Characterization of electric discharge in liquefied petroleum gas

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Conversion of LPG to hydrogen using electric discharge is one of the promising efficient techniques for alternative fuels production. The electric discharge was generated in LPG at low pressure where the electric and spectroscopic characteristics of the discharge were studied. The current waveform of the discharge showed the formation of two discharge modes, glow discharge and spark discharge. The light emission spectra indicated to the formation of hydrogen atoms (emission of Hα line) and carbon clusters (emission of C₂ Swan system band). Such formations confirmed the conversion of LPG to hydrogen in the discharge channels. The role of the spark discharge in enhancing the conversion process was discussed. It was found that the conversion rate increases by increasing the discharge voltage.

1. Introduction

Liquefied petroleum gas (LPG) is a group of hydrocarbon-based gases derived from crude oil or natural gas. LPG used in the present work consists of around 70% butane (C₄H₁₀) and 30% propane (C₃H₈). It also includes traces of other hydrocarbons like ethane, ethylene, propylene, butylene, etc. LPG is widely used as a household fuel for heating and cooking in many countries. Its transportability and easy storage have boosted its popularity. On the other hand, LPG is rarely used as a vehicles fuel. LPG generates air pollutants lower than gasoline [1] but it has a lower energy output than gasoline, about 74% of the energy output of gasoline [2]. The low energy output makes LPG not a common alternative fuel for vehicles. To overcome the low energy output some reforming of LPG is required.

Recently electric discharge in hydrocarbon gases has been widely used for reforming purposes. While there are many studies published in the electric discharge of methane, ethane, acetylene and other hydrocarbons [3-6], there is a shortage in the investigations of electric discharge in LPG in the literatures. The electric discharge is expected to be an efficient technique for conversion of LPG to other alternative fuel gases like hydrogen.

The aim of the present paper is to study the characteristics of the electrical discharge in LPG. The electric discharge has been generated by applying a DC high voltage (0.5 - 3 kV) between two electrodes with gap distance of 1 to 10 mm in LPG with pressure of 2 - 200 torr. Electric and spectroscopic characteristics have been investigated for monitoring the discharge mechanism and its effect on the conversion processes in the gas. The emission spectra have been used to confirm the production of hydrogen from the conversion process of LPG.

2. Experimental setup

Figure 1 a) shows the schematic diagram of the experimental setup of the electric discharge system. Figure a) b) shows a photographic plate of the discharge in LPG. The discharge cell consists of a cylindrical glass vessel with 80 mm diameter and 110 mm length. Two movable electrodes are placed on the axe of the glass tube. The electrodes made of brass (alloy of copper and zinc) with diameter 30 mm and the gap distance between the two electrodes are varied from 1 to 10 mm. The vessel has been evacuated to base pressure of 10⁻² torr using rotary pump and then LPG is left to flow through the discharge cell at constant flow rate of 1 L/min. Using two needle valves, before and after the vessel, the LPG pressure in the vessel has been controlled in the range of 2-200 torr. A DC power supply (0-3 kV) has been used a high voltage source. A load resistance of 22 kΩ has been used to limit the discharge current. The discharge voltage has been measured via potential divider (500:1) and the discharge current has been measured by measuring the potential drop across a resistance 100 Ω. The voltage and current waveforms have been recorded using digital storage oscilloscope (type HM1508). A photomultiplier (type 9558QB) has been used for time resolved measurements of the total light emission. A spectrometer (Type: Solar laser systems M266) has been used for spectroscopic measurements.
3. Results and discussion

Figure 2 shows the voltage and current waveforms of the discharge in LPG at pressure 20 torr. It can be noticed that there are two different components of the current. The first component is the glow component which is characterized by uniform current with low values (few tens of mA). The second component is the high current component (hundreds of mA) with pulsed behavior of very short time (around 50 ns). The current values and duration time of the second component indicates to the occurring of spark discharge in this component. By naked eye it has been noticed that; the discharge in LPG is characterized by very bright discharge channels that are moving on the electrode surface, see figure 1 b). Such behavior of these channels confirms the presence of spark discharge. As will be discussed later this spark channels play an important role in the conversion processes of the hydrocarbons to hydrogen. The transition from glow discharge mode to spark discharge mode may be attributed to the following: as the glow discharge mode is formed some of propane and butane molecules are decomposed forming hydrogen atoms. The hydrogen atoms play an important role in increasing the ionization processes in the gas and hence rising the discharge current. The effect of hydrogen on the discharge current has been discussed in previous work [7]. As a result of the increase in the discharge current the gas temperature is elevated which in turn increases the reduced electric field (E/N) in the gas which enhances the formation of spark discharge.

The intensity of the total light emitted from the discharge is measured directly by using a photomultiplier. A comparison between the time behavior of the discharge current and of the total light emission is shown in figure 3. It can be noticed that the light is emitted as the discharge current is built up and decays slower than the discharge current. The duration time of the current pulse is around 50 ns while that of the total light emission is around 2000 ns. This slower decaying of the total light emission is attributed to the effect of the relaxation time of the de-excitation processes of the excited atoms and molecules. This time is called the relaxation time. As the discharge collapses the current decays very fast with time depending on the deionization processes rate which is very fast compared with the de-excitation processes. Such difference between the deionization and de-excitation processes leads to the behavior shown in figure 3.

The light emission spectra of the discharge in LPG have been measured at different conditions using a spectrometer model M266. Figure 4 shows a sample of the measured spectra. The most important emission lines and bands are Hα line and C₂ Swan system band. Emission of Hα line and C₂ Swan system band confirms the success of the conversion process where the hydrocarbons (mainly Butane and Propane) in the LPG were dissociated to hydrogen atoms which emit the Hα line and carbon atoms which are collected in clusters and causes the emission of C₂ Swan system band. The formation of spark discharge is very important in the present work for conversion processes. In spark channels two factors lead to conversion process: i) the excitation of gas molecules due to the incident of electrons and photons ii) the elevation of the gas temperature in the spark channel. The effect of the excitation of hydrocarbon molecules and the gas temperature on the conversion to hydrogen was discussed in details in literatures [8,9].
The presence of Cu and Zn lines in the spectrum indicates to the occurrence of sputtering process from the cathode materials, in the present measurements it is brass (alloy of copper and zinc). The brass electrode has been replaced by Ni electrode, in this case the Cu and Zn lines have disappeared and Ni lines has appeared in the spectrum which confirms the sputtering of the electrode martial.

In the present work, the intensity of Hα line has been used as a qualitative indicator on the success of the conversion of LPG to hydrogen. Figure 5 shows the intensity of Hα line as a function of the applied voltage. It can be noticed that as the applied voltage increases the intensity of Hα line increases. As the applied voltage increases the discharge current increases which in turn increases the effect of the two factors affecting the conversion process (the excitation of hydrocarbon molecules and the gas temperature increase).

4. Conclusion

Electric discharge in LPG has been found to be an efficient technique for the conversion of LPG to hydrogen and carbon. The transition from glow discharge mode to spark discharge mode in LPG has been found to be very important to enhance the conversion process. In spark discharge channels the gas molecules are excited and the gas temperature is elevated, both factors enhances the decomposition of hydrocarbons to hydrogen and carbon.

5. References


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