Effect of initial temperature and initial pressure on the lower explosion limit of aviation kerosene

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Abstract. The effect of initial temperature and initial pressure on lower explosion limit (LEL) of RP-3 aviation kerosene vapor was investigated experimentally. The experiments were conducted in an explosion limit equipment at initial temperature of 40-160 °C and initial pressure 100-160 kPa. In the temperature-pressure range studied, the LEL decreases with the increase of the initial temperature, while increases as the initial pressure increases. A correlation formula established in the present study can predict the experimental data well. A comparison of the temperature dependence and pressure dependence indicates that the LEL of RP-3 aviation kerosene vapor is mainly affected by the initial temperature. This guides people to pay more attention to the aspect of the heat transfer in the fuel tank of aircrafts avoiding the explosion risk caused by high temperature.

1. Introduction

The aircrafts with a large amount of fuel in the fuel tanks are prone to involving the hazards of fire and explosion during operation, parking and maintenance, resulting in disastrous consequences [1-3]. Statistics show that one serious fire/explosion accident of aircraft fuel tank occurs every three years around the world [4]. The fuel, namely aviation kerosene, is composed of various hydrocarbons such as chain hydrocarbons, alkanes and alkenes in different proportions [3, 5]. The fire/explosion behavior of aviation kerosene is different from the common pure fuel. Explosion limits (lower explosion limit (LEL) and upper explosion limit (UEL)) are one of the most important properties to characterize the explosion characteristics of fuels [6]. Previous studies focused on explosion characteristics and mechanisms of explosive mixtures and proposed some suppression technologies for the relative fire/explosion [7-10]. Van den Schoor et al. [11] observed that the UEL of lower alkanes and alkenes in air increases as the elevated pressures and temperatures rising. Sanchirico et al. [12] reported that increasing initial pressure weakens the turbulence kinetic energy, leading to the extension of the explosion region increases. Chen et al. [13] investigated the vapor explosion characteristics of nitro thinner under different initial temperature and initial pressure. The results showed that LEL and UEL increase with the increase of the initial pressure, while decrease with the increase of the initial temperature. Note that initial temperature and initial pressure will affect the explosion limits of the explosive mixtures [6]. For aviation kerosene, Sochet et al. [1, 2] and Hill et al. [3] explored the explosion characteristics of kerosene in civil and military aviation under normal atmosphere. Wang et al. [14] studied the explode danger of aviation kerosene in low pressure and found that the range of explosion limit decreases with the decrease of initial pressure. Considering the real situation in
aircrafts, from a safety point of view, the most effective method is to prevent vapor concentration of aviation kerosene from exceeding the LEL. But the research on the LEL of aviation kerosene in the environment of high temperature and pressure has been inadequate and needs further study. Thus, the explosion limit experiments are conducts to study the effect of initial temperature and initial pressure on the LEL of RP-3 aviation kerosene in this paper.

2. Experimental setup
In current work, an explosion limit instrument was adopted to determine the LEL of the flammable gases vaporized by RP-3 aviation kerosene. The photo of the experimental apparatus is shown in Fig. 1. It consists of two parts: flammable liquid evaporation device for preparing vapor and explosion limit instrument for measuring the LEL of the flammable mixture. Fig. 2 shows the detailed sketch of the equipment. The test method was based on the EN 1839-2017 and ASTM E681-2009 standards [15, 16]. Four initial temperatures (40, 60, 80 and 160 °C) and three initial pressures (100, 130 and 160 kPa) were selected in this study. All tests were performed in triplicate. Table 1 lists the experimental scheme of the LEL for RP-3 aviation kerosene.

![Figure 1. Photo of the experimental instrument (a) Explosion limit instrument and (b) Flammable liquid evaporation device.](image)

![Figure 2. Sketch of the equipment used for explosion limit tests.](image)

**Table 1.** The experimental scheme in this study.

| Case | Initial temperature/°C | Initial pressure/kPa |
|------|-------------------------|---------------------|
| 1-1  | 40                      | 100                 |
| 1-2  | 60                      | 130                 |
| 1-3  | 80                      | 160                 |
| 2-1  | 40                      | 100                 |
| 2-2  | 60                      | 130                 |
| 2-3  | 80                      | 160                 |
| 3-1  | 40                      | 100                 |
| 3-2  | 60                      | 130                 |
| 3-3  | 80                      | 160                 |
| 4-1  | 40                      | 100                 |
| 4-2  | 60                      | 130                 |
| 4-3  | 80                      | 160                 |
3. Results and discussion

3.1. Effect of temperature on the LEL

Table 2 summarizes the LEL date of RP-3 aviation kerosene. Fig. 3 depicts the temperature dependence of LEL of RP-3 aviation kerosene at different pressures. It can be found that the LEL decreases monotonously with the increase of initial temperature, regardless of the initial pressure. Previous studies proposed a linear temperature dependence of LEL for some flammable gaseous mixtures [17]. However, the correlation between initial temperature and LEL is in a form of exponential function in this work. Increasing initial temperature can promote the molecular activity and less combustion energy will be needed, consequently, reduce the LEL values. It means that there is potentially hazardous explosion under the lower concentration of the vapor of RP-3 aviation kerosene. When the initial temperature exceeds a threshold, the difference in LEL is slight. Besides, the decrease rate of LEL with initial temperature at higher initial pressure is faster than that at lower initial pressure. The above results imply that it is critical to control the heat transfer rate from the surroundings to the fuel and its vapor in aircraft fuel tank.

### Table 2. A summary of the LEL of RP-3 aviation kerosene.

| Temperature/°C | Pressure/kPa | 100 | 130 | 160 |
|---------------|-------------|-----|-----|-----|
| 40            | 1.72        | 3.48| 5.24|
| 60            | 1.00        | 1.12| 1.24|
| 80            | 0.89        | 0.88| 0.87|
| 160           | 0.62        | 0.64| 0.64|

![Fig. 3. Lower explosion limit of RP-3 aviation kerosene plotted versus initial temperature at different pressures.](image)

3.2. Effect of pressure on the LEL

As we all know, initial pressure variations will not present a considerable effect on LEL compared with the effect of initial temperature [6]. The effect of initial pressure depends on the properties of each specific mixture. For some mixtures, the LEL increases and UEL decreases as pressure increases. Fig. 4 presents the pressure dependence of LEL of RP-3 aviation kerosene. A linear relationship between initial pressure and LEL can be observed under the current pressure range. LEL increase roughly with initial pressure, which is ascribed to the weakened molecular collision at higher pressure due to the effect of inactivated molecule [18]. However, increasing pressure has no significant influence at a higher initial temperature. It is a possible reason that the pressure range selected in the present study is narrow.
3.3. Combined effect of temperature and pressure on the LEL

Based on above analysis, LEL of RP-3 aviation kerosene is generally proportional to the initial pressure but inversely proportional to the initial temperature. Fig. 5 shows temperature and pressure dependence of LEL of RP-3 aviation kerosene. The 3-D nonlinear surface fitting was applied to determine the LEL expression corresponding to the temperature and pressure. An equation form is defined as follows,

\[ \text{LEL} = A + \frac{B}{(aP + b)T + c} \]  

(1)

where \( \text{LEL} \) is the lower explosion limit; \( P \) is the initial pressure; \( T \) is the initial temperature; \( A \), \( B \), \( a \), \( b \) and \( c \) are the constant coefficients. According to the fitting results, Eq. 1 can be transformed into Eq. 2. Herein,

\[ \text{LEL} = 0.48 + \frac{0.18}{(-2.84 \times 10^{-5}P + 0.015)T - 0.36} \]  

(2)

where \( P = 100-160 \text{kPa}, \ T = 40-160 \degree \text{C} \), correlation coefficient \( R^2 = 0.965 \).

Note that the above experimental data are based on the assumption that the relative molecular mass of RP-3 aviation kerosene is 142 g/mol. In practice, the composition of RP-3 aviation kerosene is complex, and the difference in relative molecular mass appears due to the different manufactures and batches. The literature review indicates that RP-3 aviation kerosene with average relative molecular mass of about 150 g/mol [19, 20]. Thus, it is necessary to modify the Eq. 2 with a correction factor of 0.94,

\[ \text{LEL} = 0.45 + \frac{0.17}{(-2.84 \times 10^{-5}P + 0.015)T - 0.36} \]  

(3)

To analyze the importance of the two factors, the partial derivatives of \( \text{LEL} \) with respect to \( T \) and \( P \) are solved separately. The difference in absolute values of partial derivatives are expressed by,

\[ \left| \frac{\partial \text{LEL}}{\partial T} \right| - \left| \frac{\partial \text{LEL}}{\partial P} \right| = \frac{0.17(0.015 - 2.84 \times 10^{-5}(P + T))}{((-2.84 \times 10^{-5}P + 0.015)T - 0.36)^2} \]  

(4)

In the current conditions, the denominator of the above equation is surely greater than zero, and its numerator is also positive value. Therefore, it can be reasonably derived that the LEL of RP-3 aviation kerosene...
kerosene is mainly affected by the initial temperature compared with the initial pressure. This coincides within the results of other studies.

**Fig. 5.** Temperature and pressure dependence of lower explosion limit of RP-3 aviation kerosene.

### 4. Conclusion

In this work, the lower explosion limits of RP-3 aviation kerosene in air were investigated at initial temperature rising from 40 to 160 °C and initial pressure rising from 100 to 160 kPa. The remarkable findings are as following:

The LEL of vapor explosion of RP-3 aviation kerosene exponentially decreases with the increase of the initial temperature. However, the decrease rate depends on the initial pressure. A stronger decrease is found at the initial pressure of 160 kPa.

The linear dependence of LEL on initial pressure can be observed. Totally, the LEL of vapor explosion of RP-3 aviation kerosene increases as the initial pressure increases, whereas, there is no significant increase of LEL with initial pressure at higher initial temperature.

A correlation between LEL and initial temperature and initial pressure is proposed. The results predicted by the formula fit well with the experimental data. Besides, the difference in absolute values of partial derivatives indicates that the LEL of RP-3 aviation kerosene is mainly influenced by the initial temperature. It implies that the effective heat dissipation is important to avoid the risk of fire/explosion for the fuel tank in aircraft.

### 5. Acknowledgments

This work was supported by the National Key R&D Program of China (No. 2018YFC0809500) and Fundamental Research Funds for the Central Universities of China (No. WK2320000039). The authors gratefully acknowledge these supports.

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