INVESTIGATION OF THE EFFECT OF COLORLESS DISTRIBUTED COMBUSTION ON FLAME TEMPERATURE AND EMISSIONS IN A MINI GAS TURBINE ENGINE

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Abstract

With the climate crisis, research has focused on emissions caused by fuels used for both civilian and military purposes. NOx emissions, which occur due to the high flame temperature in gas turbine combustion chambers used in aviation, are an important research topic.

In this study, the colorless distributed combustion method, which has been observed to be beneficial in reducing NOx emissions in the literature, has been simulated by CFD in the combustion chamber of the mini turbojet engine. The outlet temperature of the combustion chamber of kerosene given from 12 jet nozzle by Discrete Phase Method (DPM) injection method with air at the rate of 21% O_2 by volume under standard conditions was confirmed by the experimental data in the literature, with analyses made at different turbine rpm.

After the validation study, the O_2 ratio in the air was reduced to 19, 17, and 15%, respectively. According to the results obtained, the maximum temperature of the combustion chamber decreased from 2239 K to 1897 K, and NOx decreased from 16.3 PPM to 0.053 PPM.

Keywords: CDC, Combustion Chamber, Mini Gas Turbine Engine

1 INTRODUCTION

The Convention on Climate Change, known as the Paris Agreement, which emerged due to the global climate crisis, aims to reduce emissions. Many studies are conducted, and methods are being developed to reduce emissions such as NO_x and CO. One of these methods, colorless distributed combustion (CDC) is used to reduce pollutant emissions and combustion chamber temperature. In this way, environmental pollution is reduced, and the material life of the gas turbine engine is extended by decreasing the maximum temperature of the combustion chamber. İlbaş et al. showed that the temperature distribution in the combustion chamber lowered with the decrease in the O_2 ratio in their CFD study [1]. Arghode and Gupta investigated the effect of the flow field for CDC with four different sample configurations with experimental and numerical studies and it has been revealed that the configuration where the air and fuel enter in opposite directions better reflect the CDC conditions [2]. This shows that the GTM-120 engine with a quasi-reverse flow combustion chamber is much more suitable for CDC studies.

Kekeç and Karyeyen showed that the thermal distribution in the burner is more homogeneous as the oxygen ratio decreases [3]. Gupta and Khalil stated that NO emissions below 2 PPM could be obtained with CDC in their experimental study on different fuels [4]. In the CFD study conducted by Karyeyen, it was concluded that NO_x and CO emissions were reduced to almost zero in distributed combustion conditions using methane as fuel, while CO_2 emission levels increased slightly at the burner outlet [5]. Gupta et al. provided CDC conditions by adding N_2 and CO_2 diluent gases and reducing the O_2 concentration. They demonstrated a 95 % reduction in NO_x emissions at 12% O_2 concentration [6]. Şahin revealed that by reducing the O_2 ratio from 21% to 15% in the k-e turbulence model, uniformly distributed thermal fields and very low pollutant emissions were revealed [7].

2 GEOMETRY

In this study, a mini turbojet gas turbine engine which is given in Figure 1 has been used for the numerical model [8]. GTM-120 is used for unmanned aerial vehicles and gas turbine engine studies such as alternative fuels and structural changes [9,10].

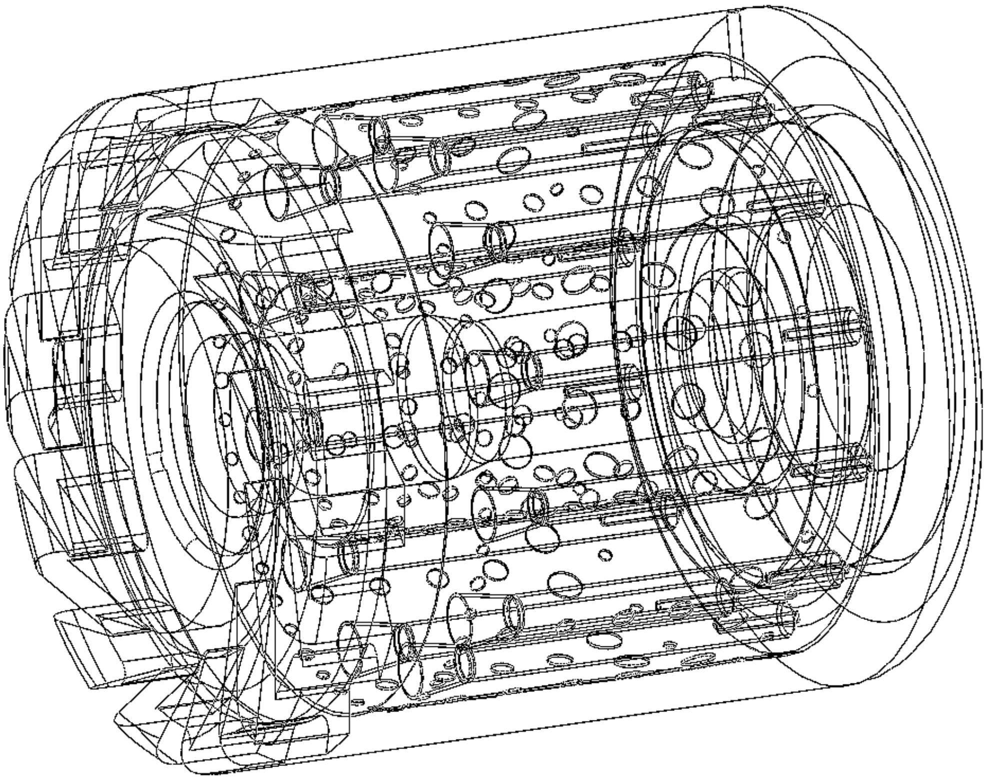

Figure 1. Simplified 3D Model of GTM-120 [8]

The 3D model of GTM-120 has been optimized by eliminating the impeller, turbine, and sharp edges to create a mesh domain suitable for CFD work. Diffuser geometry is included in the study as it will change the direction of the incoming air. Since there are 13 diffuser vanes, the full body had to be worked on.

3 NUMERICAL SETUP

Steady-state simulations were made using the non-premixed combustion method with a compressibility effect in Ansys Fluent. The Standard k-ε turbulence model was chosen as the turbulence model with scalable wall function. The discrete ordinates (DO) model was chosen for the radiation model. Kerosene fuel was injected into the combustion chamber from 12 different points with DPM. The study was compared with the experimental and numerical results in the literature. Verification was made with SIMPLE algorithm and 1600 iterations with combustion chamber outlet temperature at 3 different engine rpms. Engine rpms are created by varying the amount of air and fuel entering. Fuel and airflow rates are taken from the literature [11].

According to the combustion chamber outlet temperatures given in Figure 2, it is seen that the CFD results are very close to the reference study. Differences of less than 3% may be due to minor changes in measuring point and 3D model.

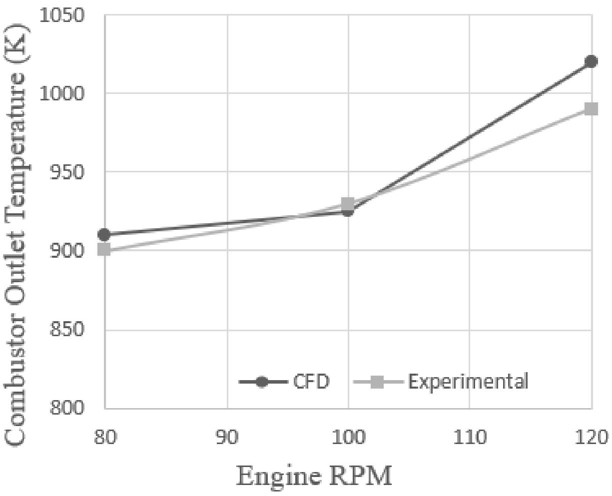

Figure 2. Validation of Model

The CDC application was also performed at 100k rpm, which is the closest result. After the validation study, the CDC was studied at O2 rates of 21%, 19%, and 15%, respectively, in the same numerical setup.

4 MESH INDEPENDENCE

Mesh independence analyses were performed with 3.6 and 5.1 million element numbers at 100k engine rpm. The obtained combustion chamber outlet temperatures and differences from reference in the literature are given in Table 1.

Table 1. Mesh Independence

Element Number(m)	C_{out}(K)	Difference %
Reference [9]	930	
3.6	925	0.541
5.1	944	-2.013

The dramatic increase in the number of mesh elements did not reveal a significant difference in temperature but greatly increased the computation time. According to the comparison with the data in the literature, it was seen that the best results belonged to the unstructured mesh with a 3.6 million element number. The mesh created for the simulation is given in Figure 3.

when the jet fuel is burned with air in standard conditions containing 21% O_2.

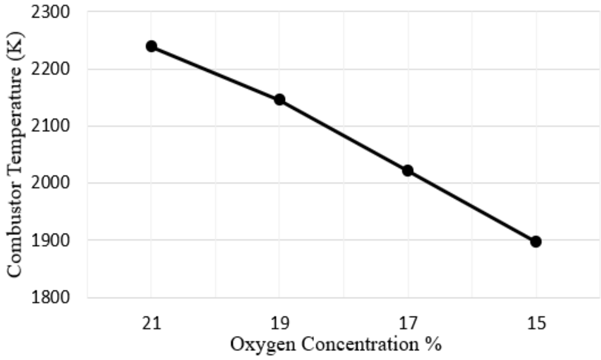

Figure 4. Combustor Temperature for O_2 Concentration

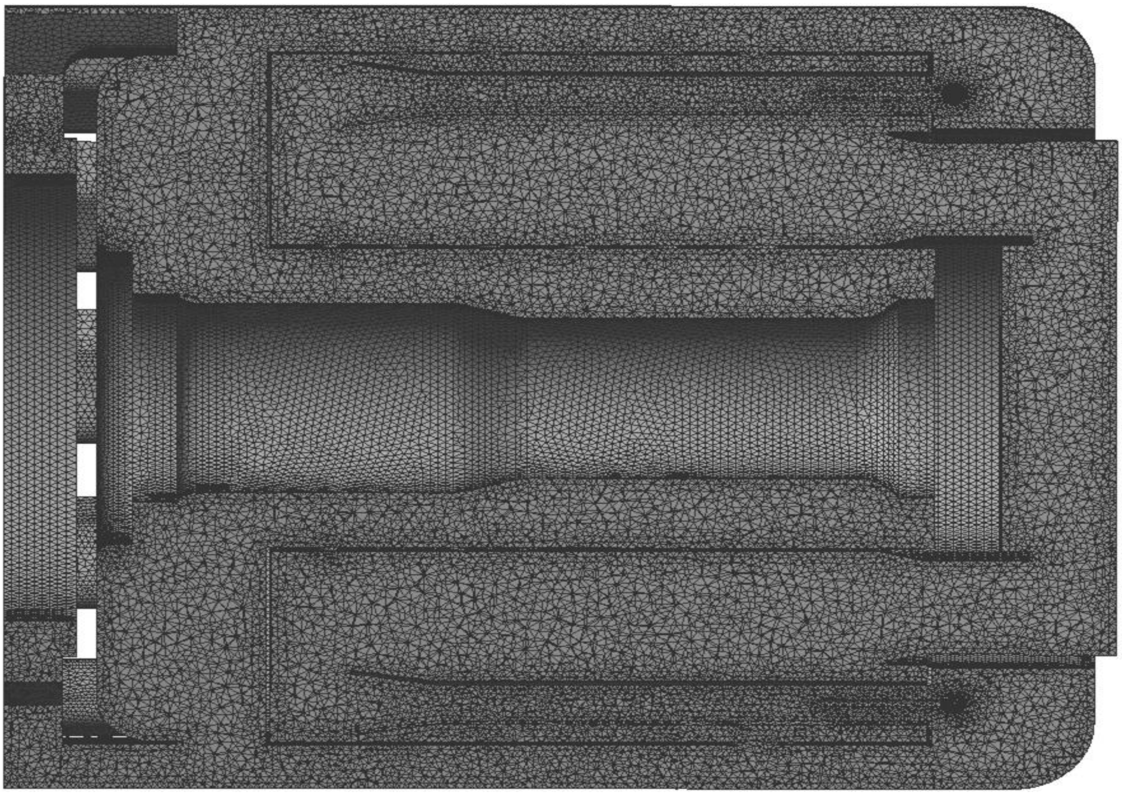

Figure 3 Figure 3. Section of Mesh Structure

For the fuel sprayed with DPM to give more accurate results, the insides of the vaporizer tubes are relatively dense.

5 CONCLUSIONS

As can be seen in Figure 4, the maximum temperature of combustion chamber is 2239 K

In the colorless distributed combustion conditions, the temperature decreased to 2146 K at a rate of 19% O_2 by increasing the N_2 ratio.
As the volumetric oxygen ratio in the oxidizing air decreased and the nitrogen ratio increased, 2022 K and 1897 K temperatures were determined at 17% O_2 and 15% O_2 ratios, respectively. When the literature is examined,

nitrogen gas does not contribute to the heating value because it is an inert gas.

On the contrary, it is known that it has the effect of diluting the combustion and lowering the flame temperature. For this reason, a 15.3% decrease in flame temperature compared to standard air combustion conditions indicates that CDC combustion conditions are met.

When Figure 5 is examined, it is seen that there is a similar decrease with temperature.

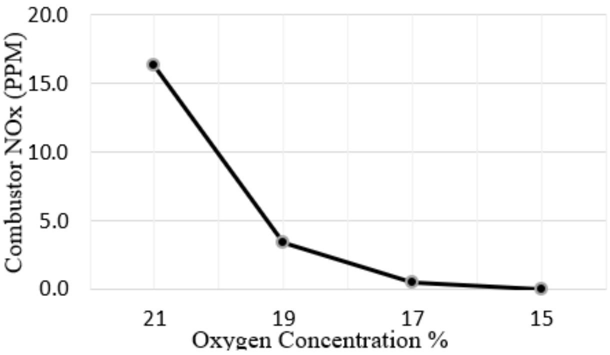

Figure 5. Combustor NOx PPM for O_2 Concentration

As it is known, one of the most dominant NO_x formation mechanisms in gas turbine engines is Thermal NO_x formation. For this reason, a significant decrease in NO_x emissions was observed with the decreasing flame temperature because of N_2 addition.

The reduction of both maximum temperature and NO_x emission shows that the CDC method can be used effectively in a real gas turbine engine.

ACKNOWLEDGEMENTS

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