

Ignition Characteristics of Alternative JP-8 and Surrogate Fuels under Vitiated Conditions

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Atmospheric pressure flow reactor experiments were performed to investigate the ignition characteristics of Fischer-Tropsch and hydrotreated renewable JP-8 fuels under vitiated conditions in order to compare these properties to conventional JP-8. Ignition experiments were conducted with reactor temperatures between 832 K and 917 K with standard air as well as vitiated air with 17% O₂ and NO_x levels varied between 0 and 755 ppmv. Experiments were also performed with jet fuel surrogate components such as n-dodecane and iso-octane to investigate the ignition behavior of normal- and iso-paraffins, respectively. Experimental measurements show that the presence of NO_x in the oxidizer stream reduces the ignition delay time of jet fuels and surrogates significantly. Furthermore, the effect of NO_x on iso-octane ignition delay time is more pronounced than for n-dodecane. Surrogate kinetic modeling results are also compared with the experimental data regarding the effect of NO_x. Overall, the modeling results agree with trends observed for the effect of NO_x on ignition delay time. However, the ignition delay time predictions for Sasol-IPK are much longer than the experimental data. This is due to the fact that the representation of iso-paraffinic components in Sasol-IPK is not correctly represented by iso-octane alone.

Nomenclature

Φ or Φ_i	-	fuel-air equivalence ratio: $(\text{fuel/air})/(\text{fuel/air})_{\text{stoich}}$
ρ	-	mass density [kg/m ³]
DCN	-	derived cetane number
TSI	-	threshold sooting index
H/C Ratio	-	hydrogen to carbon molar ratio
MW	-	molecular weight [g/mol]
FT	-	Fischer-Tropsch fuels
HRJ	-	hydrotreated renewable jet fuels
PMT	-	photomultiplier tube
IDT	-	ignition delay time

I. Introduction

Vitiated air refers to a high-preheat oxidizer stream with recycled combustion products used in various devices to reduce emissions [1,2], improve flame stability [3], improve combustion efficiency [4,5], or to achieve high-enthalpy hypersonic flight conditions at ground level [6]. The presence of combustion products in the inlet oxidizer stream has been found to influence the combustion chemistry of hydrocarbon fuels. In particular, the presence of NO_x has an effect on induction chemistry [7,8,9], and CO₂ and H₂O affect the flame propagation [7,10]. A previous study applying a three-level fractional factorial design of experiments by the authors [8] demonstrated that the presence of NO_x in the vitiated air has significant influence on the ignition delay time of JP-8. A seven-variable, three-level Box-Behnken design of experiments was performed to investigate the effect of vitiation on JP-8 ignition between 950 K and 1125 K [8]. The experimental variables were temperature, equivalence ratio, and vitiated air

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composition (i.e., O₂, H₂O, CO, CO₂, and NO_x). The summary of the experimental results in Figure 1 shows that NO_x and O₂ each play a significant role on the ignition of JP-8 at these conditions in addition to temperature. The positive and negative values for NO_x and O₂, respectively, indicate that increasing NO_x reduces the ignition delay time while reduced O₂ in the oxidizer increases it.

Previous flow reactor ignition delay time measurements [8,9] showed that a small amount of NO_x (50-900ppm) can significantly reduce the ignition delay time of JP-8 under atmospheric and sub-atmospheric pressure conditions. The primary objective of the current work is to investigate the effect of NO_x on alternative JP-8 fuels produced from natural gas via the Fischer-Tropsch (FT) process and from fatty oils via hydrotreatment techniques (forming renewable jet (HRJ) fuels). Experiments were also performed with typical surrogate components of jet fuels: n-dodecane and iso-octane.

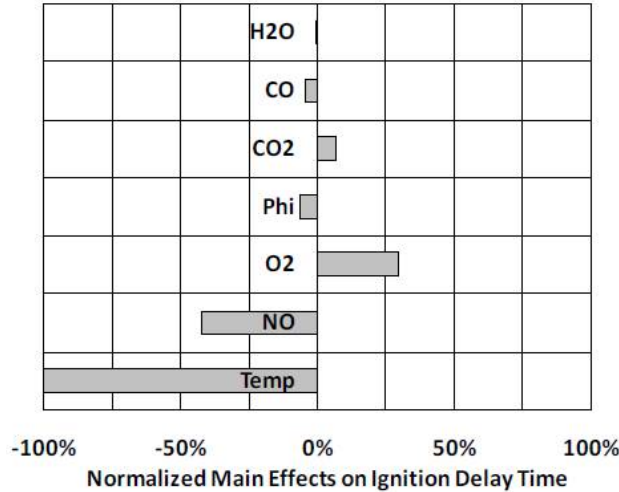


Figure 1. Main effects of experimental variables on ignition delay time of JP-8. Effects are normalized based on the effect of temperature. (adopted from Fuller et al. [8]).

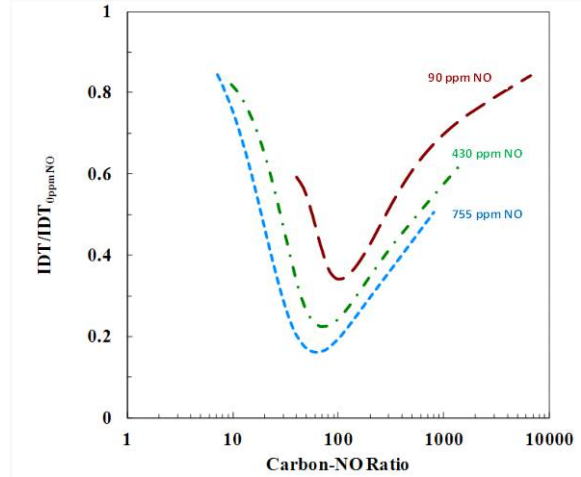


Figure 2. Normalized ignition delay time versus carbon-NO molar ratio for stoichiometric propane/O₂/NO/N₂ mixture at 875 K and 1 atm (adopted from Gokulakrishnan et al. [7]).

Several experimental studies of the effect of NO_x on natural gas fuel components have been reported in the literature, and a detailed review of this can be found elsewhere [7]. Most of the experimental conditions used in the previous works were performed using heavily diluted fuel/oxidizer mixtures, and hence, the carbon to NO ratio in these studies were less than is found in typical combustion devices. The experimental and modeling study of Gokulakrishnan et al. [7] showed that the carbon to NO ratio plays a significant role in determining the reaction pathways of propane ignition. Figure 2 shows modeling results [7] demonstrating the influence of carbon to NO ratio on the reduction in propane ignition delay time at 875 K and 1 atm. The effect of NO to promote ignition increases as the carbon to NO molar ratio is increased until it reaches a turn-over point. The effect of NO in reducing the ignition delay time diminishes as the carbon to NO molar ratio is further increased beyond the turn-over point as shown in Figure 2.

The experimental and modeling results [7] found that the chemical kinetics effect of NO_x to promote fuel oxidation stems from the interaction between NO_x and less reactive radical species such as HO₂, CH₃ and CH₃O₂. In the low- and intermediate-temperature oxidation regimes, a chain-terminating reaction (R1) is favored over a chain-branching reaction (R2). However, when NO is present, the relatively less reactive hydroperoxy radical (HO₂) is converted to OH radical via reaction (R3). The NO₂ generated in reaction (R3) converts CH₃ into CH₃O and NO via (R4), while relatively less reactive CH₃O₂ is converted to more reactive CH₃O radicals via (R5).



It was shown [7] that H-atom abstraction from the fuel molecule by NO₂ also plays a critical role in promoting hydrocarbon fuel oxidation under high carbon to NO ratios (i.e., right-hand side branch of the curves in Figure 2) via reactions (R6) and (R7).



HNO₂ species formed in reaction (R6) will quickly be converted to HONO via reaction (R8), while HONO will decompose into NO and OH via (R9).



Reactions (R3) to (R9) form a chemical catalytic cycle to promote the oxidation of hydrocarbon fuels at low- and intermediate temperatures.

II. Experiments

In the current work an atmospheric pressure flow reactor facility is used to measure the ignition delay time of JP-8 and its alternatives at various conditions. A premixing section, shown in Figure 3, consists of a swirler to achieve near-perfect mixing of fuel and oxidizer streams at the inlet of the flow reactor. The downstream portion of the premixing section is a gradually expanding duct that connects to the test section, a long ceramic alumina tube with an internal diameter of 5 cm. The test section is heated and insulated to maintain a uniform reactor temperature up to 1200 K using with three independently controlled electric zone heaters. The total mass flow rate of the oxidizer stream was maintained at ~2.0 g/s for each test condition in this study, and the fuel flow was varied depending on the desired equivalence ratio. The oxidizer stream is pre-heated prior to mixing with the fuel stream in order to maintain the same inlet temperature of the fuel/oxidizer mixture as in the test section. The liquid fuel is prevaporized under a nitrogen environment at 650 K before mixing with the oxidizer stream. The fuel stream is radially injected into the oxidizer stream prior to passing through a swirled, annular mixing section as shown in Figure 3. The well-mixed fuel and oxidizer streams enter the diffuser section and then the test section.

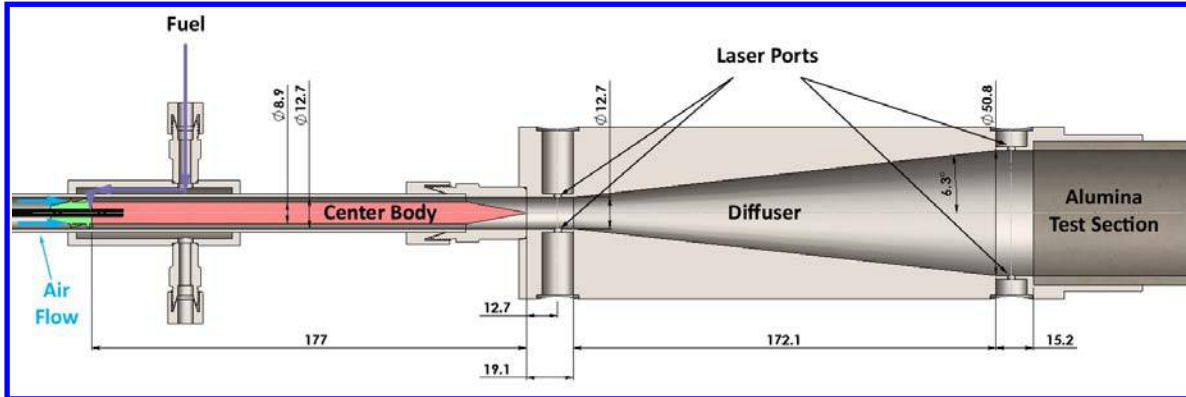


Figure 3. Schematic of the fuel/oxidizer premixing section of the flow reactor apparatus. Dimensions are in millimeters

A laser absorption technique to monitor the fuel injection system was installed at the inlet of the diffuser section to monitor the time of injection of the fuel into the flow reactor. An infrared beam at 3.39 μm supplied by a HeNe laser is directed across a diameter of the flow channel through quartz optical ports in the diffuser (see Figure 3). A photodiode measures the intensity of the transmitted beam. When the laser beam passes through a medium that contains a hydrocarbon fuel, the signal is attenuated due to the absorption of the laser by the C-H bonds in the fuel. This attenuation denotes the presence of fuel entering the diffuser and is used to determine the actual start time for timing the autoignition of the fuel/oxidizer mixture. The start time used to measure the ignition delay time of the mixture is the time at which the laser signal attenuates to 50% of the difference between the maximum and minimum measured signals during fuel injection. The time of ignition is measured by the detection of the chemiluminescence signal of OH* emission that occurs during ignition. A photomultiplier tube (PMT) is located at the downstream end of the flow reactor with direct line of sight along the axis of the test section through a quartz window. The PMT is equipped with a 310 nm narrow band pass filter (± 5 nm) to observe OH* chemiluminescence

emission. The ignition delay time values reported in this work are designated as the difference between the time recorded to mark 50% attenuation in the pre-diffuser laser signal (which denotes the fuel/air mixture entrance into the diffuser) and the time of PMT excitation due to the chemiluminescent radical emission of OH*. A detailed description of the flow reactor set-up can be found elsewhere [7,9,11].

The primary objective of the current work is to investigate the effect of vitiation on alternative JP-8 fuels relative to conventional JP-8. The chemical composition of typical vitiated air consists of combustion products such as CO₂, H₂O, CO and NO_x under reduced O₂ levels. Previous work by the authors [8,9] showed that NO_x and O₂ had significant impact on the induction chemistry of JP-8 compared to other vitiated species such as CO₂ and H₂O. Therefore, in the current work, experiments were performed by varying NO and O₂ concentrations in the oxidizer stream along with temperature and equivalence ratio to study the effect of vitiation on the autoignition of alternative JP-8 fuels relative to conventional JP-8. Four different alternative JP-8 fuels and one conventional JP-8 were chosen for the experiments. The alternative fuels include two Fischer-Tropsch fuels (i.e., Shell-SPK and Sasol-IPK) produced from natural gas and two hydro treated renewable jet fuels (i.e., HRJ-Camelina and HRJ-Tallow) produced from biodiesel. The chemical and physical properties of these fuels are listed in Table I. Figure 4 shows the chemical class compositions, namely, normal-paraffins, iso-paraffins, cyclo-paraffins and aromatics, which comprise these fuels. It can be noted that the Shell-SPK, HRJ-Camelina and HRJ-Tallow mainly consist of normal- and iso-paraffins (> 95%) with nearly identical DCN values, while the Sasol-IPK consists almost entirely of iso-paraffins (> 95%) which leads to the lowest DCN.

Table I: Properties of the fuels used in the current work

Jet Fuel Type	Air Force POSF #	Density ^a [kg/m ³]	DCN ^b	TSI ^b	H/C Ratio ^b	MW ^b [g/mol]	Molecular Formula ^b
JP-8	6169	785	47.3	19.28	2.02	153.9	C _{11.0} H _{22.1}
Sasol IPK	7629	739	31.3	17.28	2.20	149.2	C _{10.5} H _{23.0}
Shell SPK	5729	730	58.4	9.11	2.24	136.7	C _{09.6} H _{21.4}
HRJ Camelina	7720	752	58.9	11.99	2.20	165.0	C _{11.6} H _{25.5}
HRJ Tallow	6308	748	58.1	11.58	2.18	161.0	C _{11.3} H _{24.7}

a – Edwards [12]; b – Won et al.[13]

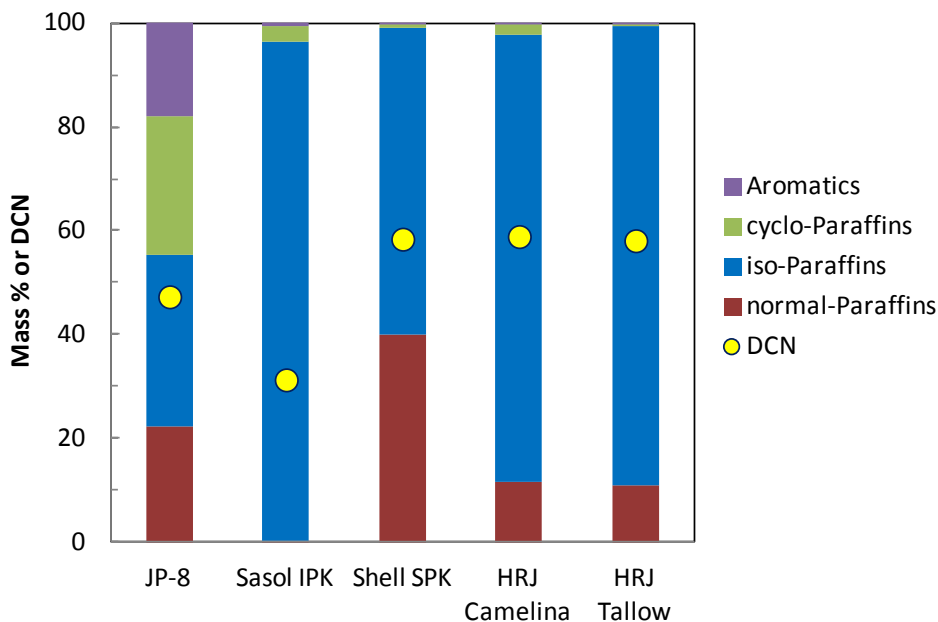


Figure 4. Chemical class composition (in mass %) [12] of the jet fuels listed in Table I along with DCN (circles) [13].

Figure 5 compares the distribution of normal- and iso-paraffin species present in the alternative fuels with that of the conventional JP-8. The carbon number distribution in Figure 5 indicates that FT fuels have narrower distribution, while HRJ fuels have a broader range compared to JP-8. For example, more than 90% of the constituents in the FT fuels account for isomers between C_9 and C_{13} , whereas more than 90% of the HRJ fuels is made up of iso- and normal-paraffins between C_8 and C_{17} . The variability in the carbon number distribution is reflected in the molecular weights. FT and HRJ fuels have lower and higher molecular weights, respectively, than JP-8 as shown in Table I.

Ignition delay time experiments were performed under vitiated conditions for each fuel listed in Table I. Extensive experiments were also performed to study the effect of vitiation on n-dodecane and iso-octane, which are two of the primary surrogate components to model the alternative fuels. The reactor temperature was maintained at 832 K, 875 K or 917 K, while the fuel/oxidizer equivalence ratio was varied between 0.5 and 1.5. The O_2 level in the oxidizer stream was set to 14, 17 or 20 mol %, while the NO_x concentration was varied between 0 and 755 pmmv.

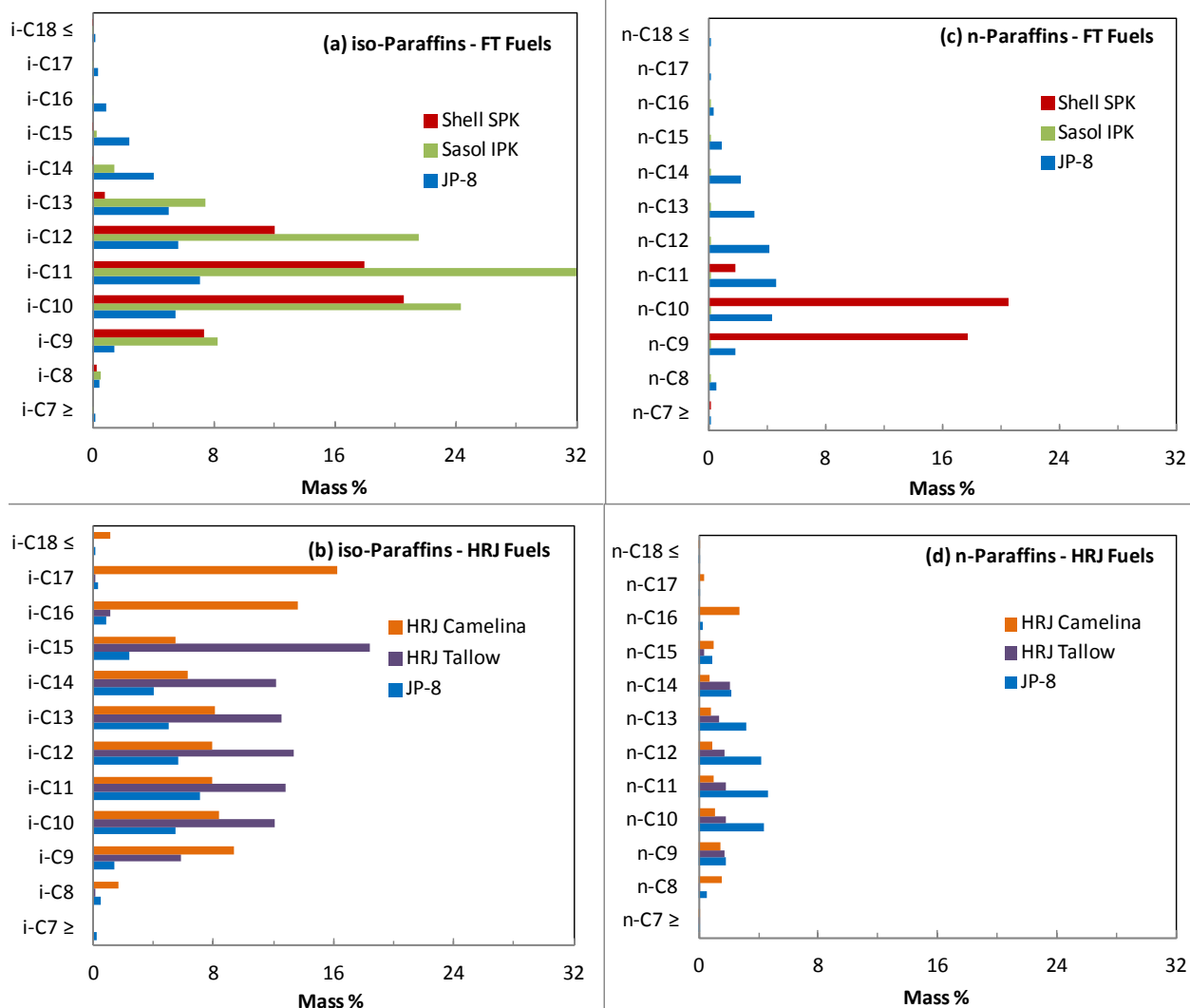


Figure 5. iso- and normal-Paraffin species composition of the alternative fuels listed in Table I are compared with JP-8 [12].

III. Chemical Kinetics Modeling

A five-component surrogate kinetic mechanism for jet fuel combustion is used to model the ignition characteristics of JP-8 and its alternative fuels. The current detailed reaction mechanism is based on an improved version of the surrogate kinetic model previously reported by authors that primarily consists of n-decane ($n\text{-C}_{10}\text{H}_{22}$), n-propylcyclohexane (C_9H_{18}), and n-propylbenzene (C_9H_{12}) to represent paraffins, naphthenes and aromatics, respectively [14]. In the current model, additional surrogate components, namely, n-dodecane ($n\text{-C}_{12}\text{H}_{26}$) and iso-octane ($i\text{-C}_8\text{H}_{18}$) are included to better represent the normal- and iso-paraffin components, respectively, that are present in typical jet fuels, including the alternative fuels shown in Figure 5. Moreover, the current surrogate kinetic mechanism also consists of a detailed nitrogen sub-mechanism that can predict the effect of NO_x (typically present in vitiated air) on ignition at low- and intermediate-temperatures as well as emissions from high-temperature flames. This surrogate kinetic mechanism was validated for a wide range of conditions using the experimental data obtained in the current work as well as various literature data for individual surrogate components. A detailed model description and validation of NO_x emissions from high-temperature combustion and the role of NO_x on vitiated combustion at low- and intermediate-temperatures can be found elsewhere [7,15,16].

The reaction sub-mechanism for the iso-octane used in the current model is a reduced version of the detailed kinetic mechanism of Curran et al. [17], and the model validation was reported elsewhere [18]. A detailed kinetic mechanism for n-dodecane is developed in the current work using a similar approach used for n-decane in the previous work [14,19]. Most of rate parameters for the low-temperature chemistry were estimated using the values recommended by Curran et al. [17] and Miyoshi [20] via the group additivity method [21,22]. The model has been validated for various experimental data from the literature.

The vitiated kinetics sub-mechanism, especially the interaction between NO_x and the smaller hydrocarbon species ($<\text{C}_4$), were adopted from Refs. [7,23]. Previous experimental and modeling work [7] on the effect of NO_x on propane showed that the H-atom abstraction of fuel molecules by NO_2 via (R6) and (R7) plays a critical role in vitiated combustion. A reaction subset for H-atom abstraction by NO_2 from n-decane, n-dodecane, iso-octane, n-propylcyclohexane and n-propylbenzene has been included in the current vitiated kinetic sub-model. The reaction rate parameters were estimated by the group additivity method using the theoretical rates recommended by Chan et al. [24], and optimized for the current experimental conditions.

Figure 6 shows the present surrogate kinetic model predictions for ignition delay times of n-dodecane and Jet-A compared with the shock tube experimental measurements of Vasu et al. [25,26]. The present kinetic model agrees fairly well with the experimental data including the NTC behavior. The ignition delay time shown in Figure 6 for Jet-A was computed using a surrogate mixture composition of 35.9 mol% n-dodecane, 33.6 mol% iso-octane and 30.5 mol% n-propylbenzene.

Table II shows the surrogate compositions used in the current work for various jet fuels listed in Table I. There are various approaches to formulate the surrogate mixture composition [27,28,29,30]. In the current work, the method proposed by Dooley et al. [28] is adapted for the surrogate mixture formulation in which the DCN, H/C ratio and TSI of the actual fuel (listed in Table I) are matched with the model fuel mixture listed.

Table II: Surrogate mixture composition (in mole %) and properties

Surrogate	JP-8	Sasol IPK	Shell SPK	HRJ Camel.	HRJ Tallow
n-decane	0.0	0.0	74.6	0.0	0.0
n-dodecane	38.2	16.0	4.5	61.1	59.5
iso-octane	37.2	64.7	12.2	29.2	31.5
propyl-benzene	24.6	19.3	8.7	9.6	9.0
H/C	2.00	2.05	2.13	2.12	2.12
DCN	48.1	31.8	58.2	60.0	59.0
TSI	18.3	15.7	9.1	11.4	11.0
MW (g/mol)	137.1	124.3	138.2	149.1	148.1

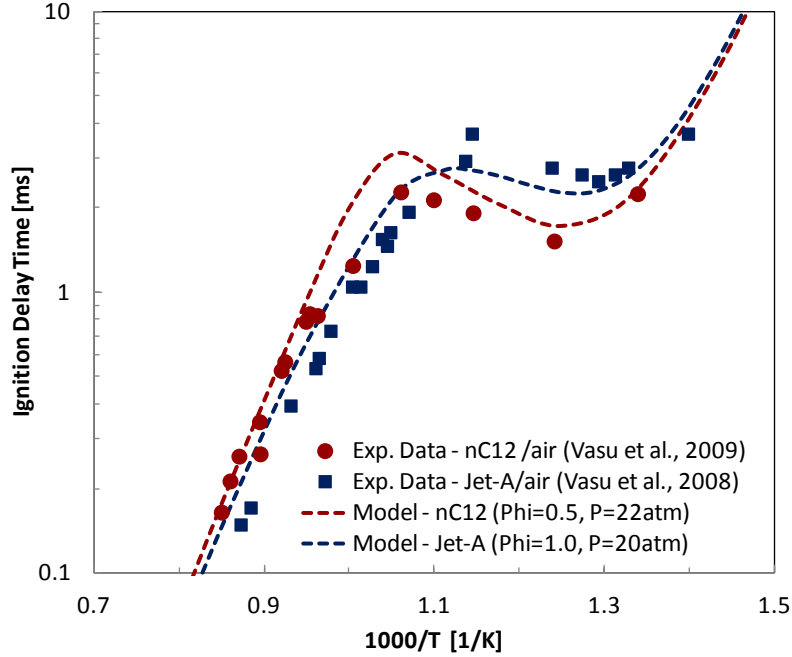


Figure 6. Shock tube ignition delay time measurements of Vasu et al. [25,26] for n-dodecane and Jet-A compared with current surrogate kinetic model.

IV. Results and Discussion

Figure 7 compares the measured ignition delay time of stoichiometric fuel/air mixtures for FT and HRJ fuels with that of JP-8 obtained in the current work in the absence of NO_x . The overall activation energies based on the ignition delay time in Figure 7 are listed in Table III. The experimental data show that Shell-SPK has very similar ignition delay time as the JP-8 with almost the same activation energy. However, Sasol-IPK has very different ignition delay time profile compared to JP-8 and Shell-SPK with the largest overall activation energy among the fuel studied. For example, Sasol-IPK has lower ignition delay time than JP-8 at 917 K, while the opposite trend is seen at 832 K. Moreover, both HRJ fuels have longer ignition delay time than JP-8 across the temperature range investigated. It is noteworthy that Sasol-IPK has a lower DCN than JP-8, while both HRJ fuels have higher DCN than JP-8 (see Figure 4). DCN is a measure of the ignition quality of fuels based on the ASTM 6890 method [31], in which ignition delay time of liquid fuels are measured using ignition quality test (IQT) meter at diesel engine conditions (i.e., 22 atm and 833 K [28]).

Table III: Overall activation energy from the experimental data shown in Figure 7

Jet Fuel	kcal/mol
JP-8	30.90
Sasol IPK	40.40
Shell SPK	30.78
HRJ Camelina	31.49
HRJ Tallow	33.11

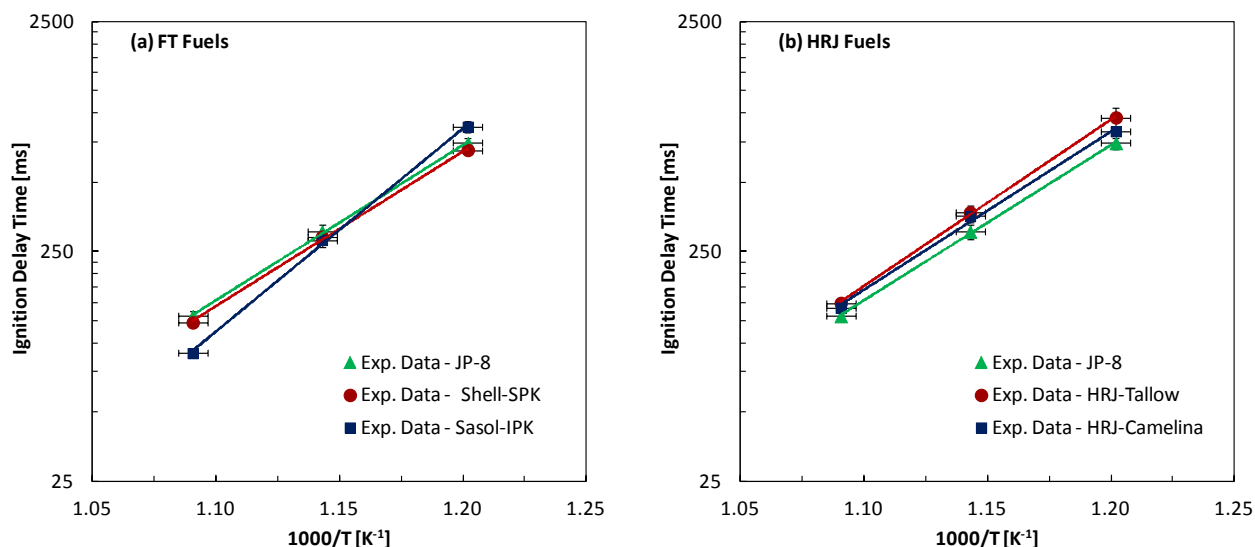


Figure 7: Ignition delay times of alternative jet fuels compared with JP-8 fuel.
Symbols – experimental data, lines – least square fit.

Figure 8 shows the effect of NO_x on the ignition delay time experimental data for stoichiometric n-dodecane/oxidizer mixtures at various nominal reactor temperatures (i.e., 832 K, 875 K and 917 K) and various O_2 levels in the oxidizer stream (14 mol %, 17 mol % and 20 mol %). Similar experiments were also performed for stoichiometric iso-octane/oxidizer mixtures with NO_x addition as shown in Figure 9. As expected, iso-octane has a longer ignition delay time than n-dodecane at similar conditions. Experimental data shows that addition of NO_x reduces the ignition delay time significantly for both n-dodecane and iso-octane. For example, 430 ppm NO_x reduced the ignition delay time of n-dodecane by ~65 % at 875 K and 20 mol % O_2 , whereas the reduction is ~75 % for iso-octane at similar conditions. It can also be noted that the reduction in ignition delay time is more pronounced at lower O_2 levels as shown in Figure 8(b) and Figure 9(b).

Figure 8 and Figure 9 also compare the experimental data with the chemical kinetic modeling results for n-dodecane and iso-octane, respectively. Overall, the current model predicts the effect of NO_x on n-dodecane reasonably well. However, the model needs further improvement to accurately predict the effect of O_2 on ignition delay time. The modeling results for iso-octane in Figure 9 predict the trends for the effect of NO_x on ignition delay time. The model consistently predicts longer ignition delay time than the experimental values.

Experiments were performed to study the effect of NO_x on jet fuel ignition delay time at 875 K with 17 mol % and 20 mol % O_2 . Figure 10 shows the experimental data of JP-8, Shell-SPK, Sasol-IPK and HRJ-Tallow for stoichiometric fuel/oxidizer mixtures as a function of NO_x . The experimental data show that Sasol-IPK has shorter ignition delay time compared to other jet fuels at 875 K, despite the fact that Sasol-IPK has the lowest DCN among the jet fuels tested (see Figure 4). However, the trends for the effect of NO_x on jet fuel ignition delay time are very similar to n-dodecane. For example, 430 ppm NO_x addition reduced the ignition delay time by ~65% on average at 875 K and 20 mol % O_2 . Figure 10 also compares the experimental data with the jet fuel surrogate kinetic model predictions. The ignition delay times for JP-8, Shell-SPK, Sasol-IPK and HRJ-Tallow were computed using the surrogate mixture composition provided in Table II.

Overall, the model predicts the effect of NO_x on ignition delay time reasonably well except for Sasol-IPK. The surrogate mixture composition of Sasol-IPK consists of 64.7 mol% iso-octane, 19.3 mol % n-propylbenzene and 16 mol% n-dodecane that matches DCN of the actual fuel shown in Table I. However, the chemical class composition break-down shown in Figure 4 indicates that Sasol-IPK is made-up of more than 95 % iso-paraffins. Alternatively, a surrogate mixture with 82 mol % iso-octane and 18 mol % n-dodecane would produce an estimated DCN of 31, and a H/C ratio of 2.23. Figure 11 shows the ignition delay time of 82 % iso-octane/18 % n-dodecane surrogate mixture as a function of NO_x addition at 875 K. It can be noted the ignition delay time of this surrogate mixture is much longer than Sasol-IPK at 0 ppm NO , although the estimated DCN and H/C is similar to the Sasol-IPK. The experimental data in Figure 11 show that the ignition delay time of Sasol-IPK is closer to n-dodecane than iso-octane. Therefore, representation of iso-paraffinic components in Sasol-IPK is not correctly characterized by iso-octane alone, and work is in progress to identify alternate iso-paraffinic model fuels.

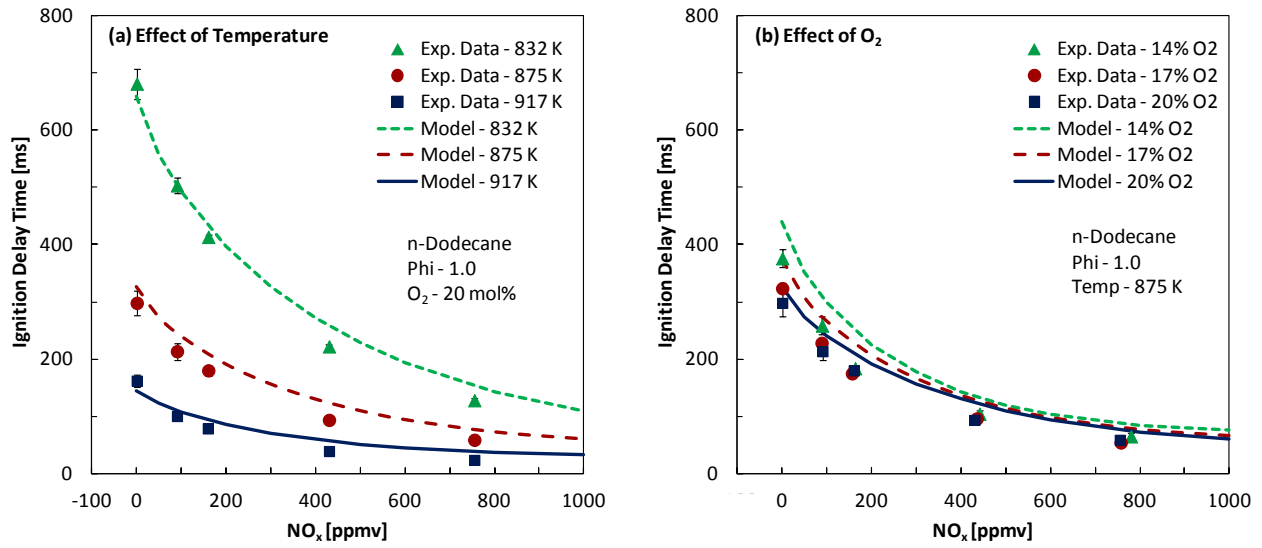


Figure 8: n-Dodecane ignition delay time: (a) effect of temperature; (b) effect of O₂. Symbols – experimental data; lines – modeling results.

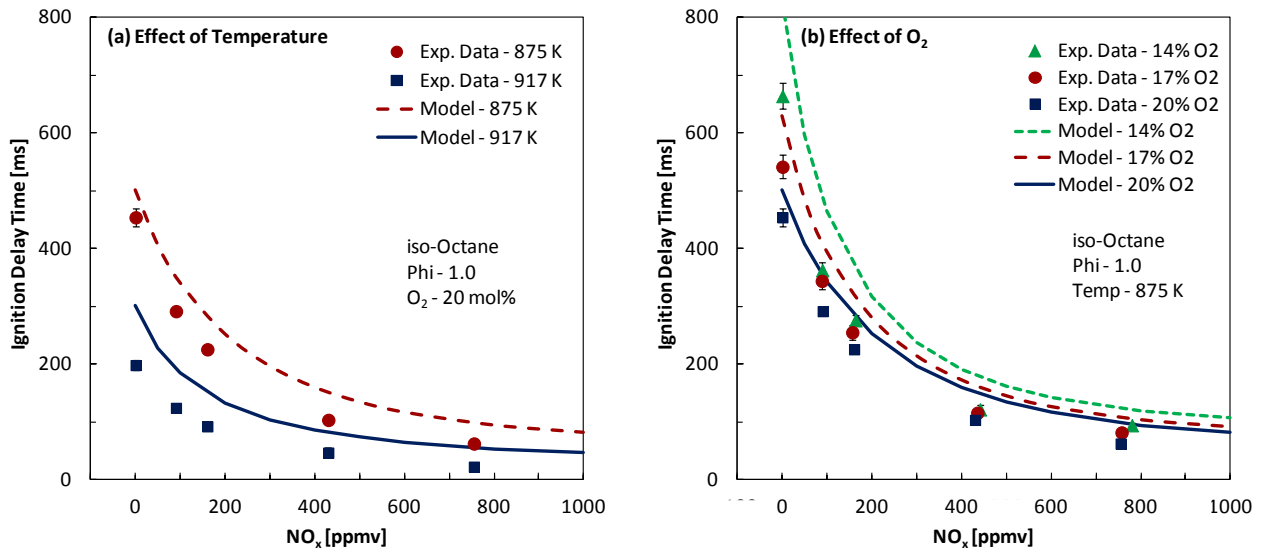


Figure 9. iso-Octane ignition delay time: (a) effect of temperature; (b) effect of O₂. Symbols – experimental data; lines – modeling results.

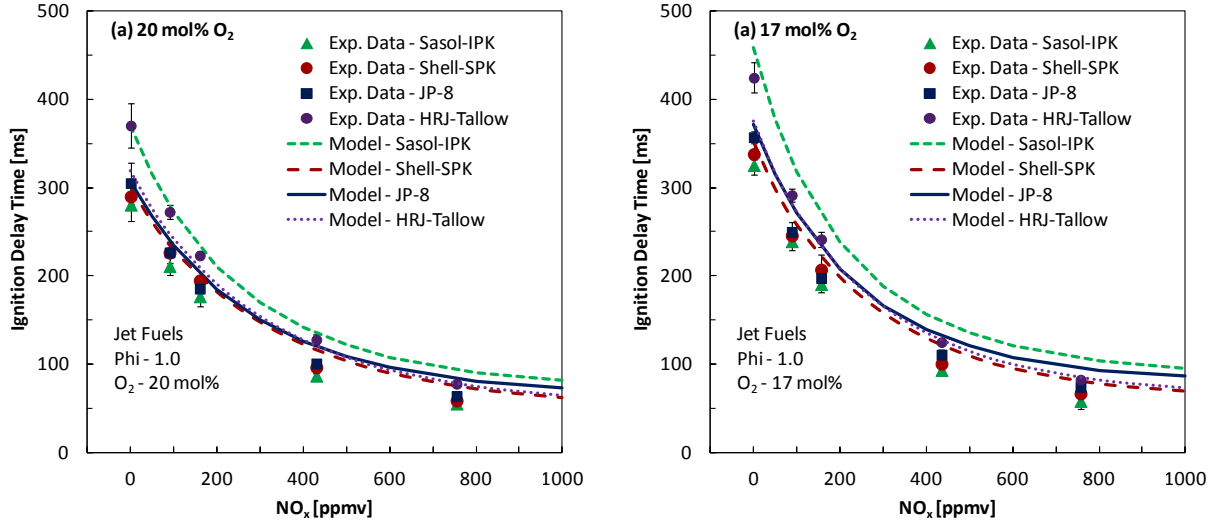


Figure 10. Ignition delay time for JP-8, FT and HRJ fuels: (a) 20 mol% O₂; (b) 17 mol% O₂. Symbols – experimental data; lines – modeling results.

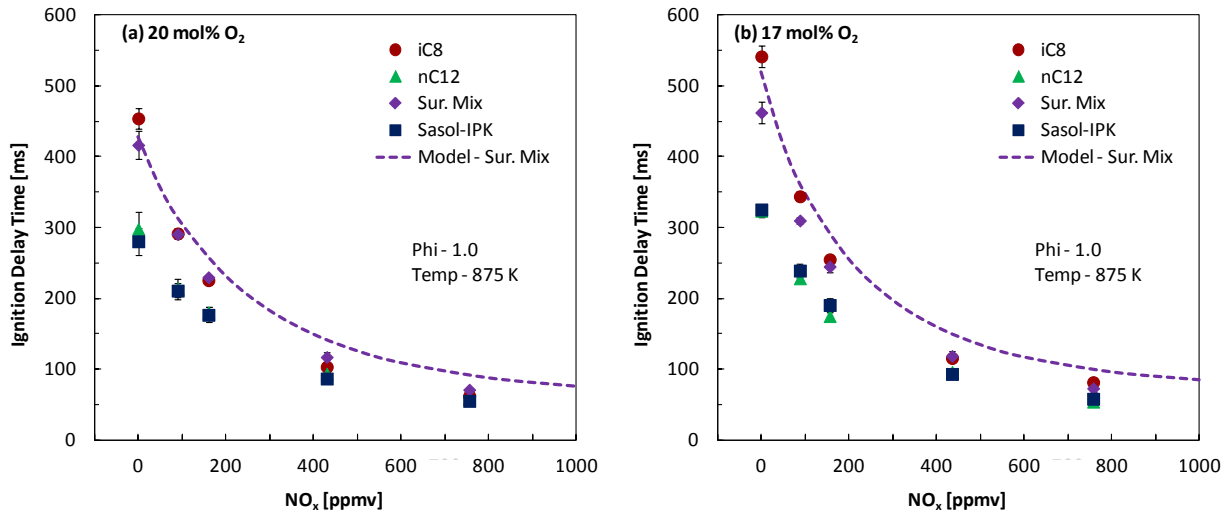
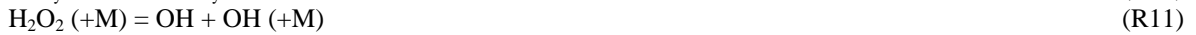


Figure 11. Ignition delay time for 82 mol% iso-octane and 18 mol% n-dodecane (denoted by Sur. Mix) compared with Sasol-IPK, n-dodecane and iso-octane: (a) 20 mol% O₂; (b) 17 mol% O₂. Symbols – experimental data; lines – modeling results for 82 mol% iso-octane and 18 mol% n-dodecane.

Figure 12 shows the normalized sensitivity coefficients of the important reactions that are responsible for the promotion of ignition of jet fuels with NO_x addition. The sensitivity coefficients were computed for stoichiometric fuel/air mixtures of n-dodecane and iso-octane with and without 500 ppm NO at 875 K and 1 atm. A sensitivity analysis was also performed for a mixture of 67 mol% n-dodecane/33 mol% iso-octane with 500 ppm NO at these conditions. The three most sensitive reactions for the oxidation of fuel molecules in the absence of NO are:



These reactions indicate that oxidation occurs under intermediate temperature regimes where the HO₂ radical formed in reaction (R1) reacts with the fuel molecules to produce an alkyl radical (C_xH_{y-1}) and H₂O₂ via (R10). In

addition, H_2O_2 is also formed via a bimolecular recombination reaction (R12). H_2O_2 then undergoes unimolecular decomposition to produce OH radicals via reaction (R11).

When 500 ppm NO is added, reaction (R4) becomes the single most sensitive reaction with respect to all three fuels shown in Figure 12. When NO is present, the relatively less reactive HO_2 radical formed in reaction (R1) is converted to OH via (R3). In the process, NO is converted to NO_2 , which in turns reacts with CH_3 to form CH_3O while converting NO_2 back to NO in reaction (R4). In addition, NO_2 generated in reaction (R3) reacts with fuel molecules to form alkyl radicals and HONO via reaction (R7). Then, HONO undergoes unimolecular decomposition to produce OH radicals and NO via reaction (R9). In addition, HONO is also generated by the decomposition of HNO_2 formed in reaction (R6).

The comparison of the experimental data in Figure 8 and Figure 9 shows that the effect of NO_x in reducing the ignition delay time is more pronounced for iso-octane as compared to n-dodecane. This is due the fact that highly-branched paraffinic molecules, such as iso-octane, have a higher number of CH_3 groups compared to normal-paraffins. Therefore, iso-octane generates a higher concentration of CH_3 intermediates, which in turn helps to increase the sensitized oxidation of NO_x via reaction (R4).

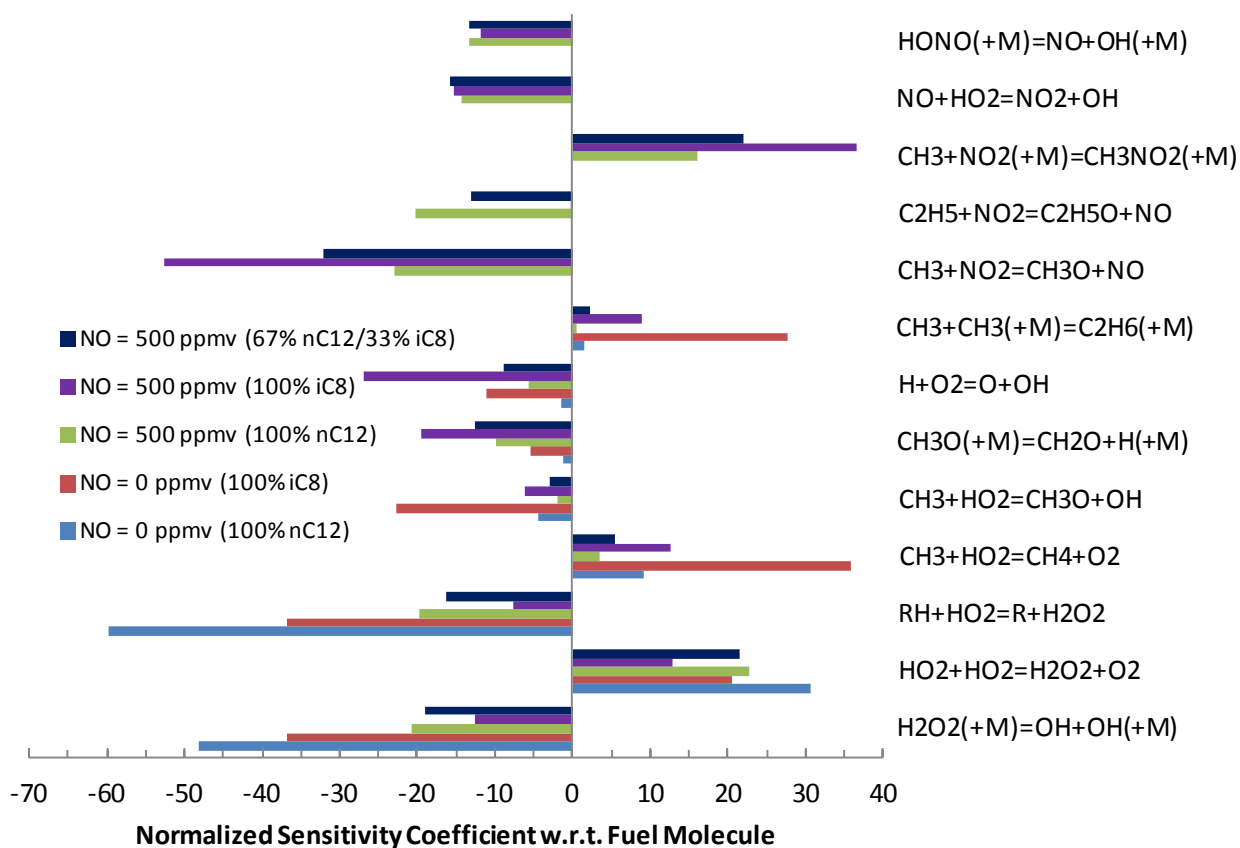


Figure 12. Normalized sensitivity coefficients for stoichiometric fuel/air mixtures of neat n-dodecane (nC_{12}), neat iso-octane (iC_8) and 67 mol% nC_{12} / 33 mol% iC_8 at 875 K and 1 atm with and without NO.

V. Conclusions

Atmospheric pressure flow reactor experiments were performed to investigate the ignition characteristics of FT and HRJ alternative jet fuels in comparison to conventional JP-8 between 832 K and 917 K. Experiments were conducted with standard air as well as vitiated air composed of 17 mol % O_2 and NO_x between 0 and 755 ppmv. Experiments were also performed with jet fuel surrogate components such as n-dodecane and iso-octane to investigate the ignition behavior of normal- and iso-paraffins, respectively. Ignition delay time measurements show that the ignition behavior of Shell-SPK is very similar to that of JP-8, while HRJ-Tallow and HRJ-Camelina have

longer ignition delay times than JP-8. However, Sasol-IPK showed varying ignition behavior relative to JP-8 depending on the temperature with the highest overall activation energy. The presence of NO_x in the oxidizer stream reduced the ignition delay time of the jet fuels significantly. A similar behavior was also observed for surrogate jet fuels as well. However, the effect of NO_x on iso-octane ignition delay time was more pronounced than n-dodecane. Surrogate kinetic modeling results were also compared with the experimental data for the effect of NO_x. Overall, the modeling results agree with trends observed for the effect of NO_x on ignition delay time. However, the ignition delay time predictions for Sasol-IPK are much longer than the experimental data. This is due to the fact that the representation of iso-paraffinic components in Sasol-IPK is not correctly represented by iso-octane alone. Work is in progress to investigate additional surrogate components that can better represent iso-paraffinic jet fuels.

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