



Contents lists available at ScienceDirect

Journal of Loss Prevention in the Process Industries

journal homepage: www.elsevier.com/locate/jlp

Effect of initial temperature on the explosion pressure of various liquid fuels and their blends

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ARTICLE INFO

Article history:

Received 28 November 2015

Received in revised form

12 July 2016

Accepted 21 August 2016

Available online xxx

Keywords:

Liquid fuels

Initial temperature

20-l Sphere

Explosion regimes

Thermodynamics

Radiant heat losses

ABSTRACT

In this work, the effect of initial temperature on the explosion pressure, P_{ex} , of various liquid fuels (isooctane, toluene and methanol) and their blends (isooctane-toluene and methanol-toluene, with three different fuel-fuel ratios) was investigated by performing experiments in a 20-l sphere at different concentrations of vaporized fuel in air. The initial temperature was varied from 333 K to 413 K.

Results show that, as the fuel-air equivalence ratio, Φ , is increased, a transition occurs from a “thermodynamics-driven” explosion regime to a “radiant heat losses-driven” explosion regime. The maximum pressure, P_{max} , is found in the former regime ($\Phi < 3$), which is characterized by a trend of decreasing P_{ex} with increasing initial temperature. This trend has been explained by thermodynamics. In the latter regime ($\Phi > 3$), P_{ex} increases with increasing initial temperature. This trend has been addressed to the decrease in emissivity (and, thus, radiant heat losses) with the increase in temperature.

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1. Introduction

According to the National Fire Protection Association (NFPA), the key parameters for classifying flammable liquids are the flash point and the boiling point. Details of such classification are given in NFPA 30 (2002).

In the literature, many efforts have been devoted to the measurement and prediction of the flash point of flammable liquids (see, e.g., Gharagheizi et al., 2012; Keshavarz and Ghanbarzadeh, 2011; Liaw et al., 2004; Rowley et al., 2010). On the contrary, the determination of explosion parameters for flammable liquids in their vapor state seems to have been somewhat ignored.

Liquid fuels are not explosive by themselves. Explosive conditions may be created when fuel evaporation and mixing with air occur. At temperatures higher than the flash point, liquid evaporation may result in the formation of a flammable cloud that, in turn, may give rise to explosion (the so-called “vapor cloud explosion”). Many accidents happened as a result of

ignition of flammable vapor clouds, causing huge damages (Herbert, 2010; Maremonti et al., 1999; Venart, 2004).

Explosion of liquid fuels becomes especially severe at temperatures higher than the boiling point. Thus, the evaluation of explosion parameters for liquid fuels has to be performed at initial temperature higher than the boiling point. Furthermore, the effect of initial temperature has to be quantified.

The effect of initial temperature on the explosion pressure is not straightforward. Indeed, for gas explosions occurring under very fuel-rich conditions (close to the upper flammability limit), it has been found that the trend of the explosion pressure with the initial temperature is opposite to that expected from thermodynamics (Holtappels, 2007a,b).

In this work, the effect of initial temperature on the explosion pressure of various liquid fuels (methanol, toluene and isooctane) and their blends (methanol-toluene and isooctane-toluene, with three different fuel-fuel ratios) was investigated by performing experiments in a 20-l sphere at different concentrations of vaporized fuel in air. The initial temperature was varied from 333 K to 413 K. Results are discussed highlighting the behavior that cannot be predicted by thermodynamics.

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2. Experimental setup

The experimental setup consists of a spherical reactor with additional modules: ignition module, sample preparation module, pressure measurement module, temperature stabilization module, safety module and data acquisition module.

The testing vessel, with volume of 20 l, is made of stainless steel (Fig. 1). It is resistant to high pressures and temperatures, and to corrosion from combustion products.

The experimental setup allows to carry out measurements up to 413 K of initial temperature (because of thermal insulation and temperature stabilization module).

Ignition is provided at the geometrical center of the reactor, by burning off the hot-wire. The data acquisition system, which consists of a dynamic pressure sensor (PCB Piezotronics transducer, model 113B21), a signal amplifier (PCB, model 480C02) and a personal computer, allows to register pressure change in time and determine maximum explosion pressure and maximum rate of explosion pressure rise.

The module dedicated to sample preparation allows to create homogenous fuel-air mixture with the partial pressure methodology.

The device along with the mixture must be properly prepared before ignition. Before starting using the device, temperature of all elements must be stabilized and it takes up to 2 h for high temperatures (like 413 K).



Fig. 1. 20-l sphere apparatus.

The first step is to install wire between electrodes and close the chamber very tight. After that, the vacuum pump takes out all air from the vessel, and pressure goes down from 1 atm to 2 mbar. Then (after closing the valve of vacuum pump), an amount of liquid test sample is introduced which, at the test temperature, quickly evaporates.

Few minutes after introducing the fuel, the air is introduced into the chamber up to ambient pressure along with working stirrer. Then, the stirrer is turned off and, 15 s after that, ignition is provided and the data acquisition system starts to probe. This delay time allows turbulence to settle, without losing the homogenous nature of the mixture.

In this study, pure fuels (isooctane, toluene and methanol) and their blends (isooctane-toluene and methanol-toluene) were investigated over a range of fuel-air equivalence ratios and for initial temperatures ranging from 333 K to 413 K (with 20 K interval).

The fuel blends were obtained by using a graduated cylinder and a calibrated automatic pipette. For each blend, three compositions were tested corresponding to volume ratio of the pure constituents in their liquid state equal to 50%-50% (1-1 ratio), 25%-75% (1-3 ratio) and 75%-25% (3-1 ratio).

For each fuel/air composition and each initial temperature, three tests were performed. However, in the case of standard deviation higher than 0.3 bar, five tests were performed.

After each test, the vessel was accurately cleaned, thus avoiding accumulation of soot (on the wall), which is formed under fuel-rich conditions.

3. Results and discussion

3.1. Pure fuels

In Figs. 2–4, the explosion pressure, P_{ex} , is plotted versus the fuel-air equivalence ratio, Φ , as measured for isooctane (Fig. 2), toluene (Fig. 3) and methanol (Fig. 4) at different initial temperatures. The fitting of the curves to the measured points was carried out by using the MATLAB[®] Curve Fitting Toolbox.

In all cases, the trend of P_{ex} with Φ is not symmetric around the stoichiometric composition, being the fuel rich region ($\Phi > 1$) wider

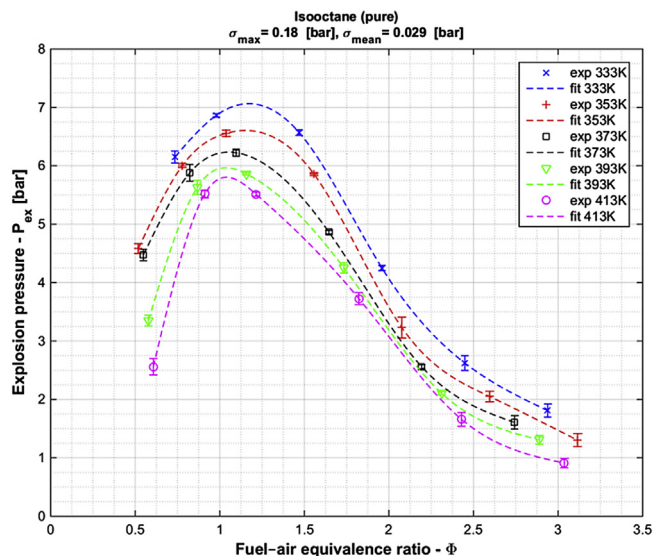


Fig. 2. Explosion pressure, P_{ex} , versus fuel-air equivalence ratio, Φ , as measured for isooctane at different initial temperatures.

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