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Influence of hydrogen enriched gas injection upon polluting emissions from pulverized coal combustion

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ABSTRACT

This paper presents the experimental results on the pollutant emission of a 2 MW thermal pilot furnace with the injection of hydrogen enriched gas (HRG) into the primary jet (coal dust and primary air). An experimental method to study the effects of this procedure on the thermal pilot furnace, which was specially designed to burn pulverized solid fuel, was conducted. The hydrogen enriched gas used in the study is dried and was produced by an electrolytic system still under patent by the authors. The primary conclusions from the results are focused on the quick diffusion of hydrogen, unlike oxygen, within the coal particles and that the hydrogen forms stable compounds with the sulfur and other elements the sterile content. A primary chemical analysis of the ash/sludge components is also presented within the paper.

Introduction

The fossil fuel resources on earth will not provide sufficient energy for the growing global energy demand. As is well known, the production of energy from burning fossil fuels generates large amounts of carbon dioxide, which in time leads to global warming and climate change, which is likely irreversible [1].

Therefore, hydrogen and biomass are very promising as alternative fuels because the mixture of hydrogen with other fossil fuels increases the calorific power, therefore reducing the greenhouse gas emissions. Hydrogen has a high calorific value and the biomass absorbs carbon dioxide.

Even though hydrogen is ubiquitous in space, current technologies for obtaining hydrogen use fossil fuels, typically natural gas, as a raw material. On the other hand, water can be dissociated into hydrogen and oxygen through thermolysis, electrolysis or photolysis processes [2–4].

After the first oil crisis, society started to seek alternative energy sources to fossil fuels. Moreover, as the level of pollution has reached alarming levels, in part due to carbon dioxide produced by burning fossil, scientists have begun to use hydrogen as a fuel source, prompting the emergence of the

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Nomenclature

C	the concentration, kg/m^3
D_i	the diffusion coefficient, m^2/s
q	the hydrogen flux, kg/(m^3·s)
x	the pore depth, m
l	the pore length, m
V	the volume of particle, m^3
S_i	the internal pore surface, m/m
τ	the time, s
ε	the Fourier criteria

hydrogen economy (HE) [5–7]. Further research on a more sustainable energy economy (sources, carriers and storage) is one of the most important tasks in the scientific world [8].

From a technical point of view, the production of hydrogen from water is a feasible and logical process. However, the crucial problem that arises is the cost of hydrogen production and the energy used in the production process. If the energy used in the production of hydrogen comes from classical sources based on fossil fuel combustion, then surely these technologies are not sustainable and will not lead to greenhouse gases reduction (mainly carbon dioxide).

Considering the fact that hydrogen fuel does not produce greenhouse gases and has high calorific power, it is considered an important energy vector and of high importance. The development of technologies for production, storage, transport and use has high scientific and technical impact. Because biomass is a renewable fuel and represents a natural source of carbon dioxide storage, hydrogen production from biomass is one of the most promising methods.

The favorable characteristics of hydrogen, which include the fact that it is virtually inexhaustible, has no harmful emissions and possesses various methods for its production, make it a promising option as an energy source [9]. The utilization of hydrogen (pure or mixed) to solid fuel combustion [10] has the ability to improve the combustion conditions, increase the reaction rate and influence the concentrations of CO, SO_2 and NO_x in the reaction products.

This paper presents the authors' results on the flame behavior of pulverized coal inside a furnace after having been treated with a hydrogen enriched gas (HRG). Pulverized hard coal has been passed through a stream of an HRG before being injected into the burner. The immediate effect upon the coal flame was a significant decrease in the sulfur oxides and a small increase in the nitrogen oxides. As a consequence, some further research has been conducted concerning both the effect of the reduction in the SO_2 concentration in the coal flame after treatment of the pulverized coal with HRG and the unknown reaction mechanism that occurs within the flame.

Because pure hydrogen production is still expensive, and because its burning is not economical and its combustion characteristics are not very high, it is preferable to use HRG in the combustion of pulverized coal. The combustion of HRG with coal powder significantly contributes to reduced nitrogen oxides emissions in the combustion byproducts.

At this time, there are no experiments in the literature regarding the use of a hydrogen enriched gas injected within a stream of pulverized coal. The lack of previous studies on the effect of HRG on coal combustion could be due to the small number of industrial applications of HRG and to the serious danger of injecting pure hydrogen gas into a furnace. Directly injecting only HRG into a furnace would not provide many significant advantages, despite the fact that it is less dangerous than pure hydrogen due to its very small density and the fact that it does not significantly increase the flame temperature. However, by injecting HRG into the pulverized solid fuel stream, some distinctive effects can occur. Burning HRG together with the solid fuel provides an advantage over burning each of these fuels separately and reduces the greenhouse gas emissions (CO_2, NO_x and SO_2) in the reaction products. The present paper addresses these synergistic aspects of treatment of coal with HRG prior to combustion.

Because the results of this study could be used in small town power plants, pure hydrogen products have to be avoided for security reasons. Moreover, pure local hydrogen production is more expensive and dangerous than HRG production, which is only a quasi-stoichiometric mixture of hydrogen and oxygen resulting from electrolysis. Another advantage of using HRG is the simplicity of the electrolytic system used for its production.

Theoretical basis

The hydrogen enriched gas (HRG) used in this study is produced from water by an electrolytic system. The electrolytic system is dynamic, keeping the fluid in a permanent flow and producing a quasi-stoichiometric gaseous mixture of hydrogen and oxygen molecules, which closely follows the stoichiometric water ratio. HRG is a gas with a high degree of reactivity which, by adsorption, diffuses into the coal dust particles. The electricity consumed to produce 1000 l of HRG is between 3.5 and 4 kWh [10], which corresponds to approximately 0.4 Euro/1000 l. This cost will be influenced by the price of electricity and the gas production capacity. In the future, a slight decrease in the price of HRG (approximately 0.35 Euro/1000 l) can be expected. The cost estimate of hydrogen production is approximately $2.87/kg hydrogen, as reported in Ref. [11].

The future of the development of hydrogen depends on its availability at low costs and with minimal environmental impact during its production. It is necessary to highlight that the current method of hydrogen production from fossil fuels (coal or natural gas) is not sustainable and is being exhausted as a resource and furthermore produces greenhouse gases (CO_2). For these reasons, the focus should be toward the production of hydrogen from renewable sources [12].

The ignition and combustion rate are improved and the pollutant emissions are reduced when the coal is treated with HRG prior to combustion. The experimental data obtained in the process of burning natural gas with hydrogen injection reveal that the flame propagation velocity is reduced in the early stage of combustion but rapidly increases in the advanced stage. In addition, a linear relationship between flame radius and time is observed, even at high hydrogen to natural gas fractions. When burning hydrogen-rich gas (HRG) with natural gas, a linear dependence of the flame radius on time is found not only when combustion