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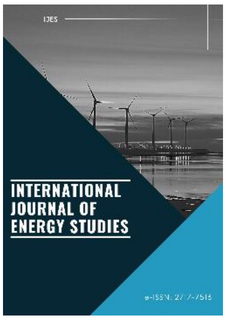

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Optimization of combustion and emission characteristics of coke oven gas doped ammonia/air mixture by colorless distributed combustion (CDC) technology

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Highlights

- CDC method provided more uniform temperature fields in the combustor.
- Substiantial reduction in NO emissions has been achieved.
- The most proper results were obtained under non-preheated and N_2 dilution conditions.

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ABSTRACT

This study's motivation is to reduce the NO emissions of ammonia/air mixture, whose NO emissions are promoted by coke oven gas (COG) addition, by implementing the CDC technology. Within this scope, the effects of the CDC technology on the termal and emission characteristics of the COG/ammonia/air mixture were numerically investigated under the non-premixed combustion conditions. In order to perform a detailed investigation, the simulations were performed for the different operating conditions where the oxidizer inlet temperature (300 K or 600 K) and diluent type (N_2 and CO_2) were varied. Under the distributed combustion regimes, declines in flame thicknesses and temperatures were observed and this provided more uniform temperature fields. Besides, the flame blowout limits varied and it observed 20% and 18.5% under CO_2 and N_2 dilutions, respectively for the 300 K inlet temperature. Increasing the inlet temperature provided wider blowout limits up to O_2 concentration of 16%. Reduction levels up to 45.83% in NO emissions were achieved compared to conventional combustion. This showed that CDC technology is a promising way to suppress the primary NO formation mechanisms of the mixture. Because the preheating promoted the reactions rates the maximum reduction in NO emissions was 29%. Therefore, it can be said that CDC method should be implemented to the mixture when the reactants are at room temperature and the diluent is N_2 to obtain the most proper combustion and emission outcomes.

Keywords: Ammonia combustion, Pollutant reduction, Syngas, Fuel-NO, Swirling flows

1. INTRODUCTION

Today, humankind faces a rise in global temperatures because of the overuse of traditional fossil fuels. Owing to the fact that scientists are making a significant effort to disseminate carbon-free or low-carbon fuels by using advanced combustion technologies to reduce CO_2 emissions which are a primary source of greenhouse gas effects on the environment [1]. At this point, ammonia (NH_3) appears as a promising alternative carbon-free fuel that can be produced by using renewable energy sources completely in the near future since it presents a high amount (17.8% by mass) of hydrogen (H_2) storage capability [2,3], can be burnt in the combustion systems (e.g. engines, boilers and gas turbines) directly and has a well-developed storage and transportation infrastructure [4]. However, direct usage of NH_3 in combustion systems brings some challenges that must be eliminated for effective utilization. Related to its' thermochemical properties, it has a low flame speed, low reactivity and generates high NO emissions during conventional combustion conditions [5]. When the literature is searched, it is seen that several strategies have been implemented to eliminate the aforementioned drawbacks of NH_3. In order to improve its' combustion performance, blending NH_3/air mixture with more reactive fuels such as H_2 [6–8], coal [9], methane (CH_4) [10–12], methanol [13] and syngases [14–17] is a common method. In addition, oxy- or oxygen-enrichment combustion has also been widely used to achieve a better combustion performance of the NH_3/air mixture [18–20]. Even though implementation of these methods provided favorable results in terms of the combustion characteristics such as flame speed, ignition delay time, adiabatic flame temperature and reactivity, they resulted in higher NO emissions as the NO formation mechanisms of NH_3 were triggered.

In order to suppress the promoted NO formation mechanisms, some combustion techniques such as staged combustion [21], SCR (selective catalytic reduction) [22], MILD (moderate or intense low oxygen dilution) [23] or reactant humidification [24] methods were applied simultaneously with the strategies used to improve the combustion performance of NH_3, as a result, positive outcomes have been obtained for NO mitigation. On the other hand, there is another alternative technique which is named Colorless Distributed Combustion (CDC). The effects of the CDC technology on the combustion and emission behaviors of carbon-based fuels have been commonly investigated in the literature and it was revealed that a substantial reduction in pollutants emissions such as NO, CO and CO_2 with a more uniform temperature field and more stable flame in the combustor can be achieved in comparison with conventional combustion conditions [25–28]. The CDC method strays from the MILD and HiTAC combustion in terms of operating conditions.

Although MILD or HiTAC combustion is based on preheating the oxidizer and increasing its' temperature to more than 1000 K, the CDC regime can be achieved without any preheating process and can be applied even when the oxidizer is at room temperature [29].

Today, coal is still widely used as a primary energy source in some countries such as Turkey, China and India [30] and during the coking of the coal, a syngas named coke oven gas (COG) is obtained. COG is a hydrogen-rich coal gas and it was before revealed in the literature that COG can be used as an auxiliary fuel as the addition of COG into NH_3/air mixture provided positive results on the combustion characteristics such as laminar burning velocity, adiabatic flame temperature and temperature distribution in the combustor. However, as in the cases where other reactive fuels have been used as an auxiliary fuel, the addition of COG increased the NO emissions of the NH_3/air mixture under the conventional combustion condition because it promoted fuel-NO and thermal-NO mechanisms which are the primary sources of NO emissions [14].

In the present study, the effects of the CDC technology on the combustion and emissions characteristics of COG-doped NH_3/air mixture have been numerically investigated. In this context, changes in the flame characteristics, temperature distribution and NO emissions levels at the transition from the conventional combustion conditions to the distributed regime are discussed. Thus, it is revealed to what extent CDC technology can be effective on the thermal field that arises from the combustion of NH_3/COG/air mixture and in reducing NO emissions promoted by the addition of COG to the NH_3/air mixture under conventional combustion conditions. Furthermore, when the articles in the literature are assessed, it can be concluded that the abovementioned combustion and emissions parameters of the mixture have not been investigated under CDC conditions yet. Accordingly, since the findings revealed in the scope of this paper fill a gap in the literature, it can be entitled as a novel study.

2. MATERIALS AND METHODS

A non-premixed burner mounted on a volumetric combustor was used for the modeling and all the simulations were conducted for 10 kW heat power and 0.83 equivalence ratio. Technical details regarding the geometries of the burner and combustor are presented in Fig. 1 and Fig. 2. As shown in Fig. 1, the oxidizer line in the burner has two different sections. The first one is an air turbulator with a 15° vane angle to have a swirl flow in the combustor and the second one is straight holes with a diameter of 2.6 mm. The swirl number of the burner was calculated as 0.18, by using the following equation [31], showing the burner used in the presented study generates a low swirl intensity. As presented in Fig. 2, the combustor chamber has a 400 mm diameter and a 1000 mm length. It also has some measuring ports at the axial distances which are 100 mm, 300 mm, 500 mm, 700 mm and 900 mm from the combustor inlet. The results related to the profiles that emerge in the combustor were presented by considering these axial distances.

$$S = \frac{2}{3}\left(\frac{1-(d_h/d)^3}{1-(d_h/d)^2}\right) tan\emptyset \approx \frac{2}{3} tan\emptyset \tag{1}$$

In the equation, $\emptyset$, d_h and d represent the vane angle of the turbulator, inner diameter and outer diameter, respectively.

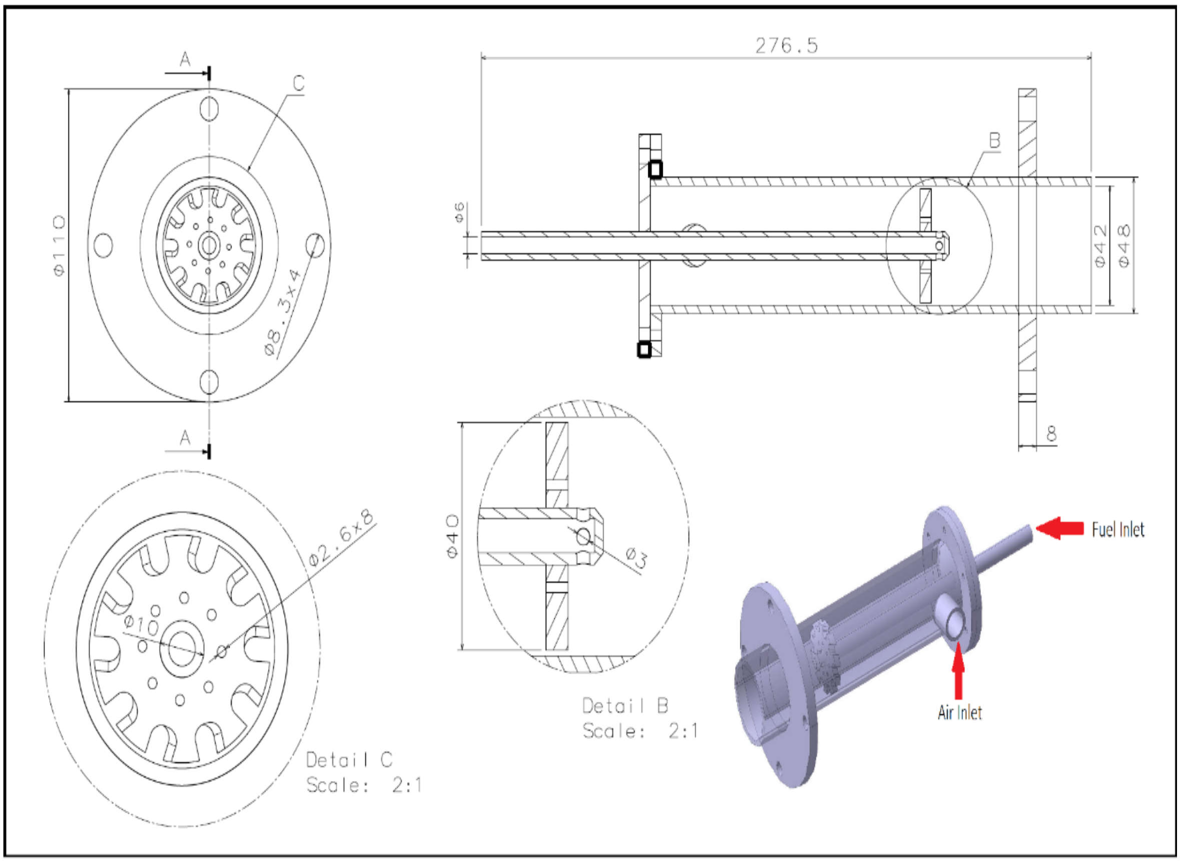


Figure 1. Technical drawing of the burner

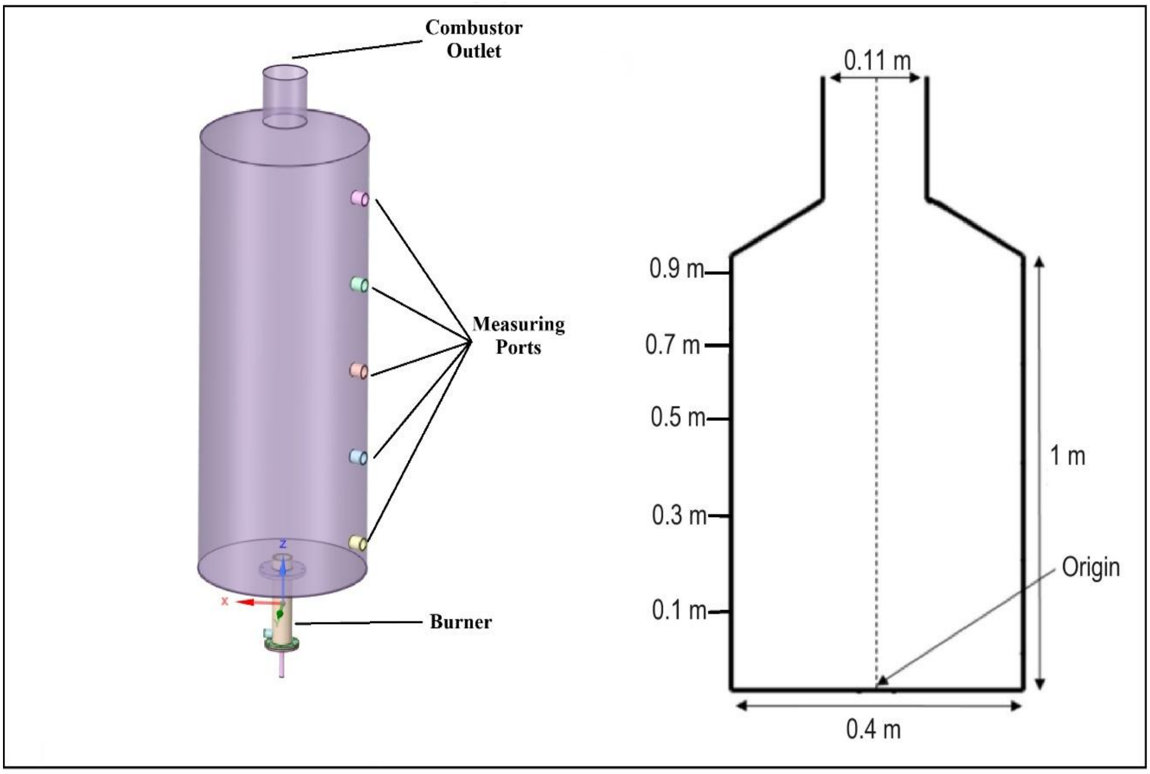


Figure 2. Combustor

The simulations were performed both for the conventional combustion and distributed combustion conditions for the fuel mixture of 50% NH_3/50% COG. As it is revealed in the literature, as the COG amount is increased in the fuel mixture, the formation of NO emissions is promoted [14]. From this viewpoint, in the present study, the effects of the CDC method on the NO emission formations of the mixture were desired to investigate for the worst possible case. Besides, the maximum COG amount in the mixture was determined as 50% by volume because it was used as an auxiliary fuel in the study. Otherwise, at higher amounts, NH_3 takes a diluent role instead of the fuel which was supported by coke oven gas addition. The volumetric percentages of the ingredients in the fuel mixture are shown in Table 1. The distributed combustion technique was implemented by decreasing the O_2 concentration in the oxidizer provided that the O_2 amount in the mixture was kept constant. In order to reduce the O_2 concentration, two different diluents which are N_2 or CO_2 were used to simulate the external recirculation of the combustion products and their effects on the combustion and emissions behaviors of the mixture under distributed combustion conditions were compared. Since the combustion air comprises 79% N_2 that is an inert gas, the large portion of the combustion products is N_2. Besides, the next largest part of the products is CO_2 [32]. Therefore, these two most abundant products in the flue gas were selected as diluents in the present study. In addition, the operating conditions which involve both the conventional and distributed regimes are presented in Table 2. In the table, the lowest O_2 concentrations were determined according to the flame blowout phenomenon encountered during the simulations.

Table 1. Fuel composition

Fuel Composition	NH_3	H_2	CH_4	CO	CO_2	N_2
50% NH_3 / 50% COG	50 %	27.5 %	13.5 %	3 %	1 %	5 %

Table 2. Operating conditions

Fuel Flow Rate (kg/s)	Oxidizer Flow rate (kg/s)	Mixture Temp. (K)	O_2 Conc. (%)	Diluent
0.000404569	0.003834749	300	21	-
0.000404569	0.003925555 - 0.004337864	300	20.5 - 18.5	N_2
0.000404569	0.003977477 - 0.004127341	300	20.5- 20	CO_2
0.000404569	0.004337864 - 0.004998204	600	18.5 – 16	N_2
0.000404569	0.004625539 - 0.005005118	600	18.5 – 17.5	CO_2

In order to perform the numerical simulations, ANSYS Fluent software was used. There are different combustion models for the modeling of non-premixed combustion in Fluent. Among them, since the Eddy Dissipation Concept (EDC) combustion model provides more consistent results with the experimental findings for the cases where the reaction zone is broader and reaction rates are slower than that of the conventional combustion condition [33], as in the distributed combustion conditions, EDC was selected for the simulations in this study. Besides, the EDC combustion model requires a detailed reaction mechanism to conduct the numerical modeling. There are some reaction mechanisms published in the literature for NH_3-containing fuels and selection of the most proper reaction mechanism for the modeling is one of the important factors to obtain accurate results. A detailed literature was conducted for the selection of the reaction mechanism for NH_3/coal-derived syngases fuel mixtures and it was seen that the reaction mechanism published by Mei et. al. [34] provided more consistent results with the experimental data [14,35]. Therefore, this reaction mechanism was used for the numerical modeling. Further information on the simulation parameters is given in Table 3.

Table 3. Simulation parameters

Combustion model	Eddy Dissipation Concept (EDC)
Reaction mechanism	Mei et. al. [34]
Turbulence model	Standard k-epsilon
Radiation model	P-1
Solution procedure	Double-precision, pressure-based
Gravitational acceleration	Yes
Pressure-velocity coupling	Coupled
Pressure and gradient discretizations	PRESTO, Least Squares Cell-Based
Spatial discretizations for other parameters	Second-order upwind
Under-relaxation factors	Default settings

In Fig. 3, the mesh structure used is demonstrated. It includes 613947 cells with a minimum orthogonal quality of 0.23 and an average skewness value of 0.167. This mesh structure was determined after performing a mesh independency study. As can be seen in Fig. 4, since the results don't change for the higher mesh number than 613947, this mesh structure was used for the further modelling.

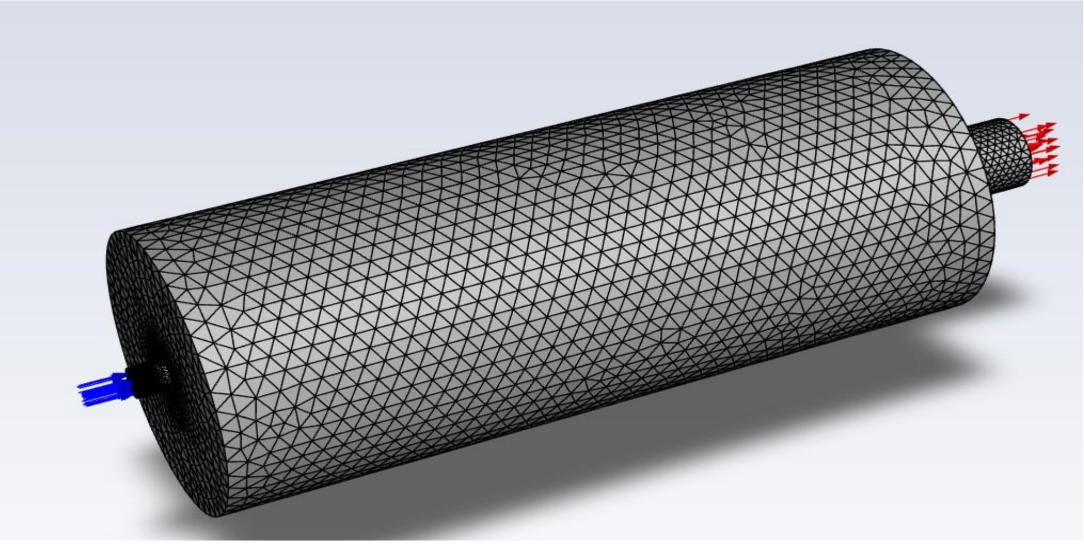


Figure 3. Mesh structure

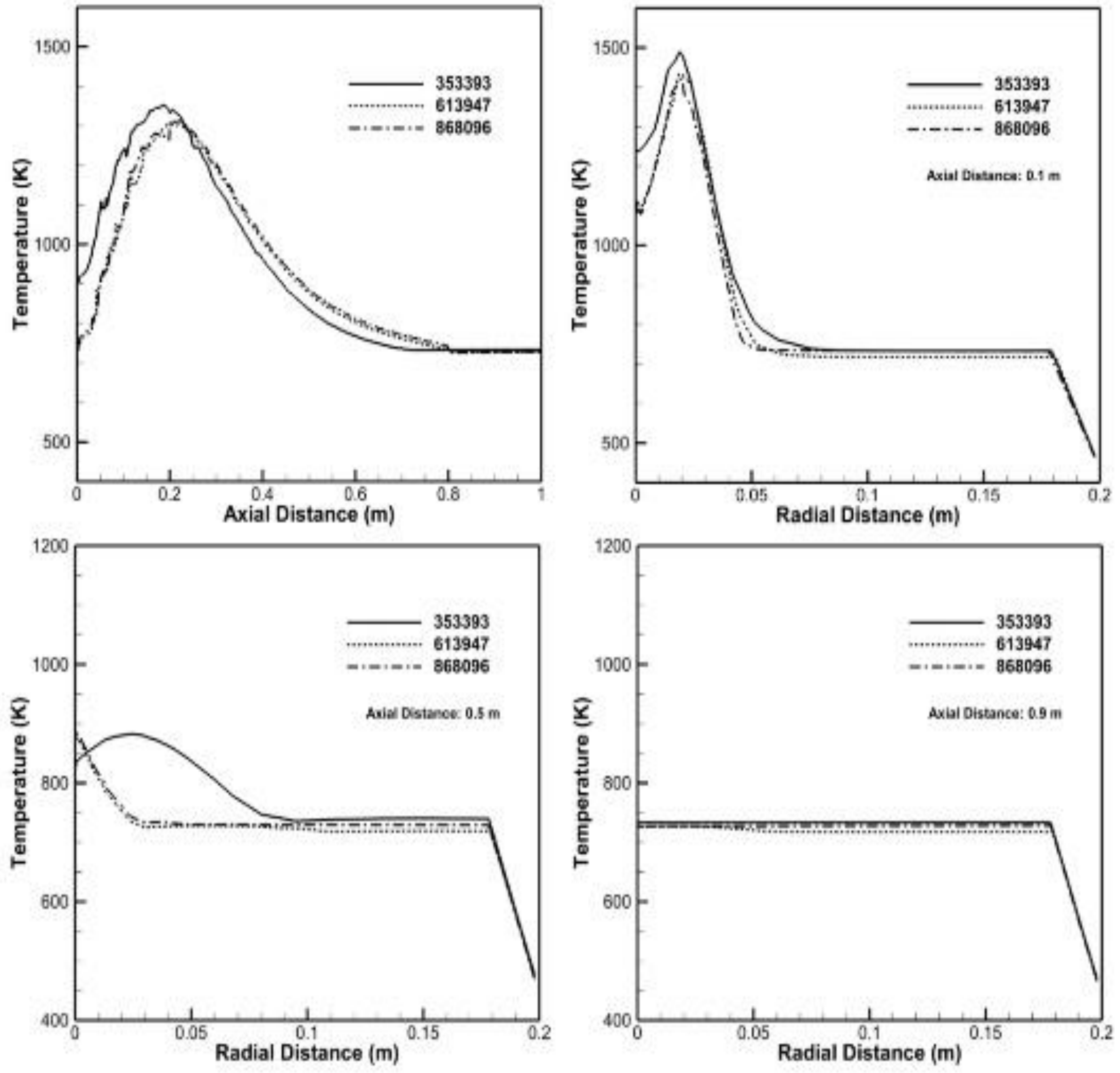


Figure 4. Mesh independency

3. RESULTS AND DISCUSSION

In this section of the study, the predictions obtained from the numerical simulations are presented and the effects of the CDC technology on the thermal characteristics and formation of NO emissions of the mixture are discussed. The case when the inlet temperature is 300 K and the O_2 concentration in the oxidizer is 21% represents the conventional combustion condition.

3.1. Effects of the CDC technology on the combustion characteristics of the mixture

In Fig. 5, predicted temperature contours when the oxidizer inlet temperatures are at room temperature for the conventional and distributed regimes are presented. It can be seen from the contours that flame shapes and temperatures are affected considerably depending on the decreasing

O_2 concentration in the oxidizer. From the conventional combustion towards the distribute regime, flame thickness decreased consistently with the reducing O_2 concentration as the reaction rates are decelerated for lower O_2 concentrations in the oxidizer. As a consequence of this, a more homogenous thermal field in the combustor was obtained. Moreover, flame temperatures also exhibited a decreasing trend from the O_2 concentration of 21% to the lower percentages.When the effects of the diluent type are evaluated for the 300 K oxidizer inlet temperatures, it can be readily said that CO_2 dilution became more effective one in reducing the flame visibility and flame temperatures for the same O_2 concentrations. This phenomenon occurred because a higher heat capacity of CO_2 than N_2 caused a greater reduction in reaction rates. In addition, owing to the lower reaction rates in the case of CO_2 dilution, the flame blowout limits became narrower and any stable combustion could not be achieved below the O_2 concentrations of 20% in the modeling. As for the N_2 dilution case, the flame blowout occurred at the O_2 concentration of 18.5%. This enabled more reduction in the maximum flame temperatures.

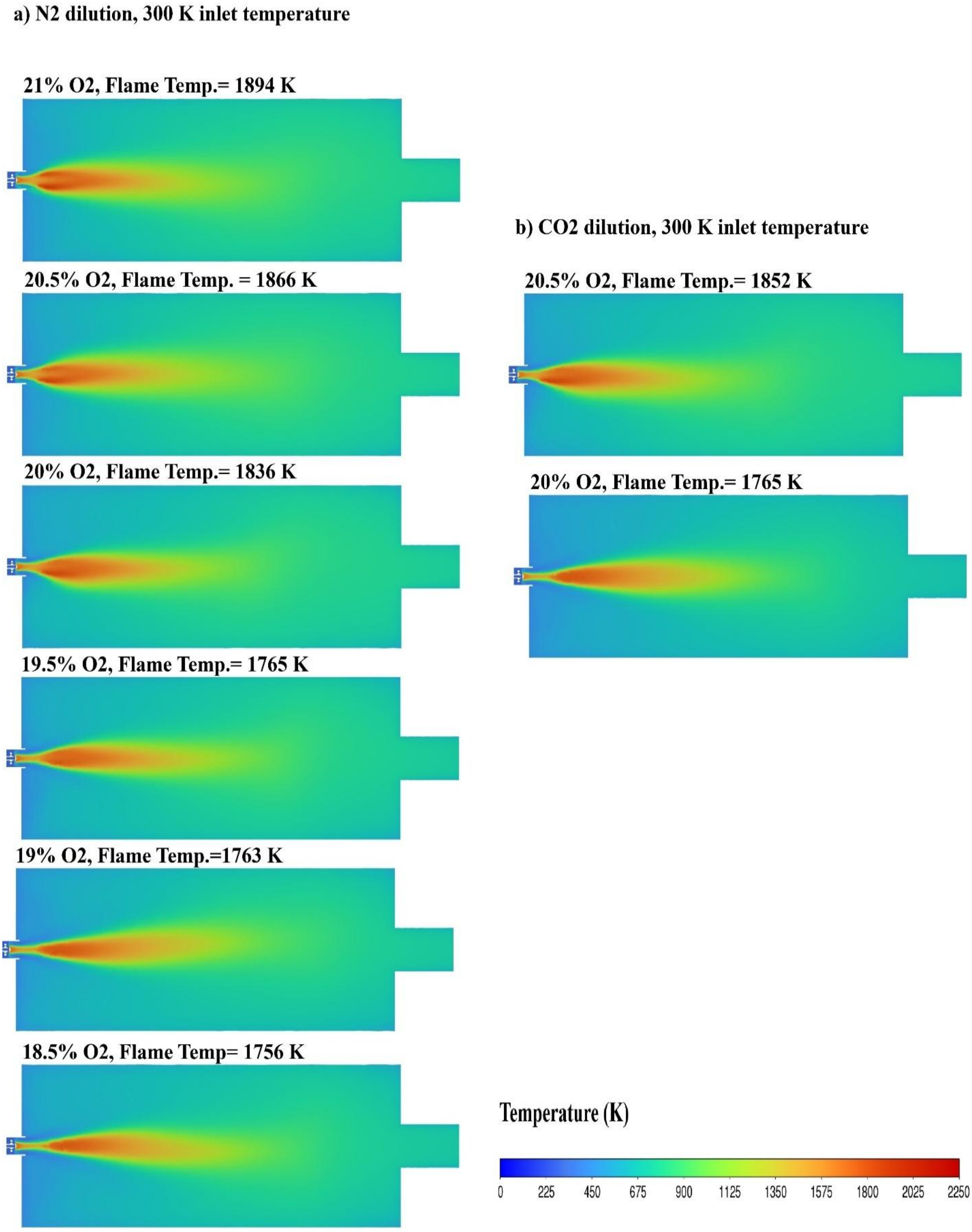


Figure 5. Temperature contours for 300 K oxidizer inlet temperature

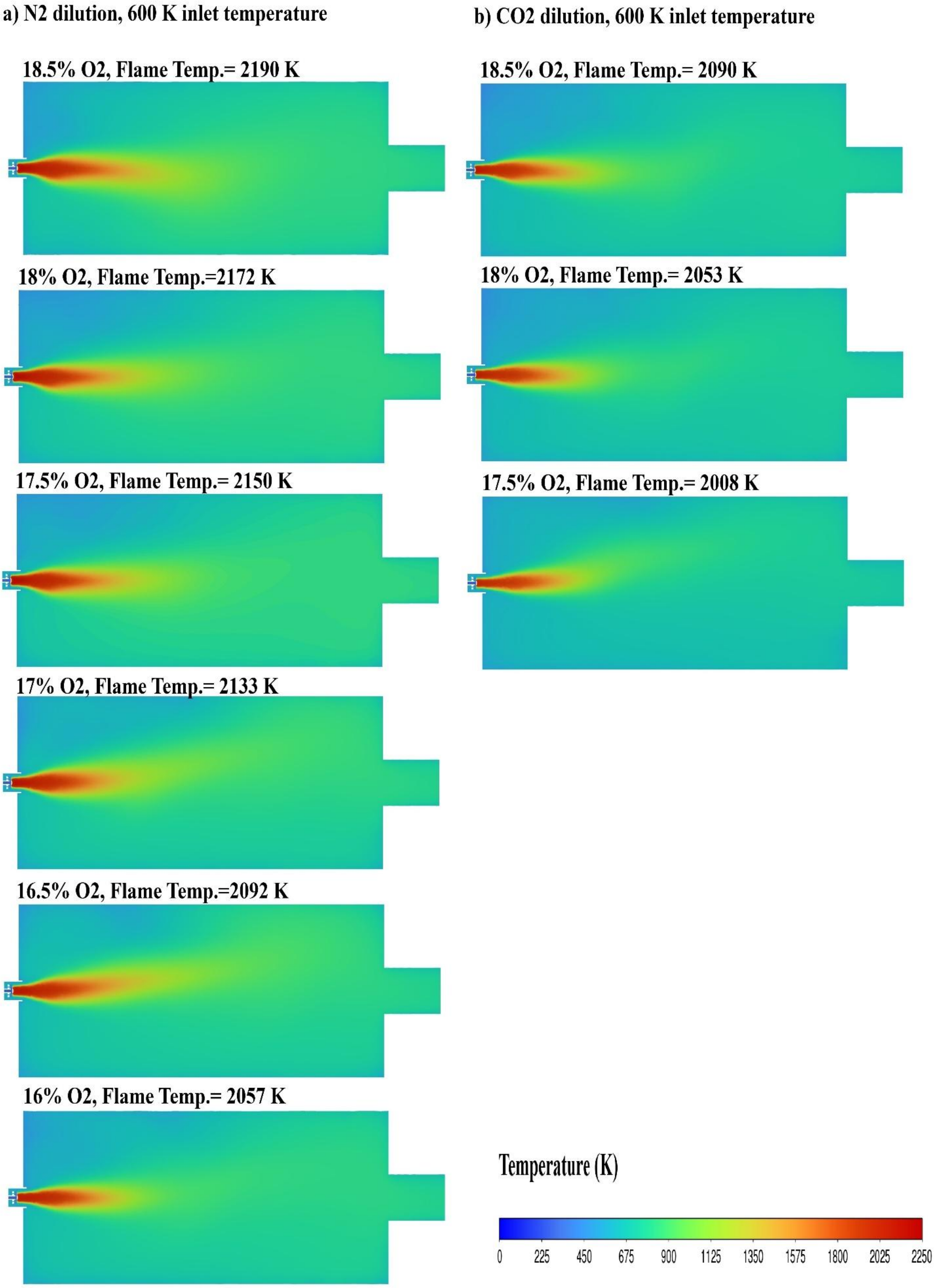


Figure 6. Temperature contours for 600 K oxidizer inlet temperature

The temperature contours in the case of 600 K oxidizer inlet temperature are shown in Fig. 6. It is well known that increasing the inlet temperatures increases the flame speed characteristic [36]. Accordingly, it can be said that the reactivity of the mixture improves as the reaction rates accelerate. As seen in the contours in Fig. 6, depending on the increased flame speed, the area of the flame substantially diminished and as a result of this, temperature distribution in the combustor became more homogenous in comparison with the case when the oxidizer inlet temperature was 300 K. Even though higher inlet temperature of the oxidizer provided a more uniform thermal field in the combustor, this also resulted in higher flame temperatures as the reaction rates increased. For instance, while the maximum flame temperature was 1894 K in conventional combustion conditions as in Fig. 5, it increased to 2190 K under the N_2 dilution and to 2090 K under the CO_2 dilution even at the O_2 concentration of 18.5% when the mixture temperature was 600 K. Similar with the case of 300 K mixture inlet temperature, CO_2 dilution provided lower flame temperature values for all O_2 concentrations. Moreover, because the higher inlet temperature of the oxidizer increased the reactivity and flame temperature of the mixture, the flame blowout limits broadened to 16% under N_2 dilution and 17.5% under CO_2 dilution. This enabled to obtain colder flames under CO_2 dilution.

In order to evaluate the transition to the distributed regime from conventional combustion conditions, the contours of the OH radical can be used as a beneficial indicator for monitoring the evolution of the reaction zone in the combustor. In Fig. 7 and Fig. 8, OH radical contours predicted in the combustor were shown. In the case of when the oxidizer inlet temperatures are at room temperature, as presented in Fig. 7, the reaction zone concentrated near the burner outlet as expected for the conventional combustion condition. However, depending on the lower reaction rates and higher inlet flow rates arising from the decreasing O_2 concentration in the oxidizer, the reaction zone tended to propagate towards the combustor outlet and finally, more distributed combustion regimes were obtained. It is also clear from the Fig. 7 that CO_2 came into forefront a more effective diluent in terms of attaining a more distributed combustion regime in the combustor for the same O_2 concentrations in the oxidizer in comparison with N_2 dilution. On the other hand, as preheating the oxidizer to 600 K resulted in higher flame speed and reaction rates, the concentrations of the OH radical in the mixing zone intensified and achieving a distributed regime in the combustor became more challenging even if higher inlet temperatures enabled the flame blowout limits to broaden. Any distinctive differences were not observed on the propagation of the reaction zones for each diluent whereas CO_2 provided lower amount of OH radical in the mixing zone for each case in Fig. 8. Finally, the predicted OH radical contours in the figures suggest that obtaining a better distributed regime in the combustor is more achievable when the oxidizer was not subjected to the preheating.

Theoretically, CDC technology is based on not only slowing down the reaction rates by decreasing the O_2 concentration in the oxidizer, but also it relies on the high internal recirculation of the hot species within the combustor to sustain the stable combustion process [37]. Accordingly, it is clear that the internal and external recirculation zones that emerge in the combustor contribute to obtain a fully distributed combustion regime in the combustor. From this viewpoint, to evaluate the effects of the recirculation zones that emerge in the combustor on the obtained thermal fields in the present study, velocity vectors predicted for each case are shown in Fig. 9 and Fig. 10. When the velocity vectors in the figures were assessed generally, it can be seen that only external recirculation zones occurred at the regions near the combustor wall for each case. It is believed that the reverse flow generated by these external recirculation zones to the reaction zone contributed to the combustion stability. However, the generation of any central recirculation zone is not observed from the figures. Generally, the formation of the central recirculation zones in the volumetric combustors strongly depends on the swirl intensity in the flow generated by the burner turbulator. At that point, the reason why any central recirculation zone has not been generated is the burned used in the modeling has a low swirl number and thus, it generates low swirl intensity in the combustor. Accordingly, it can be concluded that better distributed combustion regimes especially under preheated oxidizer conditions can be achieved by increasing the swirl number of the burner since this provides wider flame blowout limits.

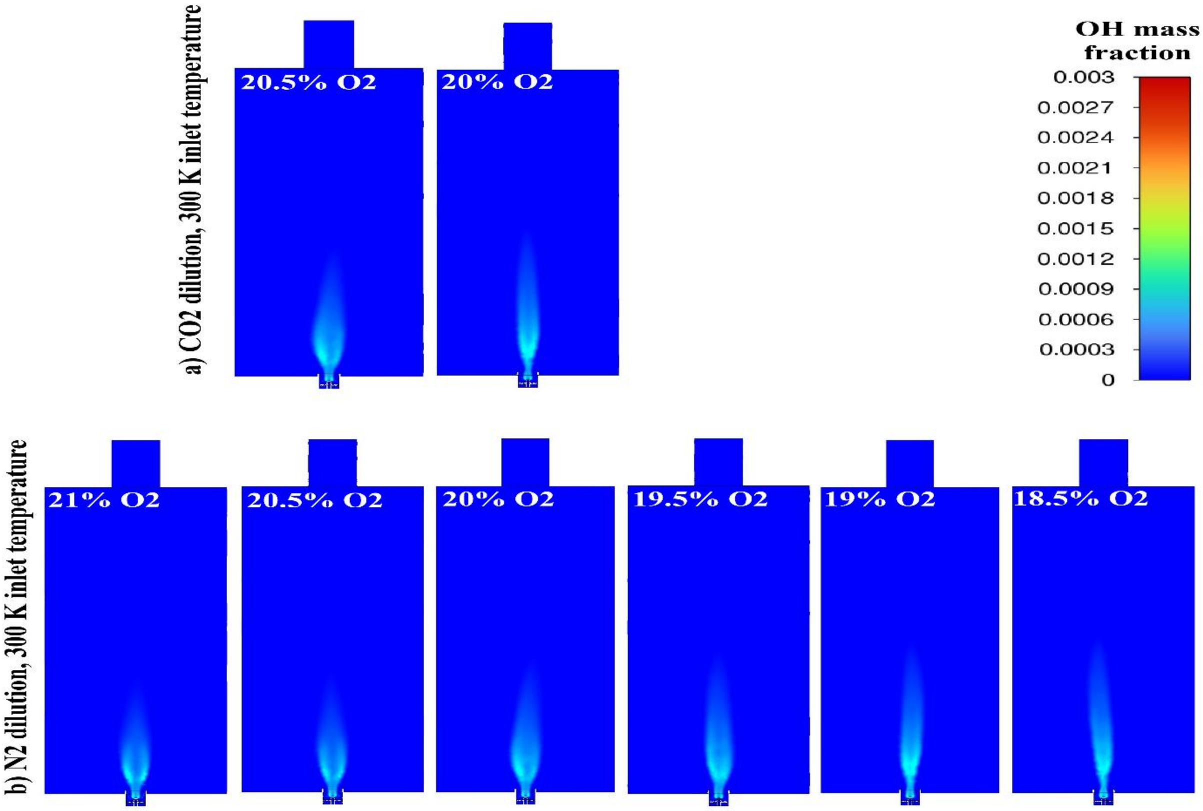


Figure 7. OH contours for the 300 K oxidizer inlet temperature

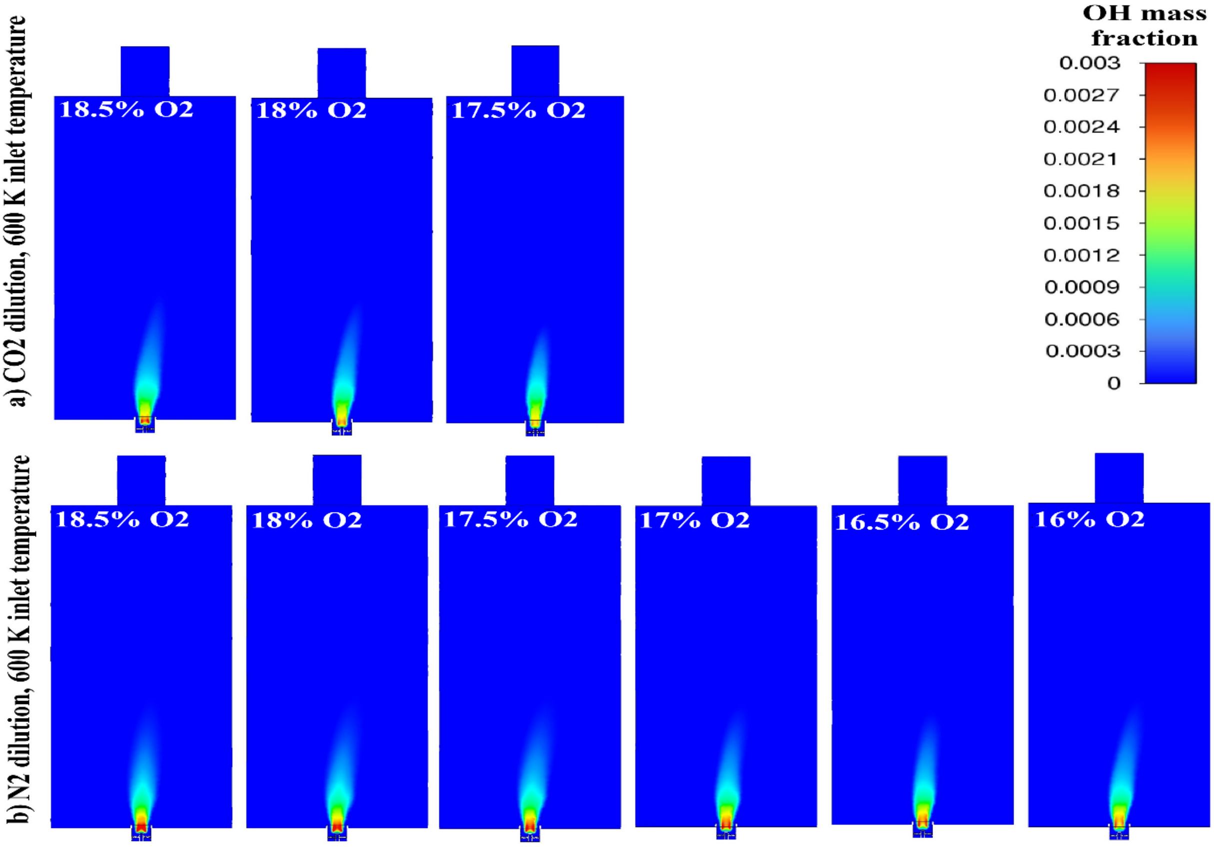


Figure 8. OH contours for the 600 K oxidizer inlet temperature

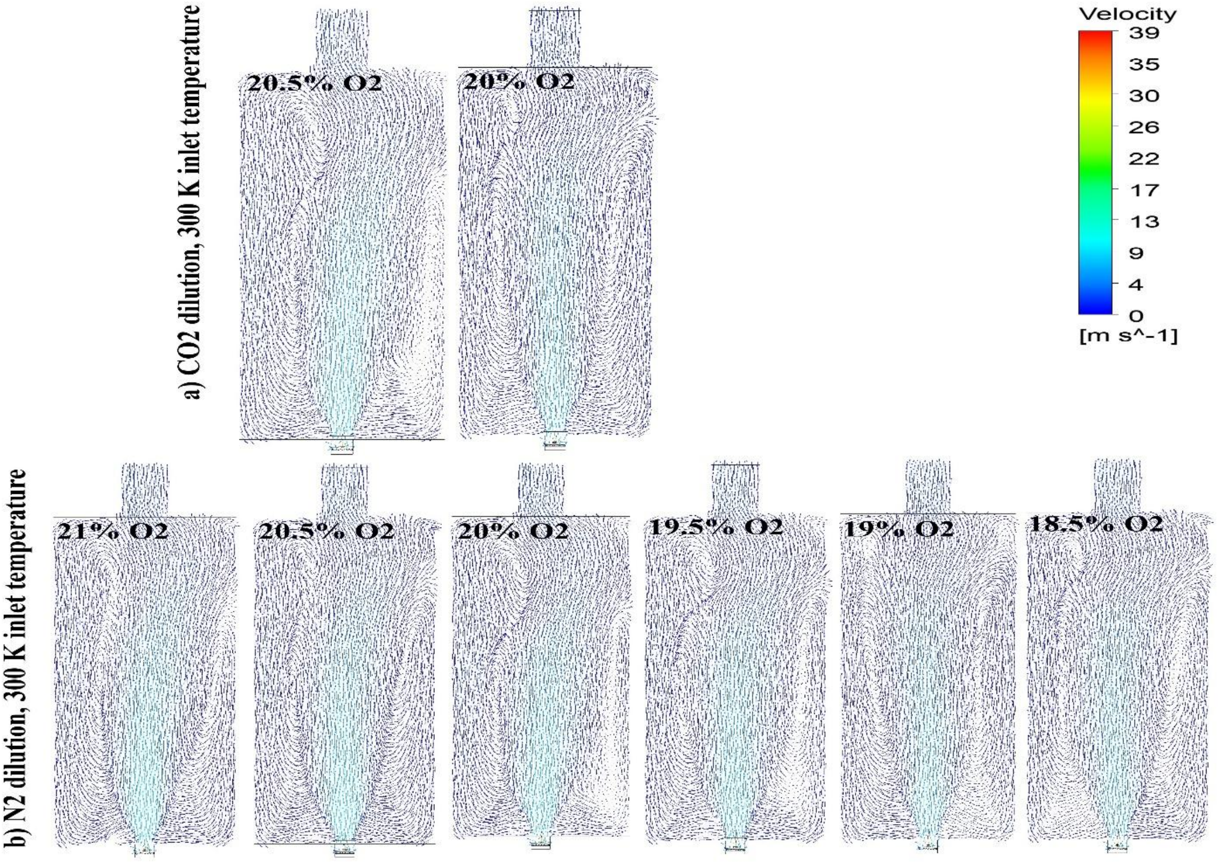


Figure 9. Velocity vectors for the 300 K oxidizer inlet temperature

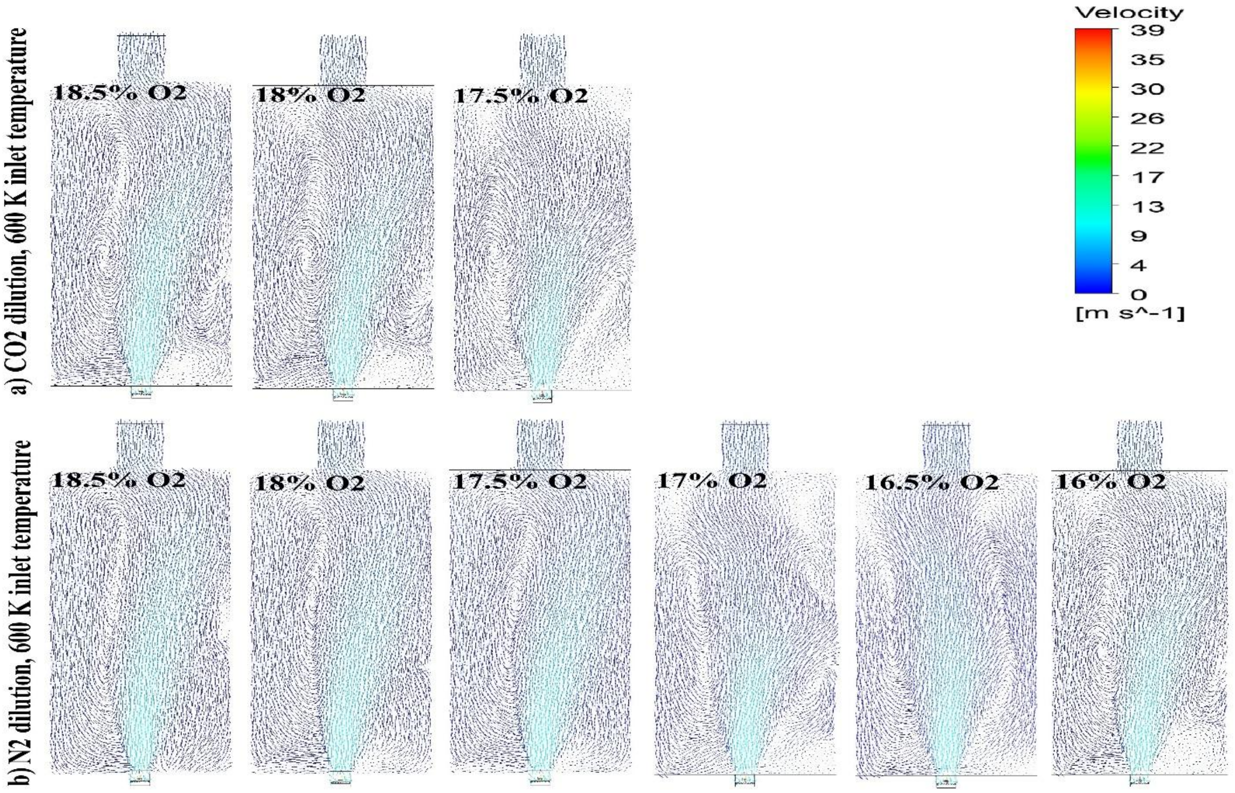
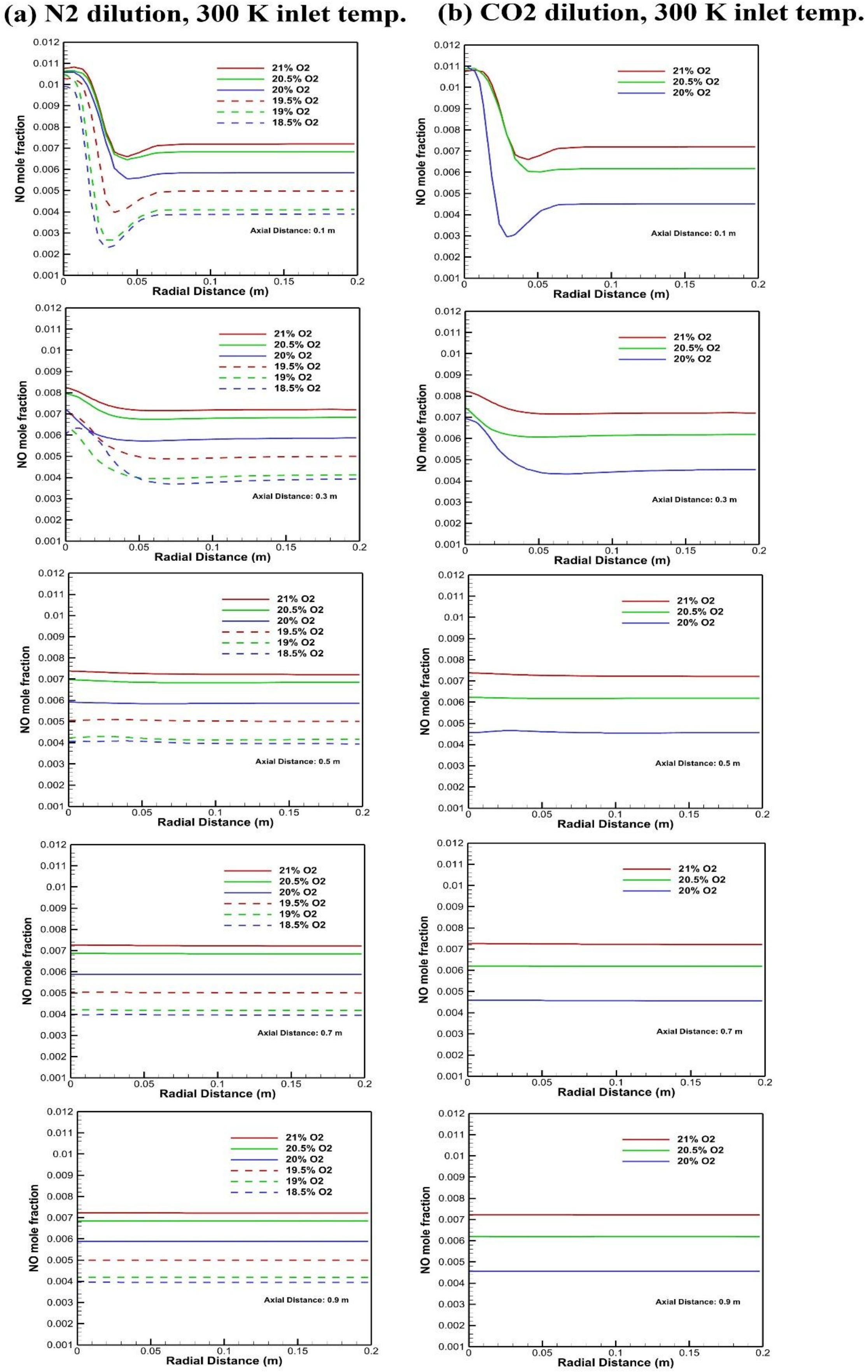


Figure 10. Velocity vectors for the 600 K oxidizer inlet temperature

3.2. Effects of the CDC technology on the emission characteristics of the mixture

In this section of the paper, NO emission charactetristics of the mixture both under conventional and distributed combustion conditions are discussed and the obtained results from the simulations are presented. Because the NO emissions constitute 95% of the whole NO_x emissions only NO emissions of the mixtures were investigated in the scope of this paper [14].

In Fig. 11 and Fig. 12, the NO emission profiles predicted in the combustor are shown. All the profiles in the figures suggest that the NO emissions which are higher at the primary zone of the combustor exhibited a decreasing trend towards the combustor outlet. The reduction in the NO emissions was observed more between the axial distance of 0.1 m and 0.3 m and, after the 0.3 m axial distance, NO emissions exhibited more uniform distributions. Besides, it is clear that implementation of the distributed combustion technology provided positive results on the mitigation of the NO emission formations and lower NO emissions were achieved than those of the conventional combustion conditions. When the oxidizer inlet temperature was 300 K, the amounts of the NO emissions in the combustor decreased consistent with the decreasing O_2 concentration in the oxidizer and comparing with the conventional combustion conditions, until the flame blowout, reductions of 45.83% and 37.50% in the amounts of NO emissions was attained at the combustor outlet under the N_2 and CO_2 dilutions, respectively. Indeed, it is clear from the Fig. 11 that CO_2 became a more effective diluent to suppress the formations of the NO emissions for the same O_2 concentrations. However, since the flame blowout took place earlier, lower NO emissions were achieved under the N_2 dilution for the 300 K oxidizer inlet temperature. As for the 600 K oxidizer inlet temperature case, even though preheating the oxidizer provided a more uniform temperature field and broadened the flame blowout limits, it promoted the formation of NO emissions and lower amounts of NO emissions than those of the conventional combustion condition was able to achieve at the O_2 concentration of 18.5% in the oxidizer. The lower O_2 concentrations enabled to reach lower amount of NO emissions and finally, N_2 dilution provided a reduction of 29% whereas CO_2 dilution provided a reduction of 25% on the amount of NO emissions at the combustor outlet. As in the 300 K oxidizer inlet temperature case, CO_2 contributed more for lowering the NO emissions in the combustor for the same O_2 concentration. Finally, it can be said that CDC technology is an effective method for NO reduction of the mixture, however, its' implementation is more favorable when the oxidizer is at room temperature for lower NO emission formations. It is also clear that lower NO emissions can be achievable for wider flame blowout limits regardless of the inlet temperatures.


(a) N2 dilution, 300 K inlet temp.

(b) CO2 dilution, 300 K inlet temp.

Figure 11. NO emission distributions for 300 K inlet temperature

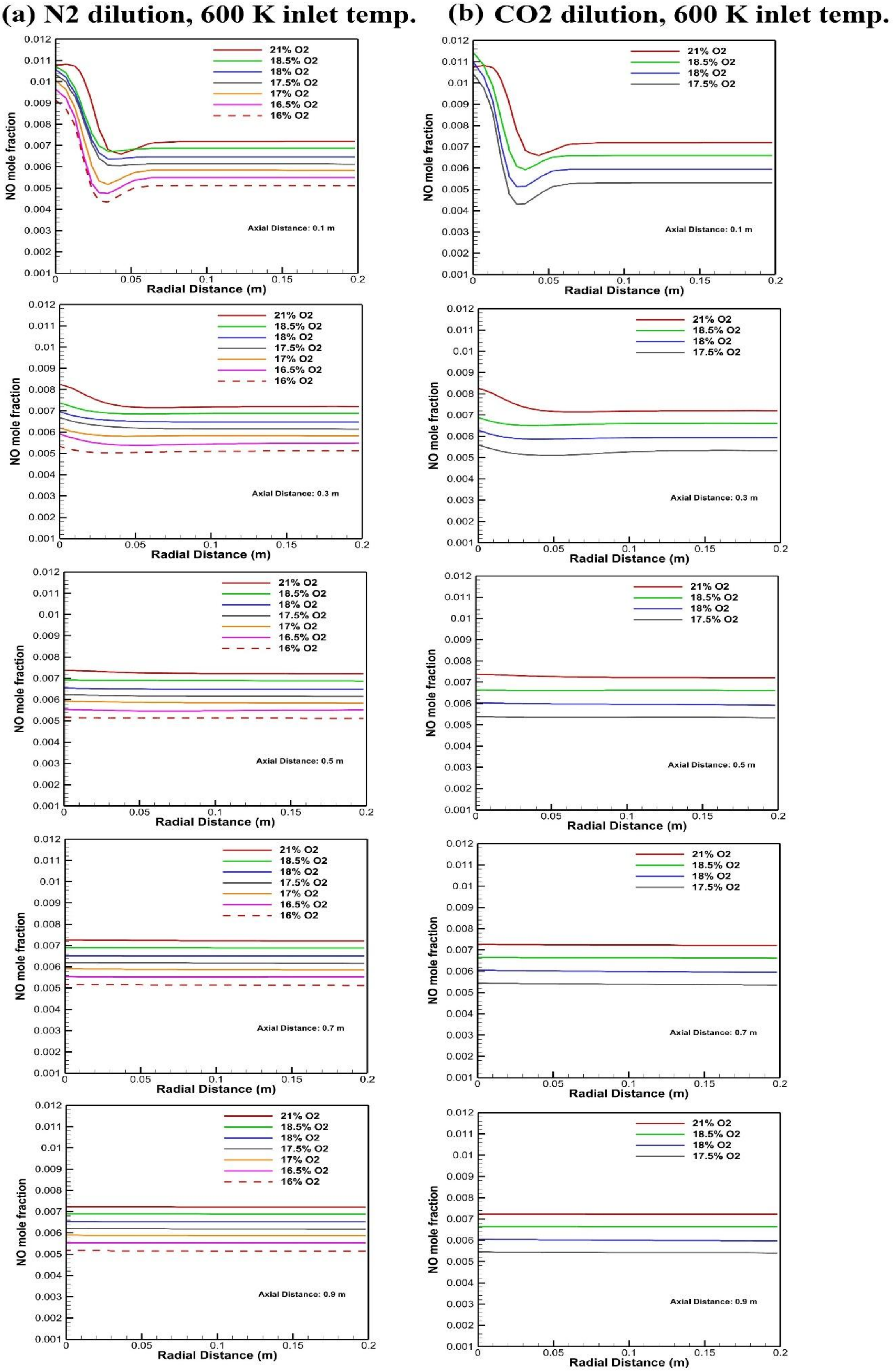

(a) N2 dilution, 600 K inlet temp. **(b) CO2 dilution, 600 K inlet temp.**

Figure 12. NO emission distributions for 600 K inlet temperature

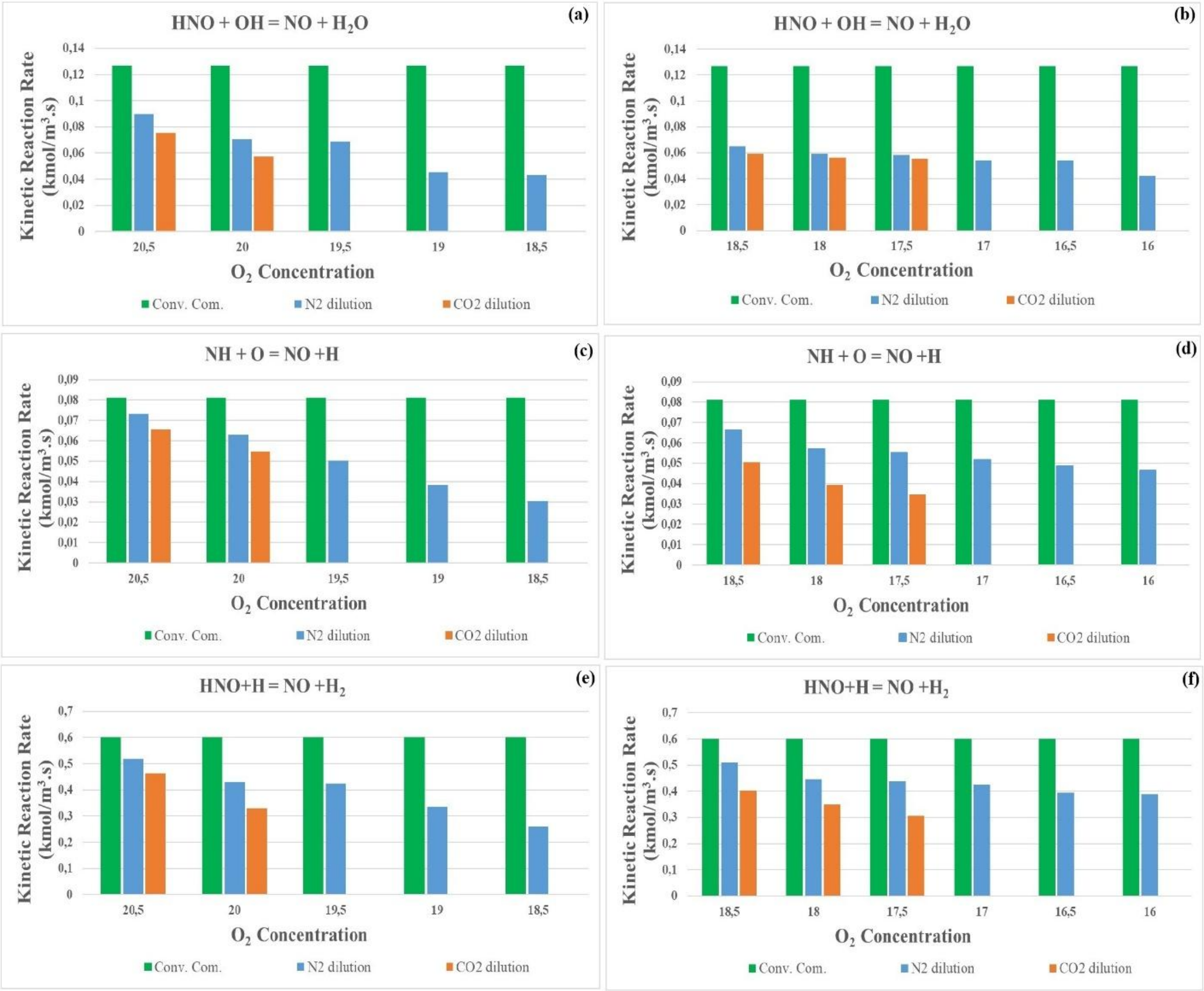


Figure 13. Maximum reaction rates for 300 K inlet temperature (a),(c),(e) and 600 K inlet temperature (b),(d),(f)

It is clear that one of the reasons for achieving lower NO emissions than those of the conventional combustion condition is the CDC technology lowered the flame temperature and therefore mitigated the effects of the thermal-NO mechanism of the mixture. However, it is well known that the NO emissions emerge from the combustion of the NH_3 containing fuels are generally dominated by the fuel-NO mechanism. Accordingly, one can say that lower NO emissions, which in a reduction of up to 45.83% compared to conventional combustion, were achieved as the CDC technology mainly suppressed the fuel-NO mechanism of the mixture. In order to validate this inference, changes in the reaction rates of the critical reactions related to the fuel-NO formation mechanism depending on the decreasing O_2 concentrations in the oxidizer can be revealed. The critical reactions for the fuel-NO mechanism of the mixture are HNO + H = NO + H_2, HNO + OH = NO + H_2O and NH + O = NO + H [23] and the variations in the maximum reaction rates of these reactions emerge in the combustor for the conventional and distributed combustion conditions are presented in Fig. 13. The graphs in the figure suggest that the lower O_2 concentrations in the oxidizer provided lower reaction rates compared to the conventional combustion. It can also be said that the reductions in the reaction rates exhibited a consistent trend with decreasing O_2 concentrations. Besides, depending on the flame blowout limits, CO_2 behaved as a more effective diluent for suppressing the fuel-NO formation mechanism for every operating condition. Herein, it can be concluded that CO_2 dilution is a more effective way of preventing the formation of both thermal-NO and fuel-NO mechanisms which are the main sources for the NO emissions of the mixture. Therefore, lower NO emissions than the cases of N_2 dilution were achieved for the same level of O_2 concentrations. These results demonstrate the CDC technology is not only effective on the thermal-NO mechanism but also mitigates the effects of fuel-NO mechanisms which is the main problem for the combustion of NH_3-containing fuels.

4. CONCLUSIONS

In this study, CDC technology has been implemented to the COG-doped NH_3/air mixture by using a non-premixed burner mounted on the volumetric combustor. Hence, the applicability of the CDC technology in achieving lower NO emissions of the COG/NH_3/air mixture with a stable combustion was numerically investigated and results obtained from the simulations are summarized as follows:

- Flame thickness decreased in agreement with reduced O_2 concentration in the oxidizer. Thus, CDC method provided more unifom temperature fields in the combustor compared with the conventional combustion condition. In addition, cooler flames were obtained under the distributed combustion regimes. Increasing the oxidizer inlet temperature from 300 K to 600 K positively contributed to the uniformity of the thermal field in the combustor depending on the increased flame speed characteristic. However, this strategy increased the maximum flame temperatures as the reaction rates were accelerated.

- Between the diluents CO_2 behaved more effectively to achieve thinner and cooler flames for the same O_2 concentrations. However, as the CO_2 reduced the reaction rates more than the N_2 dilution, flame blowout limits were observed narrower for different oxidizer inlet temperatures. Depending on the flame blowout limits, N_2 dilution provided colder and thinner flames when the oxidizer inlet temperature was 300 K as the combustion process continued for lower O_2 concentrations. Vice versa, in the case of 600 K oxidizer inlet temperature, even though the flame blowout phenomenon took place earlier, CO_2 provided cooler and thinner flames.

- Contours of the OH radicals showed that feeding the oxidizer at room temperature (300 K) is more favorable to achieve a better distributed regime in the combustor. At the same O_2 concentrations, CO_2 provided a better distributed regime under room temperature inlet conditions. In contrast, since increasing the oxidizer inlet temperature promoted the flame speed characteristic of the mixture, the reaction zone was forced more to take place in the primary zone of the combustor even though lower O_2 concentrations require higher mixture inlet velocity under the 600 K oxidizer inlet temperature.

- The predictions in the present study revealed that achieving a more distributed combustion regime in the combustor strongly depends on the flame blowout limits of the mixture under different operating conditions such as diluent type and oxidizer inlet temperature. It can also be noted that the flame blowout characteristic of the mixture strongly depends on the generated recirculation zones in the combustor as the recirculation of the hot products into the reaction zone sustains the combustion process for lower O_2 concentrations. The predicted velocity vectors illustrated that although external recirculation zones in the combustor were observed, any central recirculation zone was not generated as the burner used in the modeling has a low swirl number. Accordingly, it can be concluded that achieving the central recirculation zones in the combustor could contribute for attaining better distributed regimes in the combustor, especially for preheated combustion conditions.

- Implementation of the CDC technology to the mixture contributed substantially for mitigating the formation of the NO emissions. Depending on the flame blowout limits, reductions of the NO emissions with 45.83% and 37.50% compared to the conventional combustion condition were achieved for N_2 and CO_2 dilutions respectively under the 300 K oxidizer inlet temperature condition. Preheating the oxidizer promoted the formation of NO emissions and lower NO emissions than the conventional combustion condition were attained in the case of 18.5% O_2 concentration. Under the preheated conditions, N_2 dilutions provided a reduction of 29% whilst the CO_2 dilution introduced a reduction of

25%. Despite that CO_2 provided more reduction for the same O_2 concentrations, lower levels of NO emissions were obtained under the N_2 dilutions for every operating condition since the mixture has wider flame blowout limits for each oxidizer inlet temperature.

- The reaction rates of the critical reactions related to the fuel-NO mechanism decreased as the O_2 concentration in the oxidizer was reduced until the flame blowout limits. This shows that the fuel-NO mechanism of the mixture was suppressed and consequently enabled to obtain reductions in the NO emissions up to 45.83% compared to conventional combustion condition. Accordingly, CDC technology played an important role in the mitigation of the fuel-NO formation mechanism which is the primary source of the NO emissions for NH_3 containing fuels. In order to obtain the most optimum outcomes, it is recommended that it should be implemented under the operating conditions where when the reactants are at room temperature and the diluent is N_2.

DECLARATION OF ETHICAL STANDARDS

The author of the paper submitted declares that nothing which is necessary for achieving the paper requires ethical committee and/or legal-special permissions.

CONTRIBUTION OF THE AUTHORS

Ozan Kekul: Performed numerical analysis and analyse the results. Wrote the manuscript.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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