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Critical concentration of helium making hydrogen–oxygen with various fractions nonflammable

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ABSTRACT

The objective of this study is to determine the critical concentrations of helium making hydrogen–oxygen nonflammable under various volume fraction ratios of hydrogen and oxygen. Tests were conducted for three volume fraction ratios of hydrogen and oxygen 2:1, 1:1 and 1:2, at the initial pressures of 0.1, 0.2, 0.3 and 0.4 MPa and the initial temperatures of 21, 40, 60, 75 and 90 °C. The flammability limits of mixtures with the lower volume fraction ratios between hydrogen and oxygen are much different from the lower flammability limits of hydrogen in oxygen or air. Compared with the lower flammability limits of hydrogen in oxygen or air, the critical concentrations of helium determined in this study are significant for process safety of the mixtures with various volume fraction ratios between hydrogen and oxygen. For the mixtures at 21 °C, the critical concentrations of helium making hydrogen–oxygen nonflammable increase with the volume fraction ratios of hydrogen and oxygen in the range from 0.5 to 2. The variation of the critical concentrations of helium with the initial pressure depends on the initial temperature. For the mixtures at the initial temperature of 60 °C and the initial pressure of 0.3 MPa, the critical concentration of helium reaches to its limit of 95% in the case of volume fraction ratio of hydrogen and oxygen 2:1. The limit values of the critical concentration of helium are 93% for 1:1 volume fraction ratio of hydrogen and oxygen and 89% for 1:2 volume fraction ratio of hydrogen and oxygen ratio, respectively.

Introduction

If enough fuel is mixed with enough oxidizer, reaction can be activated with some type of energy. Generally, the reaction is not what we expect, even worse, it can lead to a fatal accident. In order to prevent such an unexpected reaction, an inert gas such as helium is used to dilute the mixture to make it nonflammable. But excess helium will add a negative weight. So it is worthwhile to determine the critical concentration of helium making the hydrogen–oxygen mixture

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nonflammable. There is a large amount of data on the flammability limits of hydrogen in oxygen or air or oxygen-dilutes [1–9]. In the existing data, the dilute concentrations were given to determine the lower flammability limits of hydrogen in oxygen. In fact, the data are useless in many cases of process industry, because the concentration ratio between hydrogen and oxygen is usually constant to meet the need of chemical reaction. The existing data on the lower flammability limits of hydrogen–oxygen-dilutes determined using the same method as that determining the lower flammability limits of hydrogen in air are meaningless in these cases. To ensure safety in chemical process, the dilute is added to hydrogen–oxygen. Enough amount of added dilute makes hydrogen–oxygen nonflammable. Therefore, the most important is the critical amount of added dilute making hydrogen–oxygen nonflammable for process safety. However, it is impossible to obtain the significant data on the critical amount of added dilute making hydrogen–oxygen nonflammable in the existing results on the lower flammability limits of hydrogen–oxygen-dilutes.

The limiting explosible concentrations of hydrogen vary with the volume fraction ratio of hydrogen and oxygen, and that of hydrogen and diluent as well [2,14–16]. Previous data [12,17–25] on limiting explosible concentrations of hydrogen–air, hydrogen–oxygen, and hydrogen–oxygen–helium can not be used to determine the safety criterion related to the practical operational case examined in this study. The limiting explosible concentrations for mixtures containing three species of gas are much more complicated than those containing two species of gas. Even the triangle flammability diagram well known for mixtures containing three species of gas is only applicable to some specific conditions of one specific initial temperature and pressure. Many practical operational cases, usually at high temperature and pressure, are different from the specific conditions. To ensure process safety of the mixtures at different high temperature and high pressure in which the volume fraction for each species of gas is fixed, the measured limiting explosible concentrations related to the practical operational cases are more significant than that determined under a specific condition.

In this study related to the practical operational case, the critical concentration of helium making hydrogen–oxygen nonflammable was determined using an experimental system measuring flammability limits. Three sets of experiments were carried out. In each set of experiments, the concentration of helium was variable and the volume fraction ratio of hydrogen and oxygen remained unchanged. The ratio between the volume fraction of hydrogen and that of oxygen were 2:1, 1:1, and 1:2, respectively in the three sets of experiments.

There are some investigations on an analytical assessment of flammability limits of gaseous mixtures at various initial temperatures. Initial pressure also has an impact on flammability limits, which has been verified by many experiments [10,14]. However, the analytical method for initial pressure impacting flammability limits requires further study. Therefore, the analytical method for the evaluation of the flammability limits at various initial pressures was created in this study.

Apparatus and instrumentation

The experimental set-up used in this study was similar to that in Ref. [10]. It consisted of a 5-L cylindrical vessel coupled with an electric ignition system and a data acquisition system. Experiments were performed in this vessel with ignition. The height h of the vessel was 340 mm and the inner diameter $2R$ was 160 mm. In the experimental vessel, ignition was achieved by means of an inductive-capacitive spark produced between stainless steel electrodes with rounded tips, separated by a spark gap of 1 mm. The electrode diameter used in the experiments was 1 mm.

The pressure rise in the vessel was measured by a Kistler pressure transducer mounted on the wall of the experimental vessel. All results were stored through a data acquisition device. The data acquisition system was triggered by the control unit, and recorded pressure data at sampling frequencies of 1 MHz. A schematic of the apparatus used to determine the flammability limits is shown in Fig. 1. A 7% pressure rise from the initial pressure value would indicate that combustion occurred.

The lower flammability limits in air were first determined using the test vessel to verify the experimental system effectiveness. This testing was done for comparison with the lower flammability limit for hydrogen in air reported in literature to assure the experimental set up was working properly. The lower flammability limits measured using the experimental set up in this study was 4% which was near to the data reported in previous literatures. The lower flammability limits of hydrogen in air and oxygen are approximately equal. The Lower flammability limits of hydrogen in oxygen reported in Ref. [11], which conducted the experiment in a 5-cm diameter, 1.8-m long tube at atmospheric pressure, was 4.1% and those in air at atmospheric pressure reported in Refs. [12] and [13] were 3.9% and 4–7%, respectively. The measured lower flammability limit of hydrogen in air was 4% using the experimental system in this study. Even though flammability limits change with vessel size, this effect has been found to be small for apparatus diameters of more than 5 cm [11]. This dimension has been found to allow the flame to propagate without being quenched by the walls. And also, the measured

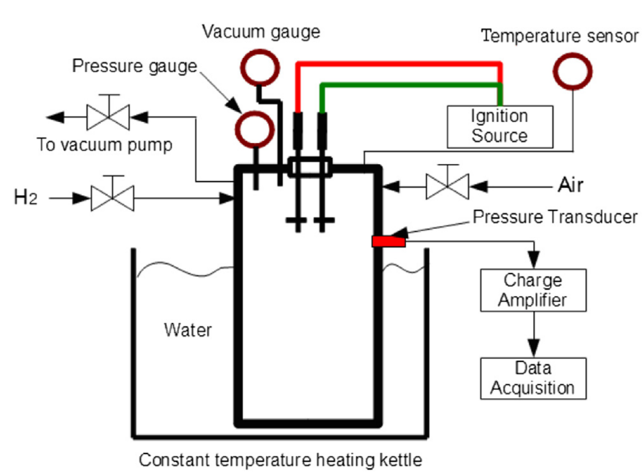

Fig. 1 – Schematic of flammability apparatus.