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Environmentally Feasible Natural Gas Combustion in Fluidized Beds

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Abstract. Environmentally favorable non-premixed combustion of natural gas (NG) in a fluidized bed of inert particles is carried out at temperatures well below 1000 °C to understand the combustion behavior and CO formation and destruction phenomena through the local measurement. The NG-based fluidized bed technology gains wide applications in metallurgical, energy, chemical and process industries. Furthermore, the need to ensure a high throughput, an enhanced gas-solid contact, a short residence time and the ease of fuel handling, makes turbulent fluidized beds a promising technology. This technology can be considered as a framework to put forward the novel devices for examining the destruction of hazardous wastes. This study also provides insights into the CO formation and destruction inside fluidized bed reactors. In-situ CO destruction and close temperature control are two important and critical signs showing that the fluidized bed combustion reported in this study is safe and environmentally feasible.

Keywords: safe combustion, natural gas, fluidized bed combustion, non-premixed combustion

1. Introduction

Conventional combustors operated at high temperatures are generating a high level of pollutants. Therefore, an environmentally feasible technology should be introduced to overcome such shortcomings having met stringent emission standards while increasing the combustion efficiency. Any development of new combustion facilities should be based on lowering the combustor temperature and using rather clean fuels. Therefore, NG certainly leads to a cost reduction in new devices. The amount of such reduction depends on their design, operation and the choice of bed materials. Among the existing technologies, the turbulent fluidized bed (TFB) is an excellent basis to develop the novel devices.

Foka et al. [1] carried out the catalytic combustion of NG in fluidized beds at 450 °C. Although, the catalytic combustion may be considered promising for energy production, its full success is strongly dependent upon the nature and cost of the catalyst, its effectiveness and resistance to attrition. Unfortunately, the catalysts are usually expensive and subject to attrition. Attempts were also made by several investigators to carry out the successful combustion of gaseous mixtures, mostly methane, in bubbling fluidized beds [2-6]. Even though, the objective of this work is to elucidate the combustion of NG in TFBs of inert particles, the review of existing literature on bubbling conditions can provide insights into how gaseous fuels burn inside fluidized beds.

To make the TFB applicable for industrial applications, the catalysts should be replaced by inert particles, and the fuel should be directly injected into the reactor. Despite the large impact of using inert particles as bed materials in combustors, limited experimental data are available in the literature regarding the combustion modes and the regimes of fluidization. Sotudeh-Gharebagh et al. [7] and Sotudeh-Gharebagh and Chaouki [8] reported the feasibility of non-premixed combustion in the TFB of inert particles at temperatures below 1000 °C. The combustion taking place at lower temperatures leads to a high safety in the combustion of flammable mixture, where NG and air could be separately injected into the reactor at any desired concentration level. In addition, less emission would be generated in these devices. Thus, a thorough understanding of safe NG combustion in fluidized beds is an important issue. Therefore, the aim of this study is to evaluate the combustion of NG in fluidized beds to provide sufficient information on CO formation and destruction to help develop NG-based fluidized bed devices.

2. Safe Combustion of Natural Gas

The safe combustion of NG in a non-premixed mode was conducted in a pilot fluidized bed reactor of 200 mm ID and 2 m tall refractory lined as shown in Figure 1.

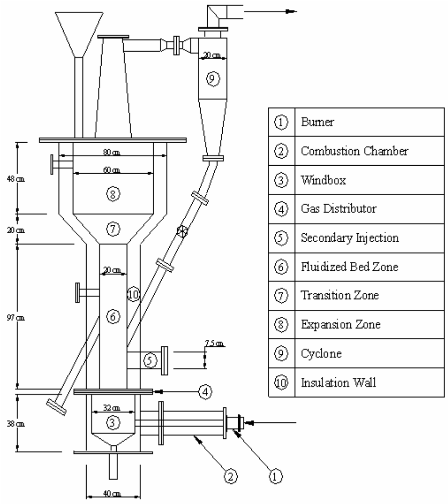

Fig. 1: Schematic of the pilot fluidized bed reactor

The reactor is divided into three zones: the combustion inlet (windbox and distributor), a fluidized bed, and a freeboard zones. An external NG burner with the 20 kW power located at the bottom of the bed provides the partial heat required for the reactor to achieve a desired temperature. The sand particles, tested in a fixed bed reactor, described by Sotudeh-Gharebagh and Chaouki [9] are used during the combustion tests. Several ports are provided along the axial position for pressure measurements, sampling and NG injection to the reactor. Sampling probes were placed along the reactor centreline with their tips protected by a filter where the samples are withdrawn with a variable pressure vacuum system. Type-K thermocouples were also placed along the reactor centreline to monitor temperature profiles. E experimental procedure details are given by Sotudeh-Gharebagh and Chaouki [8]. Upon reaching the bed temperature to a desired level, NG is injected through the secondary injection port and the combustion takes place inside of the bed.

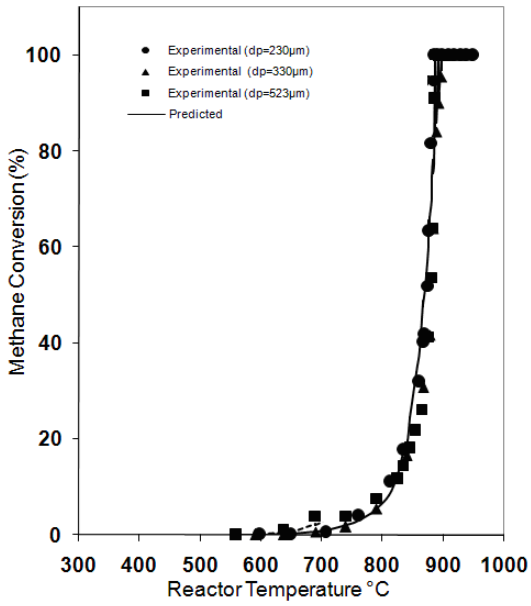

Fig. 2: Comparison of experimental methane conversion to the model predictions (d_p=mean particle size) [8].

3. Results and Discussion

In this section, experimental data obtained in the fixed and the pilot fluidized bed reactors are discussed. Figure 2 shows the experimental data for the fixed bed reactor filled with sand particles. The figure also shows the plug flow model predictions obtained with the Gas Research Institute methane combustion mechanism [10] as modified by Sotudeh-Gharebagh and Chaouki [9]. The results showed that accelerating catalytic effect of particles is quite small. In addition, the inhibition effect is considerably higher at moderately high temperatures (850-900 °C), and it may be neglected at high temperatures well above 1000 °C. Therefore, it is concluded that inert particles would be an excellent choice for bed materials in order to develop a new reactor. However, since the sand particles are easily available and less expensive, they were chosen as the bed particles in this study.

There are two major signs for the safe controllability of NG in turbulent fluidized beds, namely, the uniform temperature profile and CO emission levels as shown in Figures 3-4. In Fig. 3, the temperature profile is shown for 8 operating conditions.

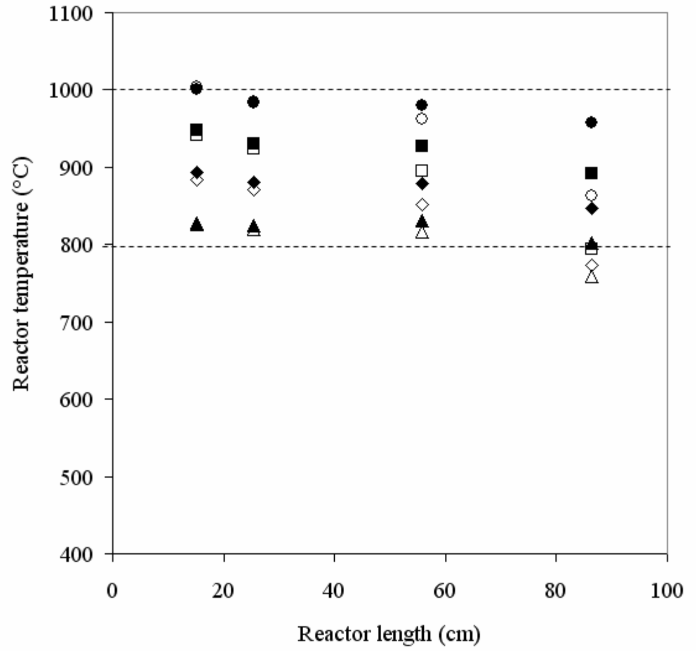

Fig. 3: Temperature range and profile of the pilot fluidized bed reactor

The experiments show that the bed can easily be operated at isothermal conditions well at 800-1000 °C, and because of an intense gas-solid mixing, the standard deviation of temperature for the bed operating at rather high superficial gas velocity (*U*) over 1.5 m/s is about ±7.5° C. This means that the bed can be easily operated in a safe mode. This also shows that the reaction zone is well located inside the bed and for this reason, run-away reactions are prevented. This Figure also suggests that the new combustion devices can be designed to be operated at the range of 800-1000 ° C which is well below 1200 °C leading to low emission levels.

In Figure 4, the axial CO profile for the fluidized bed reactor is reported. In the CO zone, the amount of O_2 is much lower than the stoichiometric value needed for the complete combustion and almost all fuels are immediately converted to CO, leading to a peak in CO concentration, and under this condition, CO rich bubbles are formed. The in-situ formation and destruction of CO reported in this study is consistent with modeling and experimental studies reported in the literature [11-12] as adapted and shown in Figure 5.

Reported correlations in the literature also confirm that CO is the dominant product at temperatures and particle sizes typically employed in fluidized bed combustion of coal particles [13]. Under fluidized bed conditions, if temperature is kept sufficiently high, the subsequent fast oxidation of the CO to CO_2 occurs within the bed. The results shown here is consistent with those reported by Baron et al. [14]. The TFB generates less CO probably due to high gas-solid interactions as compared with the bubbling fluidized bed.

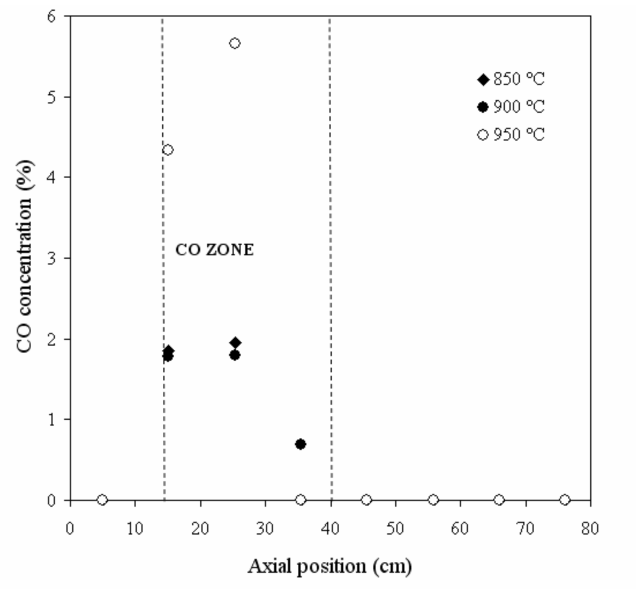

Fig. 4: Axial CO profile using one-hole sparger placed at 17 cm from the reactor base (jetting velocity = 30 m/s)

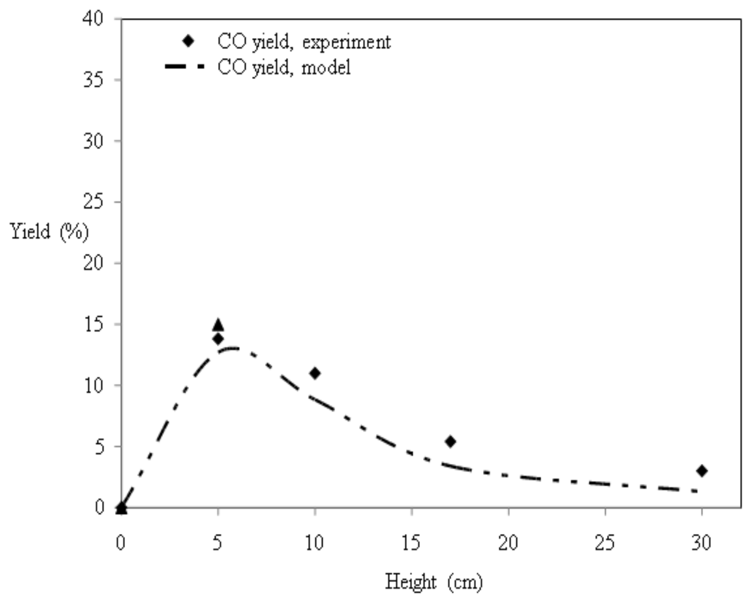

Fig. 5: Axial CO yield: (adapted from [11]).

4. Conclusion

A fluidized bed reactor with minimal in-situ CO formation has been proposed for energy processing applications using inert bed materials. This study shows that sand particles would be excellent and less expensive bed materials for safe combustors development. The corresponding safe combustion may lead to the in-situ destruction of CO and pollutants generated during the fluidized bed combustion of fuels and industrial wastes. Complete NG conversion is achieved over 800 °C, and novel devices can be designed to operate at 800-1000 °C, accordingly. This technology can be considered as a framework to put forward the novel and environmentally-friendly devices for co-firing, gas re-burning, foundry sand reconditioning, the incineration of high-moisture sludge, the cleaning of metallic parts and direct combustion for heating and energy applications.

5. References

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