EMISSIONS CHARACTERISTICS AND ENVIRONMENTAL IMPACT OF COKE OVEN GAS COMBUSTION

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Abstract
Coke oven gas (COG) is a possible alternative fuel and byproduct of coal carbonization in steel production. COG is a type of synthetic gas combination mainly made up of hydrogen, carbon monoxide, carbon dioxide, and methane, and it also has different proportions of other hydrocarbons. COG is also increasingly utilized as a fuel due to its high calorific value and potential for energy recovery. However, its combustion generates pollutants that create high environmental pollution. This study investigates the emissions characteristics and environmental impacts of COG combustion, focusing on key pollutants such as carbon monoxide (CO), and greenhouse gases (GHGs) like carbon dioxide (CO_2). Theoretical analyses reveal that COG combustion emits lower CO_2 and CO than pure methane. In terms of emissions, Cokes 3 and 4 outperformed the others. The findings provide valuable insights for researchers aiming to balance energy recovery and sustainable production in steel and related sectors.

Keywords: Coke oven gas combustion, pollutant emissions, low-carbon, alternative fuel

Introduction

Heavy industry's effects on the environment have grown in prominence for nations as it has developed. In the industry, some of the gases obtained from fossil fuels are discharged into the environment without being utilized. These gases can be gas mixtures containing high hydrogen (H2) levels. These potential sources of H_2 fluids can be, firstly, a) surplus products and secondly, b) waste by-products from process industries that are not further utilized [1,2]. It is assumed that Europe has a total potential of 2–10 billion Nm^3 of usable surplus hydrogen: up to 5 billion Nm^3 from the first set of plants (a) and 2–5 billion Nm^3 as waste by-product (b) [2].

Coke oven gas (COG) can be considered a type of syngas with some distinctions. COG is a by-product of the coke-making process in steel production, when coal is heated without air to produce coke. It typically contains H_2 (~50-60%), CH_4 (~25-

30%), CO (~5-10%), N_2 (~5-10%), and other light hydrocarbons [3]. Due to its high H_2 content, COG has significant potential in combustion applications. Besides, H_2 reduces HC, CO, CO_2, smoke, and PM emissions with zero carbon atoms [4]. Recent studies show that COG can be utilized in efficient combustors depending on the plants where it is produced due to its high H_2 composition and volumetric flow (~280-450 Nm^3/h) [5] produced per ton of coke. Liu and Guo conducted a study on energy consumption, carbon emissions of COG conversion to hydrogen, natural gas, methanol, and power. COG to power is the most economical utilization scheme since it performs better in every condition and produces less CO_2-eq of carbon emissions [3]. Ortiz-Imedio et al. demonstrated that COG combines the advantages of pure H_2 and pure CH_4 to achieve better performance and lower emissions than pure gases over a wider equivalence ratio range [6].

There are many research activities related to COG in combustion applications, but this study provides a new perspective to fill the gap in the literature with a theoretical approach to different types of coke oven gases compared to pure CH_4 fuel. The objective of the study is to theoretically compare different COGs and provide insight into emissions and environmental impacts. In addition, the presented approach can enhance the recovery of a part of industrial waste COG.

Methodology

In this study, four different COGs and CH_4 were compared at different equivalence ratios. Table 1 shows COG compositions obtained from the industrial applications examined in the literature [7–9].

Table 1. COG Compositions

COG No	CH_4	H_2	CO	N_2
Coke 1	35%	45%	7%	13%
Coke 2	30%	50%	9%	11%
Coke 3	27%	55%	8%	10%
Coke 4	25%	60%	9%	6%

The variation of the chemical composition of the combustion gases was analyzed. The general combustion equilibrium equation and exhaust components of the COG mixtures are demonstrated in Eq. (1) [10].

$$C_aH_bO_cN_d + \frac{a_s}{\phi}(O_2 + 3.76N_2)$$
$$\rightarrow y_1CO_2 + y_2H_2O + y_3N_2 + y_4O_2 + y_5CO + y_6H_2 + y_7H + y_8O + y_9OH + y_{10}NO \quad (1)$$

where a, b, c, and d are the C, H, O, and N content in different coke oven gases, respectively. n_1, n_2, n_3, ... n_{10} are the molar ratios of the exhaust components, a_s is the stoichiometric molar air-fuel ratio, and ϕ is the equivalence ratio. In the study, the equilibrium constants method [10] is utilized in combustion calculations. The chemical equilibrium problem must be solved for ten species to obtain reactants in this equation, where O, H, OH, and NO dissociations are essential [11]. Mole fractions for ten distinct species are represented as y_i. The atomic equilibrium of the components C, H, O, and N is described by four equations. The total mole fraction of species is equal to one when the number of moles of each species is divided by the total number of species. Six gas-phase equilibrium processes have equilibrium constants shown in Eqs. (2) to (9). These reactions include the production of OH and NO and the breakdown of hydrogen, oxygen, water, and carbon dioxide [11].

$$\frac{1}{2}H_2 \Leftrightarrow H \qquad K_1 = y_7 P^{\frac{1}{2}} / y_6^{\frac{1}{2}} \tag{2}$$
$$\frac{1}{2}O_2 \Leftrightarrow O \qquad K_2 = y_8 P^{\frac{1}{2}} / y_4^{\frac{1}{2}} \tag{3}$$
$$\frac{1}{2}H_2 + \frac{1}{2}O_2 \Leftrightarrow OH \qquad K_3 = y_9 / \left(y_4^{\frac{1}{2}}\, y_6^{\frac{1}{2}}\right) \tag{4}$$
$$\frac{1}{2}O_2 + \frac{1}{2}N_2 \Leftrightarrow NO \qquad K_4 = y_{10} / \left(y_4^{\frac{1}{2}}\, y_3^{\frac{1}{2}}\right) \tag{5}$$
$$H_2 + \frac{1}{2}O_2 \Leftrightarrow H_2O \qquad K_5 = y_2 / \left(y_4^{\frac{1}{2}}\, y_6 P^{\frac{1}{2}}\right) \tag{6}$$
$$CO + \frac{1}{2}O_2 \Leftrightarrow CO_2 \qquad K_6 = y_1 / \left(y_4^{\frac{1}{2}}\, y_5 P^{\frac{1}{2}}\right) \tag{7}$$

The water-gas shift reaction given by Eq. (6) and (7) is represented by the last two reactions. The equations of the species' atomic balance and K coefficients were combined to create a total of ten equations. The Newton-Raphson method was implemented to numerically solve ten unknowns using ten linearized equations.

Results and Discussion

The equilibrium compositions generated through combustion were examined based on the four different COGs and CH_4 from ϕ =0.8 to 1.2. Fig. 1 shows the variation of CO_2 and CO with respect to equivalence ratio under constant temperature.

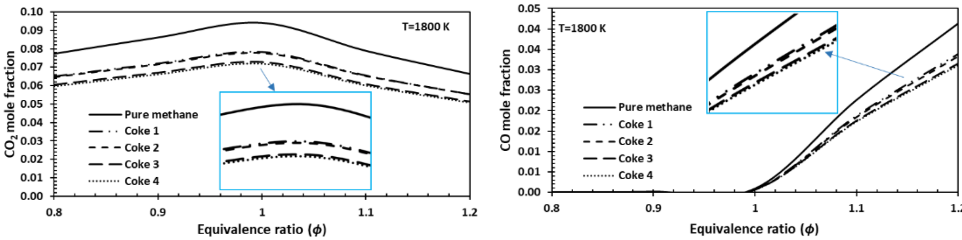

Figure 1. Mole fraction of (a) CO_2 and (b) CO for the COGs and methane

Combustion of COGs reduced CO_2 and CO emissions compared to pure methane. Coke 3 and 4 performed better than the others in terms of emissions. The equivalence ratio for CO_2 reached a maximum at ϕ = 1. CO emissions, on the other hand, showed a rapid increasing trend after the equivalence ratio ϕ = 1.

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