Experimental and Numeric study on the inhibition properties of Novec

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1 Introduction

1,1,1,2,2,4,5,5,5-nonafluoro-4-(trifluoromethyl)-3-pentanone, commonly known as Novec, is considered as one of the suitable fire inhibition agent and has an ability to replace current halon based agents. In the tests carried out to ascertain the inhibition abilities, Novec showed complete extinguishing capabilities for wheel-brake fire, three-dimensional inclined-plane fire, 16 ft pan fire and, in simulated engine nacelle with running fuel fire tests [1]. Nevertheless, the compound showed higher overpressure than that of the uninhibition case [2]. Along with the Novec, two other agents C_2HF_5 and $C_3H_2F_3Br$ showed similar behaviors [3,4]. Owing to this unexpected behavior various research groups have carried out experiments and numeric studies on all three above-mentioned agents and tried to explain the behavior of Novec at low concentrations [1,2,4,5].

Continuing this, here, we present results from systematic experiment carried out with propane as a fuel to understand the inhibition properties of the Novec. The experimental work is supported by the numerical calculation carried out to understand flame properties of Propane/Novec mixture.

2 Experimental Set-up

The experiments were carried out in NC2V chamber at ICARE-CNRS laboratory. The chamber has an internal diameter of 130 mm and a wall thickness of 35 mm. A set of two electrodes, at the center of the chamber separated by a distance 6 mm is used to ignite the mixture using a custom-made ignition box. A Phantom V12 camera was used to record the images from the ignition. Two pressure sensors, PCB (113B26) and Kistler (603B) were used to measure the pressure profile inside the chamber. The discharge voltage and the current were recorded using Tektronix P6015A; voltage probe and Bergoz Current Transformer CT-D1.0-B; current probe, respectively. As it is expected that the Novec on decomposition produces considerable quantity of HF, the burned product was diluted with nitrogen and then flushed for 40 mins through CLEANSORB, Model Number: CS025LS, column. A photograph of the facility is shown in Figure 1 while the schematics are shown in Figure 2. A schematic of the cross-section of the chamber, which is also shown in Figure 2, gives details on DAQ connection and electrode orientation in the chamber. Novec 1230, Propane (N25 grade) and Air (Alpha 2 grade), supplied by Air Liquide, were used in the present work.

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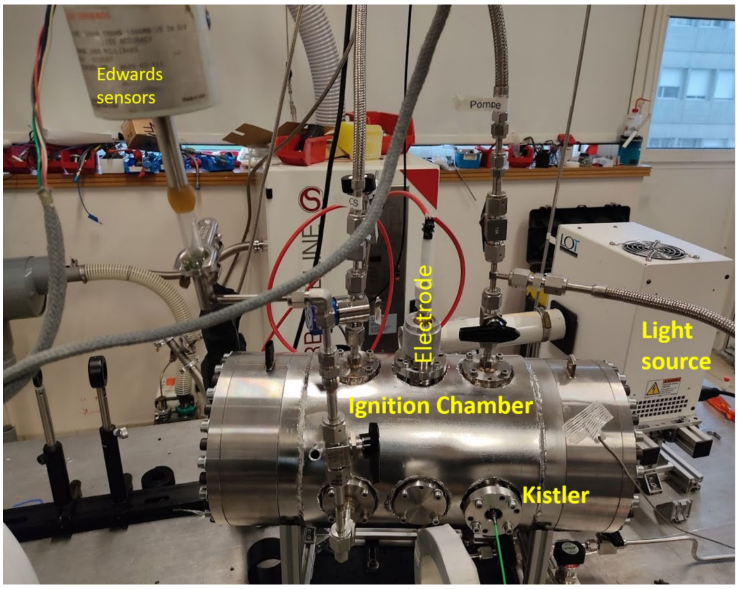


Figure 1: Photograph of the ignition chamber (left) and the

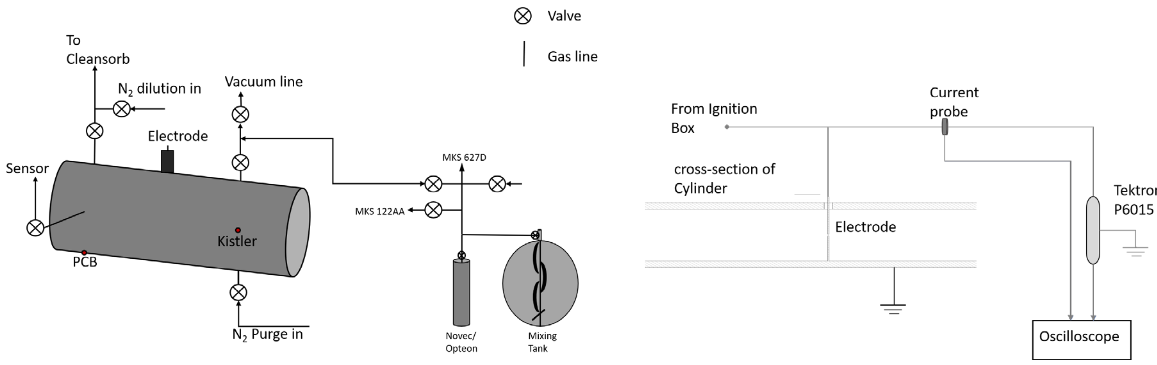


Figure 2: Schematics showing various parts of the chamber (Left). Schematic showing the cross-sectional view of the chamber and the DAQ scheme (Right).

3 Result and Discussion

The flammability limits, high flammability and low flammability limit, of propane were experimentally measured to ascertain the behavior of the system as a whole. The discharge energy across the electrode in the propane/air mixture, both in the rich and lean fuel concentrations are given in Figure 3. The non-flammability of the mixture is defined as the lack of combustion to cause an increase in the pressure value above 2% of the base pressure. In this case this value is 0.02 bar as the experiments were carried at 1 bar initial pressure. The results from this work showed that the flammability limits for the propane ignition at a mean dissipation energy of 169 and 249 mJ, for lean and rich mixture are 2.12±0.08 % and 10.18±0.09 %, respectively at 95 % confidence. The logistic distribution function for the lower and higher propane flammability limits are shown in Figure 4. These data acted as a baseline for the flammability measurement of Novec in stoichiometric propane/air mixture.

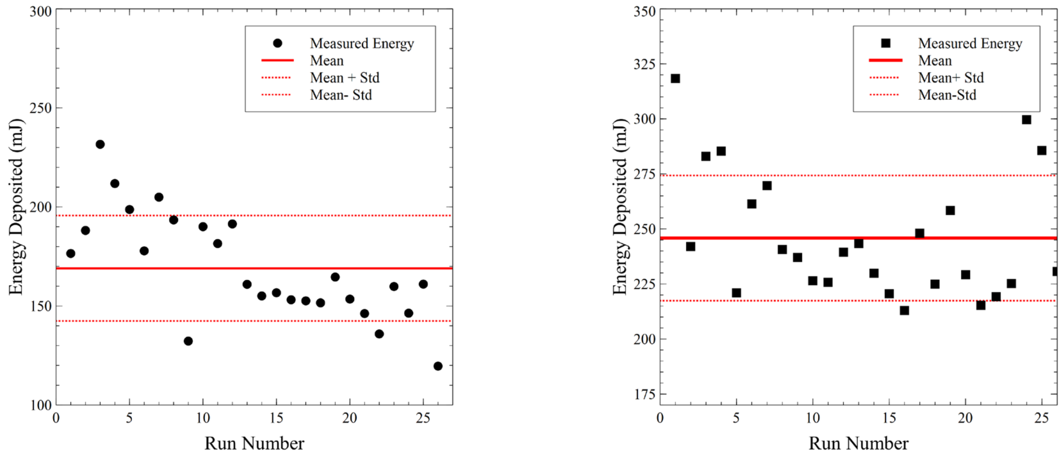


Figure 3: Calculated energy deposited values in lean propane/air mixture (Left) and rich mixture (Right) for an electrode distance of 6 mm.

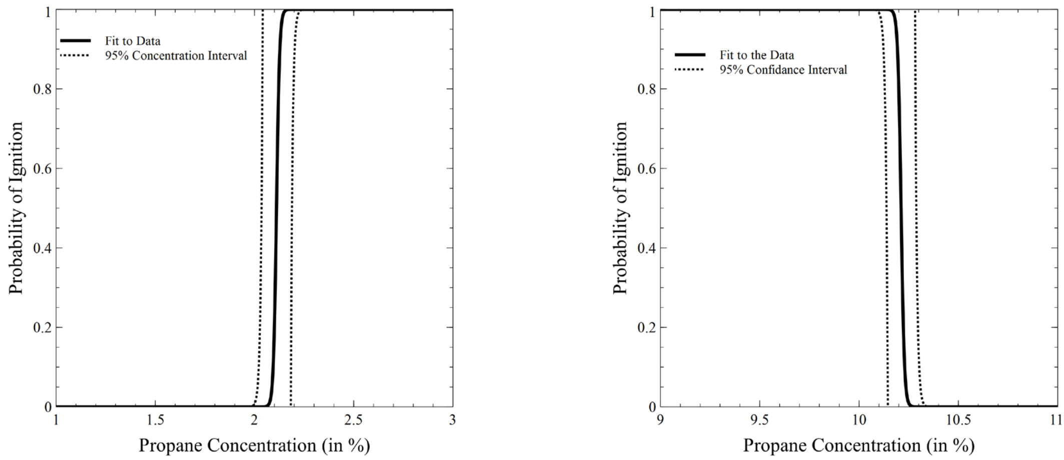


Figure 4: Logistic distribution function for propane flammability limit. Lower flammability limit (Left) and higher flammability limit (Right).

The experimental determination of flammability limit of Novec in propane/air mixture was done at stoichiometric fuel/oxidizer condition. The percentage of Novec in stoichiometric propane/air mixture was varied from 6 to 10.4 %. The uncertainty in the added Novec Concentration was 0.1% and in the equivalence ratio was 0.02. The definition of the flammability is same as that used in the propane condition. As the energy dissipation across the electrode is considerably high, shown in Figure 5, the Novec flammability could be positively ascertained to be 9.3±0.4% at 95% confidence interval for the mean dissipated energy of 296 mJ. The logistic distribution function for the flammability is shown in Figure 6.

We observed that at 9.5%, the flame that could increase the pressure by over 2% occurs only one in ten trials (having 2.1% rise). If the definition of the pressure rise for flammability is raised to 5% from 2%, the concentration of the Novec to inhibit the flame reduces to 9% from 10%. The overpressure observed in the experimental for various Novec concentration is shown in Figure 5. As seen in the figure, the overpressure reduces considerably even at 7.5%. However, for total inhibition, a concentration of 10% is desired. Schlieren images for three Novec concentrations at three distinguished time intervals is shown in Figure 7. The flame at 9.5% is weak, sustainable, and can act a pilot flame for any mixture at higher temperature ahead in the combustion region.

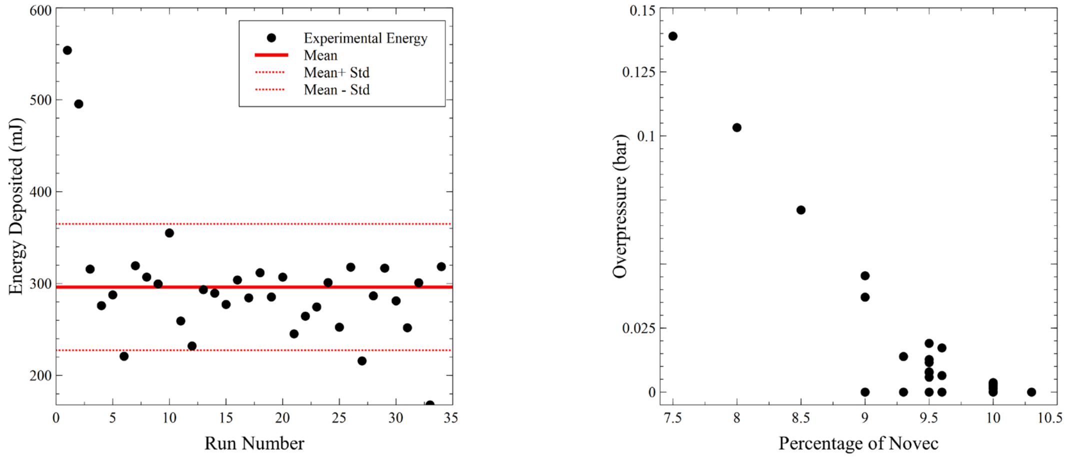


Figure 5: Energy Dissipated in Propane/Air/Novec experiments (Left) and Measured overpressure for different Novec concentration (Right).

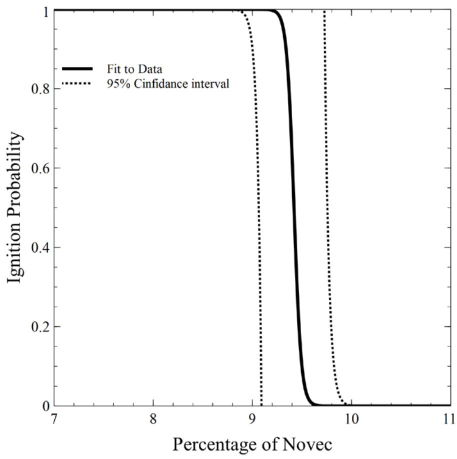


Figure 6: Logistic distribution function for Novec flammability limit in Propane/Air stoichiometric mixture.

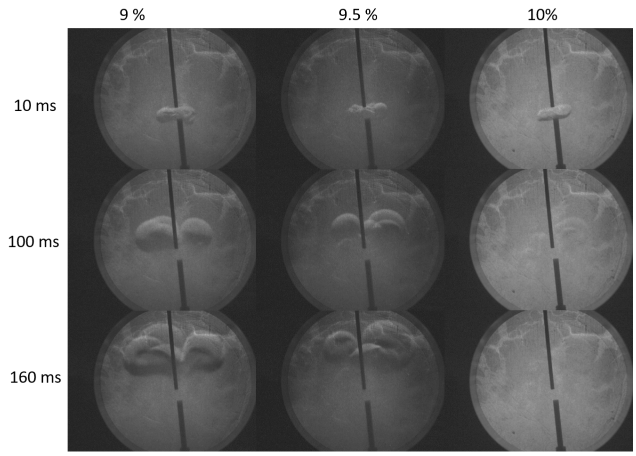
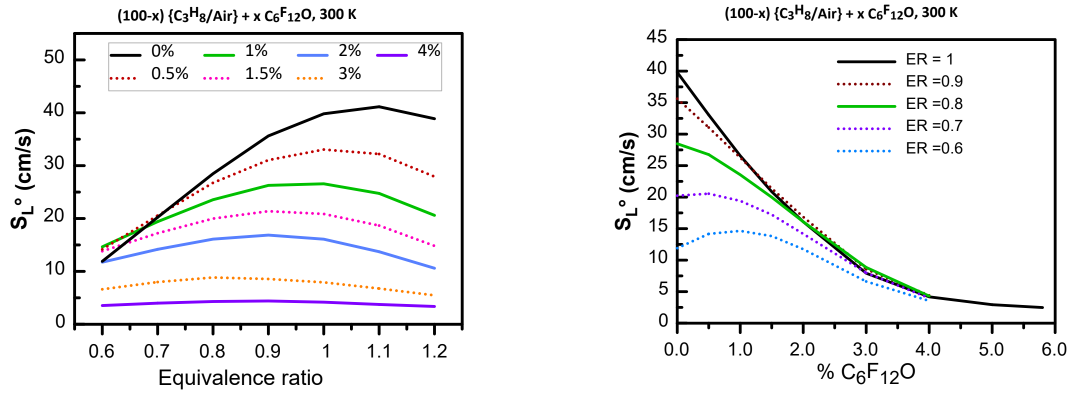


Figure 7: Schlieren images of the flame at three different times for three Novec concentration in stoichiometric propane/air mixture.

4 Numerical Studies

Numerical studies were carried out in Cosilab [6] using the mechanism from Linteris et al [7]. At an initial temperature of 300 K, the laminar flame speed has been simulated for an equivalence ratio from 0.6 to1.2 (Fig. 8a). As one can see the flame speed decreases when the Novec is added to propane when the equivalence ratio is larger than 0.7. For very lean mixtures, (ER=0.6 and 0.7) the addition of small amount of Novec (≤2%) the flame speed is enhanced in presence of Novec. This effect is better seen in Fig. 8b where the flame speed is reported versus the amount of Novec at different equivalence ratios.



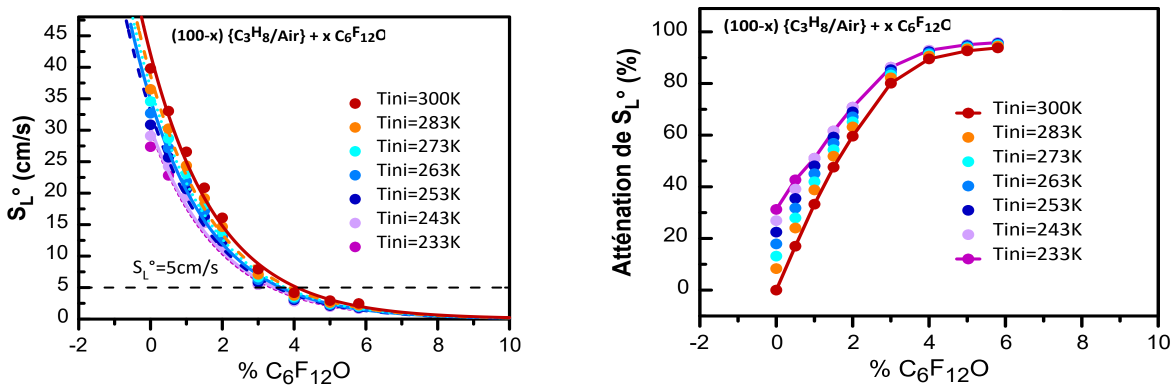
(a) (b)

Figure 8: (a) Computed laminar flame speed versus equivalence ratio for different Novec concentrations (b) Computed laminar flame speed versus Novec concentration at different equivalence ratios.

The enhancement of the combustion due to the low amount of Novec is problematic as it has the opposite effect. If Novec is used and it is not well-distributed when sprayed to inhibit the combustion, the consequences would be the opposite of what is needed.

Moreover, since the flammability limit has been measured for propane, the simulated flame speed at the flammability limit was found to be 5 cm/s based on the detailed kinetic mechanism used in this study. So, this value is used to define the condition for which it is unlikely to obtain a sustainable flame associated with a pressure increase.

Since the behavior of Novec should be assessed at flight conditions, the effect of an initial temperature below he ambient one on the flame speed must be investigated. The calculated flame velocities at various temperatures with different initial Novec concentrations is shown in Figure 9(a) and the attenuation is shown in 9(b).



(a) (b)

Figure 9: (a) Computed laminar flame speed for different Novec concentration at various temperature and (b) attenuation at various temperature.

The main results are:

- the laminar flame velocity decreases exponentially with the addition of the inhibiting agent at all initial temperatures between 233 and 300 K;
- the lower the temperature, the greater the attenuation

- the laminar flame speed is lower than 5 cm/s for a minimum content of 4% of Novec, whatever the initial temperature between 223 and 300 K.

Conclusion

In this paper, new results on the inhibiting effect of adding Novec to propane has been investigated experimentally through the determination of flammability limits, and numerically via the laminar flame speed using the available mechanism of the literature. First the flammability limits have been measured for propane/air mixtures in a closed cylindrical vessel (NC2V) using both pressure measurements and high-speed imaging. The inerting point using Novec has been measured at 300 K and 1 bar initial conditions. It was found that 9.3% of Novec is needed to suppress any combustion of stoichiometric propane/air mixtures. The simulation of laminar flame speed of Propane/Novec/air mixtures has been conducted over a large domain in terms of equivalence ratio (0.6 to 2) and Novec content (from 0.5% to 6%).

Acknowledgement

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References

[1] Casey, Jeremy, (2019). Full-scale evaluation of novec™ 1230. DOT and FAA report number DOT/FAA/TC-19/27

[2] J. W. Reinhardt, Aircraft cargo MPS test of FK-5-1-12, in: International Aircraft Systems Fire Protection Working Group, October 25-26, 2006, Atlantic City, NJ, 2006, Federal Aviation Administration

[3] J. W. Reinhardt, Behavior of bromotrifluoropropene and pentafluoroethane when subjected to a simulated aerosol can explosion, Report No. DOT/FAA/AR-TN04/4, Federal Aviation Administration, Washington, D.C., USA, 2004.

[4] Xu, W., Jiang, Y., Ren, X. (2016). Combustion promotion and extinction of premixed counterflow methane/air flames by C6F12O fire suppressant. J. Fire Sci. 34: 289.

[5] Linteris, G. T., Pagliaro, J. L. (2016). Burning Velocity Measurements and Simulations for Understanding the Performance of Fire Suppressants in Aircraft. National Institute of Standards and Technology, US Department of Commerce : Washington, DC, USA.

[6] Cosilab combustion simulation laboratory manual, version 2.0

[7] Linteris, G.T., Babushok, V.I., Sunderland, P.B., Takahashi, F., Katta, V.R.,Meier, O., (2013). Unwanted combustion enhancement by C6F12O fire suppressant. Proc Combust Inst. 34:2683.