Pressurized oxy-coal mild combustion for clean-coal technology

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Abstract: In this paper we consider an oxy-coal thermoelectric plant fed by a coal-water mixture (*slurry*) and oxygen (instead of air). The use of pure oxygen makes it easier to capture CO_2. A distinctive feature of such a plant is that the combustion and flue gases system operates at high pressure (about 10 bar). We develope a model based on first principles equations in order to study the startup procedures.

Keywords: Power plant; oxy-combustion; flameless combustion; startup manouvres; modeling.

1. INTRODUCTION

Accordingly to International Energy Agency, energy derived from fossil fuel usage currently accounts for approximately 81.4% of the world's energy output and 60.5% of total greenhouse gas emissions. Fossil fuel based carbon dioxide emissions in member countries of the Major Economies Forum (MEF) accounts for 78.8% of the world's emissions. It is estimated that CO_2 emissions will increase by 130% by 2050 in absence of new policies or supply constraints.

Currently, approximately 30% of CO_2 emissions come from coal fired power stations; however other industrial processes, such as gas stripping, steal making, sement production and alumina refining, account for close to 50% of CO_2 emission.

Therefore, resorting to coal fired plants calls for the development of technologies for the capture and sequestration of CO_2. Among the various technologies which have been proposed, a promising one (see Saponaro et al. (2007) and also Croiset et al. (2005)) is based on the use of pure oxygen in the combustion process. The use of pure oxygen in place of air has the advantage of avoiding the presence of huge quantities of nitrogen in the flue gases. In this way the capture of CO_2 is remarkably simplified.

In the plant we study the oxy-combustion takes place at high pressure (10 bar) in order to enhance the combustion quality. Furthermore the production of CO_2 at high pressure reduces the amount of pumping power for its sequestration.

One of the distinctive features of such plant is the high internal recirculating factor K_v defined as

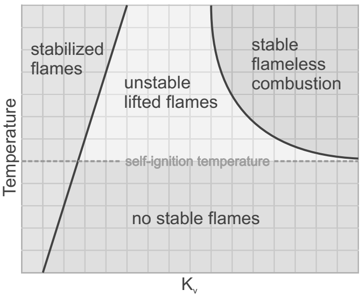

Fig. 1. Qualitative diagram of the combustion modes as a function of temperature T and internal recirculating factor K_v

$$K_v = \frac{w_{ric}^{(i)}}{w_{comb} + w_{O_2} + w_{g_{ric}}}$$

where $w_{ric}^{(i)}$ is the mass flow rate of the combustion gases internally recirculated, w_{comb} is the fuel mass flow rate, w_{O_2} is the oxygen mass flow rate and $w_{g_{ric}}$ is the externally recirculated gases mass flow rate. As clearly seen from Figure 1 a sufficiently high temperature together with a high value of K_v leads to a stable combustion taking place without the presence of a flame front. This condition, known as "flameless"combustion or "mild" combustion (Milani (2006), Wunning and Wunning (1997)), enables a remarkable improvement in the combustion quality.

Due to such a peculiar high pressure characteristic, standard dynamic models cannot be used. We have therefore studied the combustion process from the very beginning by working out a new model based on first principles mass-energy conservation equations.

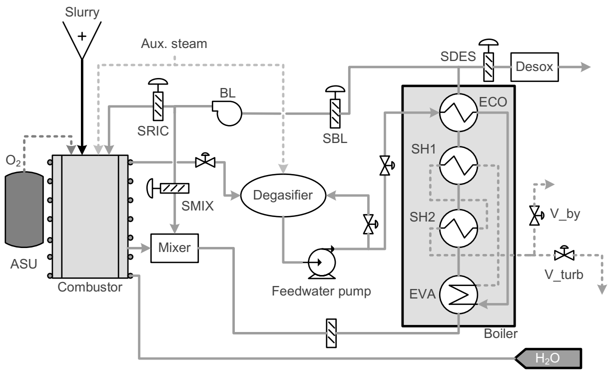

Fig. 2. Reference plant scheme

With the obtained model, it has been possible to study the startup procedures and devising suitable control strategies.

After the description of the plant structure, we focus on the modeling of the combustion chamber and the flue gases system. The applicability of the model is illustrated by means of some simulation trials. Finally, we present the use of the model in the simulation of the startup procedure.

The equation we will write are rather complex. For simplicity, we organize all symbols in Table 1.

2. REFERENCE PLANT

The plant is schematically depicted in Fig.2.

In the mixer, the output gases of the combustor, at 1600C, are mixed with recirculated gases so lowering the temperature to $1200C$; in this way the ash melting (*slag*) is avoided so guaranteeing clean surfaces of the evaporator and heat exchangers.

As can be seen in the scheme, the location of the heat exchangers along the flue gas path is a typical one of a boiler without re-heater. The combustion chamber is adiabatic and the evaporator is placed at the outlet of the mixer, where the temperature of the combustion gases is $1200C$.

Along the flue gases path, there are two heaters and then the economizer.

Due to the high pressure of the gases, a double case is necessary. The outers sleeve, made of steel, supports the pressure stresses whereas the inner one is constituted by a membrane wall whose tubes are fed by the economizer cool water.

The flue gas recirculation is obtained through a blower which keeps the outlet pressure constant. The flow rates to the burner and to the mixer are controlled by two dumpers.

The boiler structure is shown in Fig.3. The feed-water flow cools and protects the refractory lining of the combustion chamber; in this way it's also possible to recover some thermal energy.

3. MODELING

3.1 Combustor modeling

The model we plan to develop is intended for simulation and control purposes. Therefore the model should be as simple as possible, without neglecting the main dynamics of the plant. Herein we work out a non-linear lumped-parameter model of order 12.

Table 1. List of symbols

η_c	combustion efficiency	
τ_{br}	time costant of the char combustion	s
τ_{ev}	time constant of the drying process	s
$\tilde{f}_x$	mass fraction of the x component in the volatiles	
f_{ash}	mass fraction of the ash in w_d	
f^a_{o2}	mass fraction of the oxygen in the air	
$f_{x_{ric}}$	mass fraction of the x-component in the recirculated gas	
f_c	mass fraction of the carbon in w_d	
f_w	mass fraction of the water in the slurry	
$h_{g_{ric}}$	enthalpy of the recirculated gases	J/kg
$H_{g_{sat}}$	water steam saturation enthalpy	J/kg
h_{rif}	reference enthalpy for normalization	J/kg
h_a	enthalpy of the startup air at the combustor inlet	J/kg
h_g	enthalpy of the gas mixture in the combustor	J/kg
H_x	low heat value of the x-component	J/kg
M_{rif}	reference mass for normalization	kg
M_x	mass of the "x"-component in the combustor	kg
p_{rif}	reference pressure for the normalization	Pa
p_g	pressure in the combustor	Pa
PM_{rif}	reference molecular weight for the normalization	kg/kmol
PM_x	molecular weight of the x component	kg/kmol
Q_{ev}	heat power for the water evaporation	W
Q_w	heat power exchanged with the combustor walls	W
R	ideal gas constant (R=8314)	J/(kmol K)
T_{ev}	temperature of the evaporating liquid phase	K
T_{rif}	reference temperature for normalization	K
T_g	temperature of the gas mixture inside the combustor	K
w_{br}	mass flow of the burning char	kg/s
w_{coal}	mass flow of the coal	kg/s
w_{ev}	mass flow of the evaporating water in the combustor	kg/s
$w_{g_{out_mix}}$	mass flow of the recirculated gas to the mixer	kg/s
$w_{g_{out}}$	mass flow of the flue gas at the combustor outlet	kg/s
$w_{g_{ric}}$	mass flow of the recirculated gas to the burners	kg/s
w_{rif}	reference mass flow for normalization	kg/s
w_{sl}	mass flow of the inlet slurry	kg/s
w_{slag}	mass flow of the slag	kg/s
$w_{unburnt}$	mass flow of the unburnt carbon	kg/s
w_a	mass flow of the startup inlet air	kg/s
w_d	mass flow of the dry part in the slurry	kg/s
w_G	mass flow of the startup light oil	kg/s