxygen-enriched or pure oxygen atmosphere for the combustion process. The enrichment of air with oxygen is an interesting means of optimizing the incineration rates in combustion chambers originally conceived for operating with air alone, fixing the combustion temperature, turbulence level and residence rates as parameters (6,7).

Oxicombustion is a technological resource for the reduction of green-house gases in which the fuel burning process is improved by the substitution of air by pure oxygen.

The oxygen can be used in four manners: It can be added to the air current; injected into a flame of air/combustion; substitution of air in the burning process or acting separately with the air in the burner (8). In the third case, the cost of pure oxygen can be justified by the high temperatures reached. The temperature of the flame increases considerably when the air is replaced by oxygen, as the nitrogen acts as a diluent, stealing the heat. In the standard burning process in air, 70% of the volume of exhaust gases are nitrogen based gases (8).

However, if the heat is not properly distributed the intense radiation of the flame in the Oxicombustion process can damage the refractory walls. To get around this problem part of the exhaust gases are recycled. As the nitrogen is eliminated the recycled gas is rich in CO_2 the combustion is done in a mixture of O_2/ CO_2 (9).

The presence of CO_2 in high concentrations in the combustion chamber affects the transmission of heat, the flame ignition and emissions. The high value of the specific heat of CO_2 compared to that of N_2, causes a reduction in the temperature of the gases (10). Other than affecting the performance of the combustion, the recycling also alters the formation of pollutants such as SO_2, NO_x and CO (11). High temperature stimulate the formation of NO_x, a problem that can be reduced by using pure oxygen as opposed to oxygen-enriched air (without considering the possible presence of nitrogen in the fuel), even when there is a control of the flame temperature (12) while the CO is converted to CO_2 .

The burning process with oxygen instead of air also implies in the reduction of the volume of gas flow which leads to a higher time of residence, a critical factor in the reduction of NO_x, which can be reduced by re-dimensioning the combustion chamber.

The recycling of gases also contributes to the reduction of NO_x due to the decrease in O_2 concentration in the combustion zone and by the reduction of the temperature (13).

After removal of the water vapor, the remaining gases such as CO_2 are captured and can be compressed. SO_2, and NO_x are also liquefied, not needing desulphurization while the other gases that are not compressible are separated by Flash process and liberated into the atmosphere. The captured gases can be transported for storage in deep Saline Aquifers. The potential of CO_2 storage in aquifers is in the order of 100 to 10000 Gt (14).

The burning process using pure oxygen has a number of advantages compared to that using air (only 21% of the air is used in the combustion process), for example, the increase of productivity due to the increase of the temperature of the flame which in turn increases the radiation to the chamber. More material can be processed in a system already in place or a new system can by implemented on a smaller scale, an important factor in plants where space is limited, and furthermore this represents a reduction of cost in the manufacturing process.

Also the elimination of N_2 from the burning process causes a decrease in the volume of the exhaust gases allowing for a reduction in the size of the existing ducts. There is also the increase in efficiency of the treatment of these gases as these pollutants are generated in high concentrations making it easier to remove them (8).

However, there is an increased cost in using pure oxygen. Its use can be validated by the energy efficiencies of the process. Another was of making this system economically viable is to use Oxicombustion as a normal burning process, that is using the same energy level as that of combustion with air.

The process can still be classified as Oxicombustion, but the energy level is the same as that of combustion with air. This is done by reducing the amount of fuel and comburant that enter the process. This burning process has the same energy efficiency as the normal burning process, but with the advantages of an oxicombustion process, namely high concentration of pollutants in the exhaust and very low or inexistent concentrations of nitrogen.

Without this gas, a large part of the heat remains in the chamber allowing for a reduction in the fuel consumption and oxygen. The reduction of the fuel costs justifies the use of pure oxygen.

2. METHODOLOGY

The simulation of the process described above was done using Natural gas (89%CH_4, 8%C_2H_6, 0.85%C_3H_8, 0.48%CO_2, 1.28%N_2) and Oil 2A ($C_{7,3612}H_{9,88}N_{0,0437}S_{0,035}$) as fuel. The schematics of the process can be described in Fig.1 as follows.

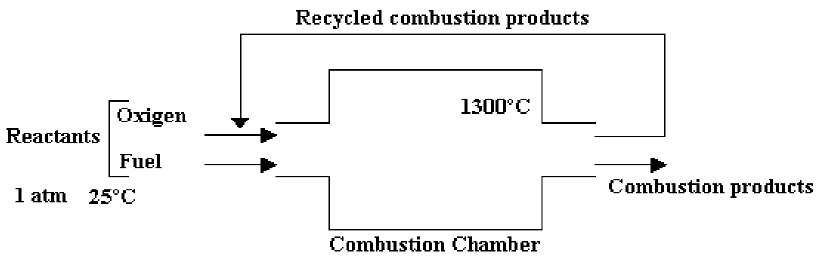

Figure 1. Process's scheme for oxi combustion with recirculation

All the simulation was executed with the help of a program called "thermochemical information and equilibrium calculations" (TCW). The output generated was treated in excel. All the simulations were done determining parameters such as pressure and temperature in the chamber at 1atm and 1300ºC respectively. For each fuel, a set of calculations were performed with different recirculation ratios of the exhaust gases, using as reference the combustion simulations with pre-heated air (by the exhaust gases) at 450ºC. From it, a comparative was made using the reference and the combustion using oxygen.

In the simulation with Natural Gas, we deployed oxygen at 5% excess. The global reaction for the combustion of 1mol of gas with air is:

$0,8936CH_4 + 0,0803C_2H_6 + 0,0085C_3H_8 + 0,0048CO_2 + 0,0128N_2 + 1,05(2,1108O_2 + 7,9366N_2) \rightarrow 1,0845CO_2 + 2,0621H_2O + 0,1055O_2 + 8,3458N_2$

And with oxygen is:

$0,8936CH_4 + 0,0803C_2H_6 + 0,0085C_3H_8 + 0,0048CO_2 + 0,0128N_2 + 2,21634O_2 \rightarrow 1,0845CO_2 + 2,0621H_2O + 0,1055O_2 + 0,0128N_2$

In the simulation with Oil 2ª (PCI = 960kcal/mol) oxygen was deployed with an excess of 20%. The Global reaction for the combustion of 1 mol of oil with air is:

$$C_{7,3612}H_{9,88}N_{0,0437}S_{0,035} + 1,2(9,867O_2 + 37,1N_2) \rightarrow 7,3612CO_2 + 4,94H_2O + 0,035SO_2 + 44,56N_2 + 1,9734O_2$$

And with oxygen is:

$C_{7,3612}H_{9,88}N_{0,0437}S_{0,035} + 11,8404O_2 \rightarrow 7,3612CO_2 + 4,94H_2O + 0,035SO_2 + 1,9734O_2 + 0,02185N_2$

3. RESULTS

3.1. Natural Gas

3.1.1.Combustion with air

For the combustion of air we calculated the value of ΔH for the reaction.

$$\Delta H = -115,82796\text{kcal}$$

This value will be the reference point for the calculations of the Energy ratio between the combustion with air and with oxygen.

3.1.2.Combustion with pure oxygen

The combustion analyzed here will be with pure oxygen instead of air. The exhaust gases will be recirculated to decrease the temperature of the flame. It is possible to calculate the energy that remains inside the combustion chamber, as shown in Tab. 1 for each level of recirculation.

With the data of the values of enthalpy for each case of combustion of gas with air or with pure oxygen, we can calculate the energy ratio between the processes. Thus it is possible to find out up to what level we can save fuel or oxygen, though maintaining the same level of energy of combustion with air inside the chamber. Results are displayed in Tab.1.

Table 1. ΔH and air/ox rate data for natural gas combustion for 0%, 10% and 20% recirculations levels.

Exhaust Recirculation Rate	**0%**	**10%**	**20%**
ΔH (kcal)	-159,07149	-159,04887	-159,052909
Air/Ox Rate	0,7281504	0,7282539	0,728235419

As can be noted, for the combustion with Natural Gas it is possible to reduce the fuel consumption and oxygen by 27% max, despite the recirculation ratio, sustaining the heat equivalent to the combustion with air, as demonstrated in Fig 2. Beyond 27%, the heat inside the combustion chamber is lower than the combustion with air. With 30% fuel economy, it is not possible to sustain the level present in a normal combustion.

3.1.3.Time of residence calculation

The time of residence for the combustion of oxygen will be calculated in relation to the time of residence for the combustion of air. With equation below (1), we obtain the relation between the times of residence for the two types of combustion shown in the equation (2):

$$t_R = \frac{VP\overline{M}}{\overline{R}T\overset{0}{m}} \tag{1}$$

Where V = volume, P = pressure, M = molar mass, R = Universal gas constant, T = Temperature, m = mass flow. All the variables are related to the gases produced by the total combustion of the fuel.

For equation (2) we have:

$$\frac{t_{R,O_2}}{t_{R,Ar}} = \frac{\overset{0}{m}_{Ar}\,\overline{M_{O_2}}}{\overset{0}{m}_{O_2}\,\overline{M_{Ar}}(1+x)} \tag{2}$$

Where $\overset{0}{m}_{Ar}$, $\overset{0}{m}_{O_2}$,M_{ar} e M_{O2} are mass flows and the molar masses of the products of the combustion with air and oxygen respectively, and x is the exhaust gases recirculation ratio. So for every recirculation ratio it is possible to calculate the relative time of residence as in Fig 3.

3.2.Oil 2A

3.2.1.Combustion with air

We will use the same procedure for Oil 2A, so we will first present the simulation of the combustion of this fuel with air, which will be used as a reference point in the reduction of reagent consumption ratio calculation.

The value of ΔH in the reaction of the combustion of the oil with air is:

ΔH = -495,688kcal

This value will be used to calculate the ratio between the enthalpies of Oil 2A with air and with oxygen.

3.2.2.Combustion with pure oxygen

In this analysis, the combustion of Oil 2A with oxygen will be carried out in the same way as we carried out using Natural Gas.

The value of ΔH was calculated as per shown in Tab. 2.

In a similar way as observed with Natural gas, the consumption of Oil 2A and oxygen can be reduced by a max of 35%, in accordance to the values of combustion Air/Oxy presented in Tab. 2 and maintaining the same energy levels present in a normal combustion with air. The reduction in the consumption of reagents is shown in Fig 2. Beyond 35% it is not possible to maintain the heat inside the chamber in a same level as in a normal combustion.

Table 2. ΔH and air/ox rate data for 2A oil combustion for 0%, 10% and 20% recirculations levels.

Exhaust Recirculation Rate	**0%**	**10%**	**20%**
ΔH (kcal)	-760,517	-760,498	-760,472
Air/Ox Rate	0,651779	0,651795	0,651817

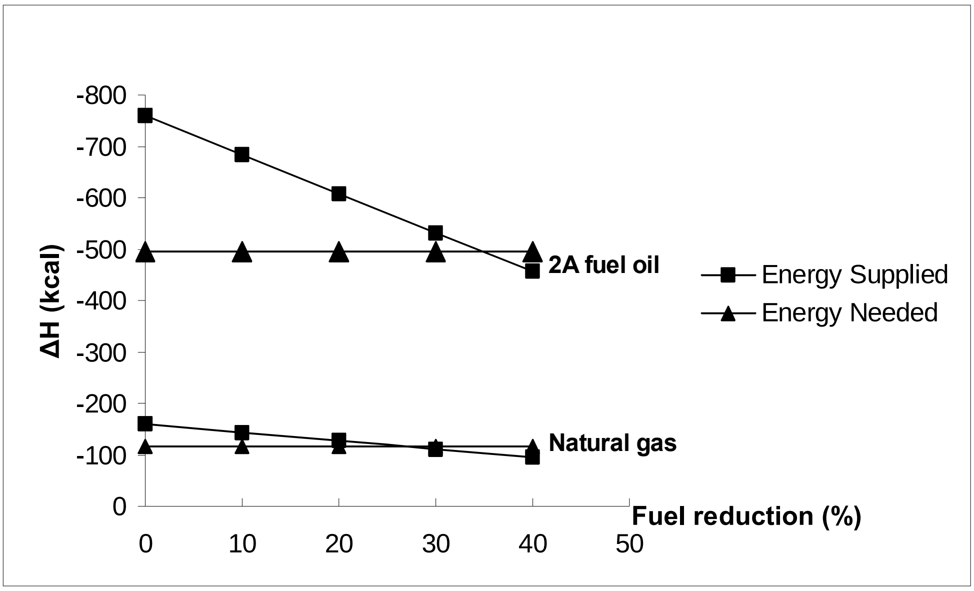

Figure 2. Reduction rate of Ox/natural gas and Ox/2A oil consumption .

3.2.3 - Time of residence calculation

We will use the same procedure for the calculation of time of residence for Natural Gas as we have used for Oil, thus using the equation (2) described above.

The results are displayed in Fig. 3.

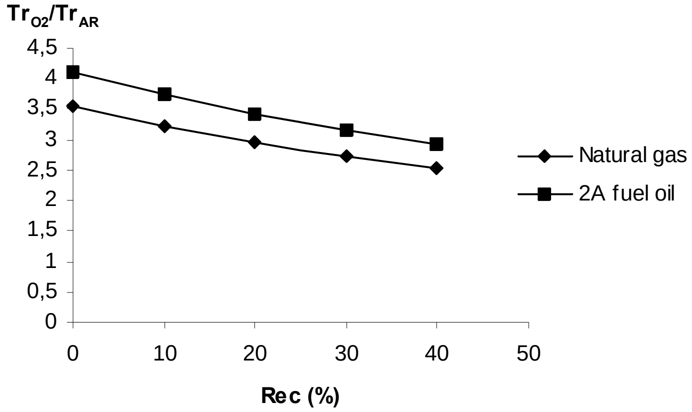

Figure 3. Relative residential time for natural gas and 2A oil.

4. CONCLUSION

The journal presented the theoretical results of the Thermal analysis of the combustion of Natural gas and Fuel Oil 2A with excess air and oxygen. As can be noted, the combustion of pure oxygen demonstrates promising results as an option to combustion with air, especially when it comes to the emission of pollutants. With Natural Gas, the emission in terms of molar fraction of CO_2 have gone up from 0,0968 to 0,3321, and for N_2 the concentrations have dropped from 0,7095 to 3,89E-3. For NO_x, the emissions have dropped from 3,69E-4 to 5,11E-5.

For Fuel Oil 2A, the emissions of CO_2 have gone up from 0,1251 to 0,5136, and for N_2 and NO_x there has been a reduction from 0,7565 to 0,001492 and from 7,23E-4 to 6,54E-5 respectively. The increase in the concentration of CO2 which helps in its capture is due to the absence of the diluted N_2 in the air, which also explains the low emission in both cases. The presence of N_2 in the fuels also allows the formation of thermal $NO_{x,}$ although in lower concentrations in relation to the combustion with air.

Due to the fact of having very little N_2 in the combustion of the fuels, the heat emitted by the flame intensifies itself, a problem which can be overcome by recirculation of the exhaust gases to lower the temperature. The energy of the fuel is better used, but part of this energy ends up inside the chamber; therefore there is an excess of energy. When the fuel is better used, its consumption and that of oxygen can also be reduced, having as energy basis the same process used for air. This way the combustion occurs in an almost N_2 free atmosphere, therefore keeping the energy at an acceptable level, with a reduction in the consumption of reactants. The greater the Heating value of the fuel, the more available energy and the greater the reduction in consumption.

The recirculation ratio of the mixture of exhaust gases does not influence the ratio of fuel reduction, having as an objective avoiding the high temperatures that the flame can reach and therefore the damage this can cause to the combustion chamber.

The use of pure oxygen is justified by the economy of fuel and oxygen consumption, without the need of great alterations to the equipment and also by the considerable reduction of pollutants such as NO_x therefore generating a chain of gases rich in $CO_{2,}$ which can be extracted later.

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