The Safety Issues of Hydrogen Energy

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Overview

Hydrogen is considered to be an important future energy carrier for significantly reducing greenhouse gas emissions. However, only limited experimental data on hydrogen flammability are available. This paper presents an experimental and theoretical study to understanding of the flammability and explosion of hydrogen to insure hydrogen safety and to realize hydrogen the economy in near future. The experimental data show that the flammable and explosive hazards for hydrogen are greater than for conventional fuels.The risk associated with an explosion hazard depends on an understanding of the impacts of the explosion, particularly the pressure-time history during the explosion in flammable range. The explosion characteristics of hydrogen is obtained by analizing the experimental data with flame growth model. There is no explosion risk if the hydrogen is diluted with nitrogen and the concentration is less than 13.7%. The probability of forming a high explosion pressure in the vent stack of hydrogen storage with an external ignition is very low.

Methods

Spherical explosion vessel with a volume of 20 l is used in this work for characterizing of hydrogen-air mixture explosion in confined space. First, the vessel is purged with ultra high purity(UHP) nitrogen and evacuated until 0.3 psia several times to remove combustion impurities in the vessel, and then UHP oxygen, UHP nitrogen, and UHP hydrogen are filled sequentially to the desired partial pressures. The partial pressure of gas filling is controlled by feedback control from a high precision pressure transducer manufactured by Sensotec and solenoid valves manufactured by Burkert. The valves are controlled by using NI PCI 6229 and LabVIEW software. Once the gases are mixed homogeneously and a temperature requirement is satisfied, the mixture is ignited under quiescent condition by electrifying and vaporizing a 40-gauge tinned copper fuse wire located at the center of the vessel. After ignition, pressure signals from the pressure transducer located on the vessel wall are monitored and saved on a computer to analysis the explosion characteristics of hydrogen-air mixture. The fusing wire has a length of 10 mm and delivers a measured 10 J at ignition. Data acquisition rate is 10,000 samples per second. If the burned gas mixture is flammable after explosion test, the burned gas is diluted to be inflammable with nitrogen before venting to atmosphere for ensuring safety. All of the experiment sequence is controlled automatically by the computer. Because of high oscillation of explosion pressure signal at the end of explosion produced by acoustic wave, a filtering program for the oscillation noise is developed and applied to obtain the maximum explosion pressure and deflagration index. Details of the apparatus and procedures are described elsewhere .

A flame growth model is used to estimate the pressure-time curve, the extent of combustion, and the radius of flame. The model was developed by assuming a spherical flame front, a uniform gas pressure within the vessel, a homogeneous gas concentration, and assuming the buoyancy force of the burned gas and the flame thickness are negligible. The unique and important feature of the model is that it uses a different heat capacity for the burned and unburned gases.

Results

The experimental data are used to produce a triangular flammability diagram showing the complete flammable zone for hydrogen in a three component system composed of hydrogen, air and nitrogen – the first time a complete triangle diagram for hydrogen has ever been completed. The results show that the flammable zone for hydrogen is a lot larger than for other typical hydrocarbons. The diagram is very useful to establish an inerting method. Absolute inerting is established when inert gas is added to the explosible mixture to such an extent, that by addition of any amount of air or fuel the explosible range can no longer be reached. The release of such an inerted atmosphere to the ambient air would thus not result in the formation of an explosive atmosphere. Any mixture with less than 13.7 % hydrogen in nitrogen will always be non-explosible even if it is mixed with air, and therefore is absolutely inert. Generally, the maximum explosion pressure for most hydrocarbons changes suddenly near the flammable limits, but for hydrogen it changes gradually at the LFL. The traditional methods to determine the flammable limit, based mostly on a pressure rise, do not work very well for hydrogen.

The pressure – time data sets were also analyzed to determine the maximum pressure and the deflagration index, both important parameters to characterize hydrogen combustion. The results show that the maximum pressure is typical of most hydrocarbons, but the deflagration index is much higher. The explosion characteristics of hydrogen-air-nitrogen mixtures are numerically formulized using a flame growth model based on the maximum explosion pressure, the deflagration index, the exponent parameter of the burning velocity and the burning parameter. The pressure-time curves computed using the flame growth model successfully fit the experimental data over the entire time and for all concentrations. The deflagration index increases with the volume of the explosion vessel – a theoretically computed value assuming no early flame quenching may reach a value as high as 1,700 bar-m/sec. The peaks in the maximum explosion pressure, deflagration index and burning parameter are observed at 30 %, 36 % and 40 % of hydrogen in air, respectively. This means that the worst case accident for hydrogen-air mixtures in a confined volume may not be an explosion near the stoichiometric concentration, but at a concentration between 29.5 % and 40 % of hydrogen.

The maximum explosion pressure in the vent stack of hydrogen storage depends on the thermodynamic parameters and the explosion characteristic parameters of hydrogen-air mixture. If the rate of pressure build up by burning of the mixture in the vent stack is greater than the rate of pressure relieved by the venting out of the burned gas, the pressure inside the vent stack will increase. Using the experimental combustion data obtained, the probability of forming a high explosion pressure in the vent stack with an external ignition is very low because the release rate of burned gas is very high comparing to the pressure buid-up rate by burning the hydrogen-air flammable mixture.

Conclusions

In this work we present an experimental data of hydrogen gas in air and analyze the data with flame growth model to understand the hydrogen safety. There is no explosion risk if the hydrogen is diluted with inert gas until the concentration of hydrogen is less than 13.7%. The probability of detonation by an external ignition in the vent stack of hydrogen storage is very low.

The deflagration index is generally known as independent on the volume of explosion vessel. But the deflagration index for hydrogen-air mixture increases with the volume of experimental vessel and it can reach up to 1700 atm.m/s if the vessel size is enough large to ignore the flame thickness. The worst case accident for hydrogen-air mixtures in a confined volume may not be an explosion near the stoichiometric concentration, but at a concentration between 29.5 % and 40 % of hydrogen

Experimental data for hydrogen show that the second derivative flammable limit criterion produces slightly conservative values for combustion in air. Visual inspection of the combustion during the tests showed that no visual combustion was observed at the second derivative criterion. For hydrogen, the second derivative criterion resulted in a flammable range in air from 3.6 to 75.2% hydrogen.

We believe that the experimental data and results of this work will be used to develope a safety guide or a safety measure of hydrogen in near future.

References

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