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EFFECTS OF INERTIZATION PROCESS IN CONFINED SPACES WITH APLLICATION IN THE AERONAUTICAL INDUSTRY

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Abstract. *A long time ago, you have heard about accidents by gas explosion, and the destruction that they can cause. To be able to avoid it requires the understanding of what a gas explosion is and what can reduced the frequency and consequences of these events. The upper and the lower flammability limits (UFL and LFL, respectively) are the maximum and the minimum concentration of the fuel in the air, respectively, in which a flame propagate, they are considered key tools in the prediction of fire, evaluating the possibility of explosion and design of protection systems. There is an interest in finding the flammability limits of ethanol mixed with an inert gas at reduced pressure as a safety measure for the future used of this biofuel in aeronautical applications, taking into account the typical altitude of a commercial airplane (<40 000 ft.). In this work the flammability of hydrated ethanol (5,18%vol. Water) was evaluated experimentally and the nitrogen was used as inert gas. The experimental bench was build according with the norm ASTM E-681. The ethanol was inject using a precision syringe with 1 ml of volume, nitrogen and air was injected using partial pressure law of Dalton. The method for measure the flammability was by visual observation of flame propagation. The results plotted as a function of the additions of nitrogen shows that when the initial pressure decreases, the UFL decreases and both the LFL and the limit oxygen concentration (LOC) increases. In addition, the variation of UFL is more noticeable than the LFL when the percentage of nitrogen increase in the ethanol/air mixture.*

Keywords: *Flammability limits, Inert gas, Nitrogen, Hydrated ethanol, Visual criteria, Experimental measure*

1. INTRODUCTION

The confined spaces are characterized by enclosures with enter and exit limited, natural ventilation unfavorable, and in the most cases with lack oxygen (< 20.8%O_2), presence of toxic contaminants or flammable substances, that were not designed for the permanent occupation of workers, as is the case of the airplane fuel tank. According to their characteristics, they are divided into; open (tunnels, sewage) or closed (tanks, silos, wells). Potential hazards in confined spaces called "class A" correspond to those where there is a great danger to life. Generally hazards atmospherics, such as flammable or toxic gases, deficiency or oxygen enrichment (Dag Bjerket et al., 1995). Therefore, know the risks that involve the gaseous and liquid fuel mixture explosion with air is very important to guarantee the industry and domestic security as well as in the aeronautical sector (Coronado et al., 2014).

Flammable substances, which characterized by having an exothermic reactions in the presence of air when are exposed to an ignition source are very important so far. Various hydrocarbons are extremely volatile under normally operated condition. To prevent explosions in the workplace it is necessary to know in what range of concentrations and conditions the handling of these materials are capable of forming flammable atmospheres (Zhao, 2008).

The range of flammable concentrations is limited by the upper flammability limit (UFL) and lower flammability limit (LFL) and is specific for a particular of gases and/or vapors mixtures. There are several factors affect the limits of flammability; however, the most important are; pressure, temperature and the oxidant of the mixture (Gibbon et al., 1994).

Explosion disasters like the one that produced the crash of the TWA 800 flight, which happened near the coast of New York in 1996, in which the central fuel tank exploded shortly after taking off resulting in 230 people dead. The cause was the formation of vapors in the fuel tank of the airplane, which reached a maximum due to the heating of the fuel - air mixture, by the air conditioning system located at the bottom of the fuel tank. The increase of the evaporated fuel in the empty region of the tank formed a flammable mixture that caused the accident (Coronado et al., 2012). Others disaster, such as the Connecticut Natural Gas explosion on 7 February 2010, the British Petroleum explosion in the Gulf of Mexico on 24 April 2010 (Tingguang Ma, 2011), and the explosion in alcohol and gasoline storage tanks in Santos-Brazil on 2 April 2015 (Escalante E.S.R, 2016),

Le Chatelier’s rule is widely used to estimate the flammability limits of a flammable gases mixture (Mashuga and Crowl, 2000). However, the industrial process also form mixtures composed of flammable and non-flammable gases, such as in the inerting process, which is a process where an inert gas be added in a flammable mixture to change the flammability limits and reduce the concentration of oxygen below of the limiting concentration in order to reduce the risk of explosion. In the aeronautical sector, for the effective prevention of fire and explosion of fuels stored in large tanks, the Federal Aviation Authority (FAA) and the National Transport Safety Board (NTSB) recommended the inertization treatment (Zhao, 2011). In industrial processes, the inert gas usually used is nitrogen or carbon dioxide, in some cases water vapor can also be used (Chen et al., 2010).

Measurements of flammability limits for high temperature and reduced pressures need time and can be complex, but the ability to accurately predict them would be useful, in particular, for the preliminary design study (Gibbson et al., 1994). Additionally, the increase of gas inert concentration in the fuel/air mixture is the technique commonly used in the industry for reduce the flammability of fuels, increasing slightly the LFL and decreasing considerably the UFL. Both meet in a common point called limit oxygen concentration (LOC), which is an important parameter in the prediction of the fire and risks of explosion that can cause losses material as well as of human lives (Zhao, 2001).

With the objective of know the comportment of LFL and UFL in the presence of a gas inert and find the point of LOC of a flammable fuel, were realized experimental tests for high temperature and reduced pressures to hydrated ethanol/air/nitrogen mixture, in a heating chamber build according with the norm ASTM E681. Considering that few models, to predict flammability limits are available in the literature for pressure and temperature different from standard. Finally, the figures presented shown the tendencies of both UFL and LFL and the values obtained will be compared with data found in the literature.

2. MATERIALS

The flammability vessel used for testing was 20.716-liter borosilicate glass spherical flask, which was heat by electrical elements with the capacity to raise the temperature of the flask to 300 ℃ as shown in Figure 1. The flask has a viewing window and on the top has a special material cover (silicone fluoride) and resistant to sudden changes in temperature, the cap was attached to four rods, each with a spring to keep it secure in the container. Combustion in case of a sudden increase in pressure.

Figure 1. Heating chamber and Flammability vessel, respectively

The supervisory and data acquisition systems, commonly abbreviated SCADA, is used to monitor variables such as pressure and temperature in the heating chamber, this information arrives of two thermocouples localized in the top and the middle flammability vessel. The SCADA was connect to a computer and helps in the visualization for the monitoring of all variables, in addition to storing the data, as shown in Fig. 2.

Figure 2. SCADA – Supervisory Control and Data Acquisition.

3. METHOD

A heating chamber, built according to the American regulation ASTM E-681, was use for the determination of flammability limits of fuels and was install in the UNIFEI Thermal Machines Laboratory (Coronado et al., 2014). The method for measuring flammability was based on electrical ignition and visual observation of flame propagation as defined by ASTM E-681. First, the upper and lower flammability limits are determined for high temperature (60 ℃) and ambient pressure (101,325 kPa) to compare the results with data published in the scientific literature. Next, we proceeded to work with reduced pressures (80, 60, 40 and 20 kPa) for this same temperature.

The vessel is heated to temperature of interest and to guaranteed the evaporation of the hydrated ethanol a vacuum pump used to decrease the pressure to range of 0 – 2 KPa. A certain amount of hydrated ethanol using a hypodermic syringe of 1 ml was introduce. The air and nitrogen were addition until test pressure using Dalton law of pressures partial for ideal gases. For guarantee that mixture of the three gases be homogeneous, a teflon magnetic stirrer at the bottom of the chamber running for two minutes was used before that the mixture was ignited. The spark caused by two electrodes separate to distance of 6.4 mm, they was localize in the middle of the flammability vessel and with an ignition energy of 0.2 mJ.

A data set was get for different concentrations of hydrated ethanol at test temperature (60℃). The tests were repeated until the "yes / no", i.e. flammable or non-flammable mixture, the half between them is considered as the flammability limit, where it was found to be lower at 3.73% Vol. The limit oxygen concentration (LOC) was calculate using the equation (1) and the inertization point of fuel (IPF) was calculate using the equation (2):

$$\%O_2 = 0.209(100\% - \%Fuel - \%N_2) \tag{1}$$

$$IPF = \frac{\%nitrogênio}{(\%etanol\ hidratado + \%nitrogênio)} \tag{2}$$

4. RESULTS AND DISCUSION

In the case of flammability of the hydrated ethanol sample, the flame propagation was evident as was a considerable increase in pressure and temperature. It is important to use both visual and auditory safety equipment in the test. It was find tests that produced flammability have propagation of the flame upwards from the point of the spark to the top of the flammability vessel and then expand through of its walls with flame propagation downward, the phenomenon is most evident when working at reduced pressures, this behavior is similar to that specified by ASTM E681.

The tests have shown that nitrogen addition does not have a significant effect on lower flammability limits, but does significantly affect the upper limit of flammability, which is one reason why studies and research to date have found it better to predict the behavior of LII and there are several empirical and theoretical models to find these values.

The addition of nitrogen causes the value of the lower flammability limit to increase little and the value of the upper flammability limit falls to a point where both limits will meet, this point was call the limit oxygen concentration (LOC). The values of LOC increase when pressure decrease and the values of IPF decrease when the pressure decrease as shown Fig. 2 and 3, respectively.

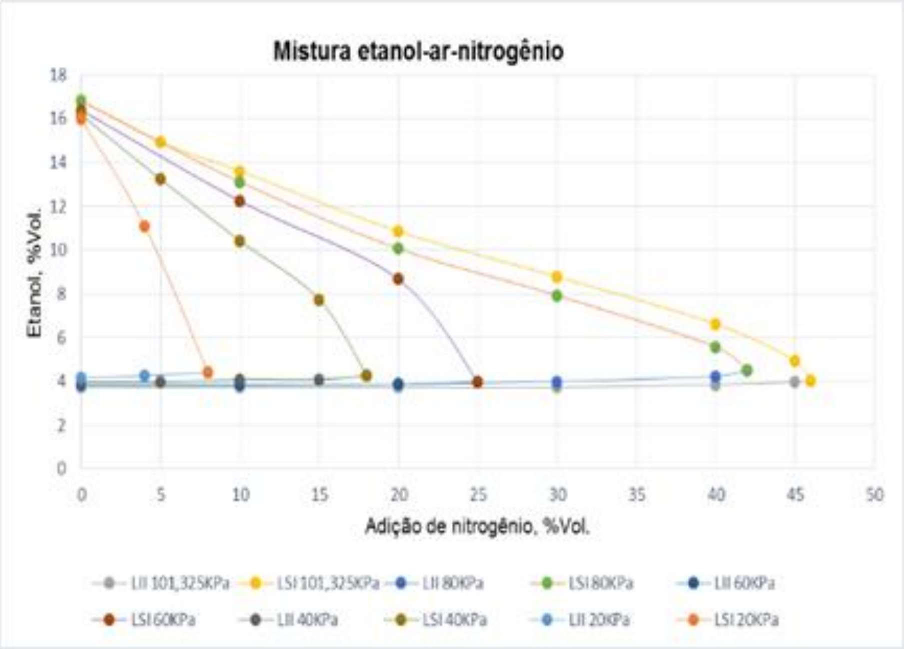

Figure 2. Influence of the addition of nitrogen on the limit oxygen concentration at atmospheric pressure and reduced pressures and 60 °C of temperature

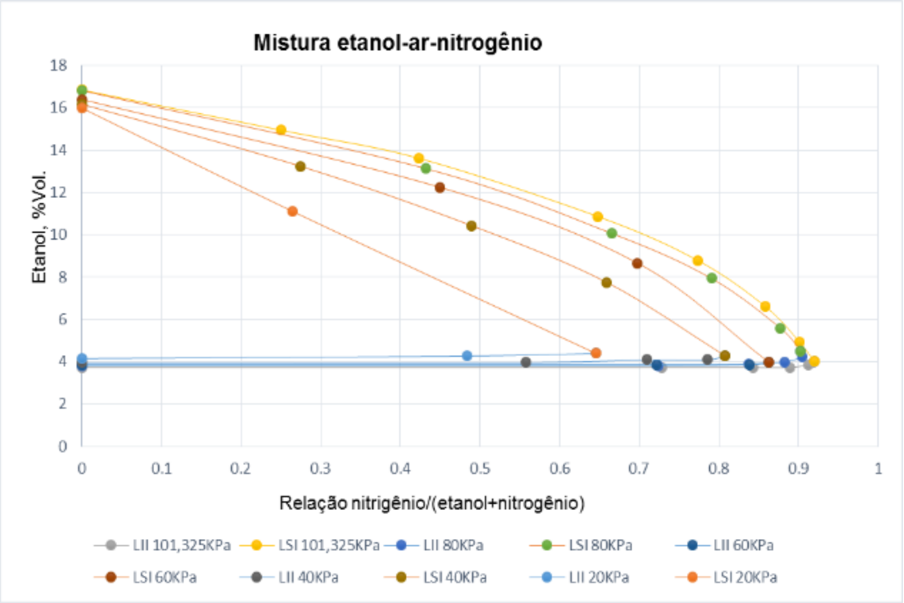

Figure 2. Influence of the addition of nitrogen on the limit oxygen concentration at atmospheric pressure and reduced pressures and 60 °C of temperature

As was observed, the experimental data plotted produce curves for flammability limits lower and upper. They have a same tendency as presented in the literature and the scientist publications as the case of Coward e Jones (1952), Zabetakis (1965), Kuchta (1985), Kondo et al. (2006), Crowl & Jo (2008), Zhenming Li et al. (2011), Tingguang Ma (2011), Gequn Shu et al. (2015) among others. However, data for hydrated ethanol/air/nitrogen mixture not was find in the literature. In the Table 1 is shown the values for the LOC and IPF summarized.

Pressão (kPa)	Temp.(◦C)	LII (%)	LSI (%)	CLO (%)	nit/(nit.+Etanol)
101.325 (0-46%)	60	3.73	16.62	10.5	0.92
	110	-	-	-	-
80 (0-42%)	60	3.74	16.61	11.23	0.9
	110	-	-	-	-
60 (0-25%)	60	3.76	16.4	14.91	0.86
	110	3.6	17.36	13.87	0.88
40 (0-18%)	60	4.27	16.27	16.32	0.81
	110	4.07	17.2	16.15	0.82
20 (0-8%)	60	4.15	16.18	18.4	0.65
	110	3.79	17.15	17.78	0.72

Table 1. Values of LOC and IPF for hydrated ethanol/air/nitrogen mixture to 60℃ and 100℃ and reduced pressures.

5. CONCLUSIONS

The study of the flammability of fuel-air-inert gas mixture was development experimentally, the fuel used was hydrated ethanol and the nitrogen was used as inert gas in different percentages, the trends of the curves obtained for each case is the same as reported in other studies.

The results show that the experimental bench, installed in the laboratory of thermal machines of UNIFEI, is operating correctly as far. It also shows that the correct procedure for each test was follow. After obtaining the results for ambient pressure 101,325 kPa and 60 ℃ of temperature, it began with the tests at reduced pressures.

The objective of this study was to show the influence of the inerting process on the flammability limits of hydrated ethanol / air mixtures and to find the intersection point of these limits called limit oxygen concentration, which was affect by the reduction of pressure and in this way to avoid flame spread and risk of explosion.

The practical application of this case was find in the aeronautical sector, considering the flight altitude of a commercial aircraft and the typical atmospheric characteristics that exist in its fuel tank.

The electrical ignition and visual observation of the flame propagation was the method used for the test, for this reason we were need a high-speed camera for the data capture, in case be difficult observe the flame either by irregular propagation or insufficient luminescence in the visible spectrum.

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