Investigation of temperature distribution inside reaction chamber of plasma-catalytic reforming system

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Abstract: Temperature of OH radical, reaction chamber wall temperatures and gas temperature distribution inside the reaction chamber in the system for plasma-catalytic reforming of hydrocarbons were investigated. Obtained data showed that gas temperature in rotating gliding discharge does not correspond with rotational temperature of OH obtained using optical emission spectra.

Keywords: plasma-catalytic reforming, non-equilibrium plasma, temperature measurement

1. Introduction

Replacement of the fossil hydrocarbons as the reagents for the chemical and energy industry with the renewable alternatives is an important part of sustainable development. Conventional methods of hydrocarbon conversion used in chemistry have difficulties when dealing with renewable hydrocarbons due to their complexity and large number of additives [1,2]. Plasma-assisted reforming of renewable hydrocarbons using low-temperature plasma provides a compelling alternative to both thermochemical, catalytic and biological conversion methods [3]. High chemical activity of plasma-born species decreases energy requirement of chemical reactions and allows to conduct them at lower temperature in a similar fashion to traditional catalysts. The contemporary rise in the renewable electricity production adds an additional appeal to the use of plasma-based conversion technology [4].

Unfortunately, the conditions inside the reaction chambers of the systems that employ plasma-catalytic approach to conversion are largely unknown. It is especially true in the case of the temperature at which the conversion takes place. On one hand, temperature measurements based on the optical emission spectroscopy, which are traditional to plasma physics, are not always representative of the gas temperature in the low-temperature non-equilibrium plasma environment [5]. On the other hand, direct measurements of gas temperature inside the reaction chamber are not always possible. This work is focused at the study of temperature distribution inside the reaction chamber of the system for plasma-catalytic reforming of renewable hydrocarbons.

2. Experimental Setup

Temperature distribution was studied in the system that is schematically represented on Fig. 1. System consisted of connected discharge and reaction chambers. System used rotating gliding discharge for plasma generation. Discharge was powered by a DC power source. Discharge system was made from the stainless steel. Reaction chamber was made of quartz to provide an opportunity for the optical emission spectroscopy. Reforming was conducted on ethanol using atmospheric air as an oxidizer. Ratios between the ethanol and oxidizer flows corresponded to rich mixtures. Oxidizer flow was separated into two parts. One part was directed into the discharge chamber as a plasma source working gas.

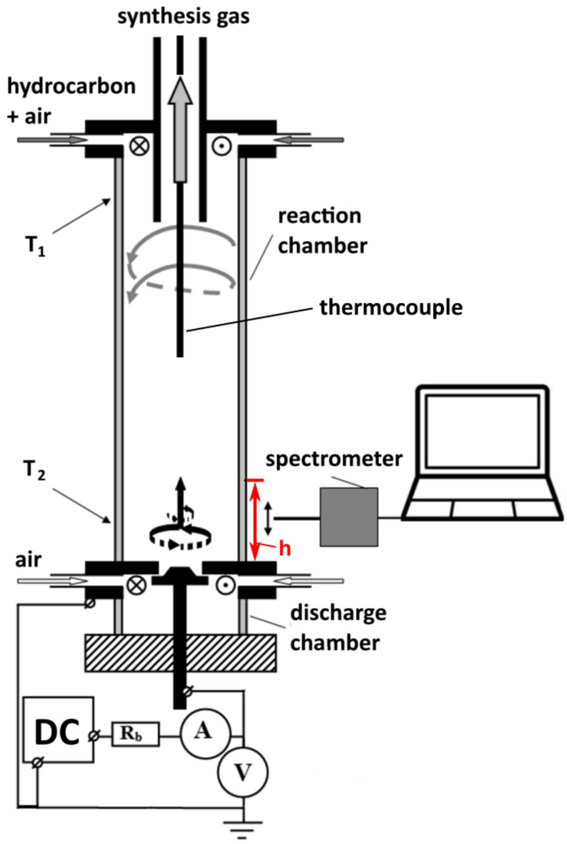

Fig. 1. Scheme of experimental setup.

Plasma torch produced by the operation of rotating gliding discharge was injected into the reaction chamber through its base. Second part of the oxidizer was mixed with the input ethanol flow and introduced into the reaction chamber as a vortex flow alongside the reaction chamber wall. Plasma interacted with ethanol inside the reaction chamber, which initiated reforming. Ethanol was converted into synthesis gas. Produced gas was cooled and combusted.

Temperature of the reaction chamber wall was measured both near the ethanol injection zone and near the discharge chamber and plasma torch using thermocouples. Temperature along the axis of the reaction chamber was measured using a thermocouple placed inside the ceramic shell. Optical emission spectra measured at different points along the reaction chamber axis were used to estimate the temperatures of OH radical produced by plasma during discharge operation and reforming. Temperatures were determined by fitting obtained spectra to the modelled spectra using Specair 2.2 software [6]. Temperature and spectra measurements were conducted at distance h from the bottom of the reaction chamber.

3. Results and Discussion

Distribution of gas temperature along the axis of the reaction chamber is shown on Fig. 2.

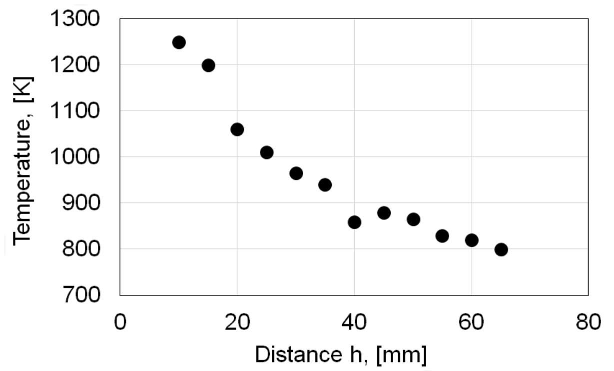

Fig. 2. Distribution of gas temperature along reaction chamber axis during discharge operation.

Obtained gas distribution shows that gas temperature at h = 10 mm reaches approximately 1300 K. From this point temperature decreases down to 800 K with the increase of h to 65 mm. Obtained gas temperature at low h can be compared with rotational temperature of OH measured for these distances. It is provided on Fig. 3.

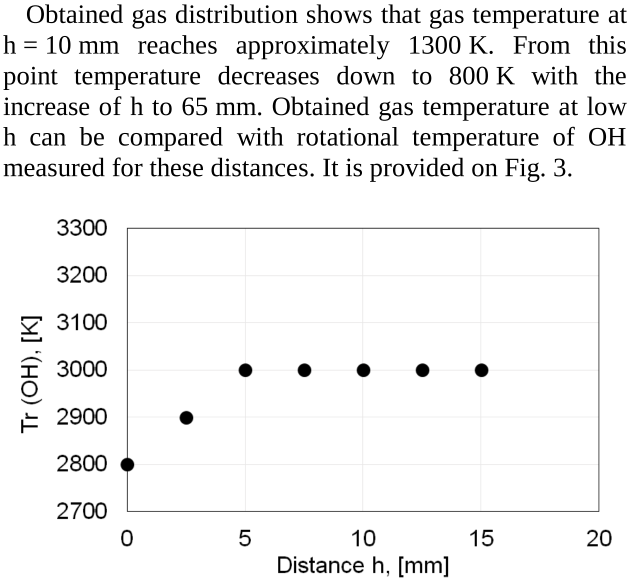

Fig. 3. Distribution of rotational temperature of OH radical along reaction chamber axis.

Comparison between the gas temperature and rotational temperature of OH at h = 10 mm and h = 15 mm shows that rotational temperature in rotating gliding discharge plasma torch can be approximately 2.5 times higher than its gas temperature. In addition, while the gas temperature decreases with distance, the rotational temperature of OH remains stable.

During the measurements of temperatures and spectra the temperature of reaction chamber wall near the ethanol injection (T_1) stayed between 320 and 340 K, while the wall temperature near the discharge chamber (T_2) was in the range of 340 – 370 K. Inner diameter of quartz reaction chamber was 36 mm, thus a distance between the reaction chamber axis and its wall is 18 mm. Temperature drop over this distance is approximately 900 K at h = 10 mm and 450 K at h = 65 mm.

4. Conclusions

Discharge operation and plasma-catalytic reforming lead to the appearance of complex temperature profile inside the reaction chamber of reforming system. Significant difference between the rotational temperature of OH and directly measured gas temperature during discharge operation showed that plasma of rotating gliding discharge is not in equilibrium. As a result, optical emission spectroscopy should be conducted alongside the direct measurements for the estimation of reforming conditions. Low temperature of the reaction chamber wall during discharge operation and reforming indicates a significant drop of the temperature between the reaction chamber axis and its periphery. Sharp decrease of the temperature can be caused by the vortex flow of ethanol-air mixture along the reaction chamber wall. Understanding of the precise nature of this difference requires experimental measurement of gas temperature profile between the wall of reaction chamber and its axis. In addition, studies focused on the determination of the temperatures inside the reaction chamber during the reforming process are needed.

5. References

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