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Reduction of NOx Emissions Using Algal Oil as Fuel

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ABSTRACT— In combustion process pollutant emissions have become great public concern due to their effects on health and the environment. The exhaust from an aircraft gas turbine is composed of oxides of nitrogen (NOx) ,carbon monoxide (CO), carbon dioxide (CO_2), water vapour (H_2O), unburned hydrocarbons (UHC), particulate matter (mainly carbon). NOx is the by-product of complete combustion. High temperatures lead to formations of pollutants such as oxides of nitrogen (NOx) It is majorly formed by four methods namely: Thermal NO, Nitrous Oxide Mechanism, Prompt NO and Fuel NO. NOx is toxic in nature and mainly causes Acidification and Tropospheric Ozone formation by photochemical reaction with oxygen. In this project, NOx is estimated for biofuel manufactured from Algae, which has a greater scope of being used as replacement for fossil fuels. NOx emission for Algae biodiesel is analysed using Fluent**.**

KEYWORDS— NO_X emission, Algal oil, Equivalence ratio.

I. INTRODUCTION

Oxides of nitrogen are called NO_X. During combustion, NO_X is formed by two methods. NO_x emission formed through the oxidation of nitrogen in fuel is called fuel NO_x and formed through oxidation of a portion of the nitrogen contained in the air in combustion chamber is called thermal NO_X. Thermal NOX is formed at high temperatures. Though NO_X emission from aviation industry constitutes only 2% of the total emissions but pose a serious concern as it causes acid rains and depletion of ozone layer. Various methods are available for control of NO_X emission. The method used in this paper is temperature control. The main objective of this paper is to control NO_X emission using biofuel. Reactions based upon Zeldovich mechanism for thermal NO_x:

$$O_2 = 2O$$
$$N_2 + O = NO + N$$

$$N + O_2 = NO + O$$
$$N + OH = NO + H$$

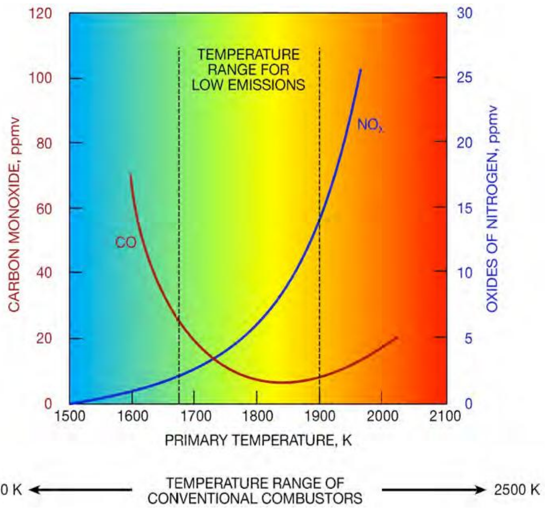


Fig 1. Level of emission of CO and NOX as a function of the primary temperature reached in the reaction zone of the combustor (*Lefebvre, 1994)*

II. ALGAL OIL

The fuel taken for analysis is algal oil (algae oil). Transestrification produces methyl esters of fatty acids, which are biodiesel, and glycerol (Fig.2). The reaction occurs stepwise: triglycerides are first converted to diglycerides, then to monoglycerides and finally to glycerol (*Yusuf chisti, 2007*).

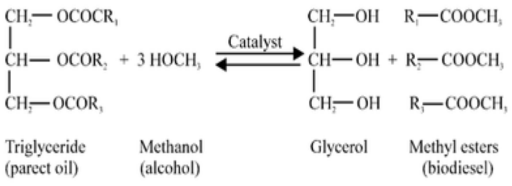
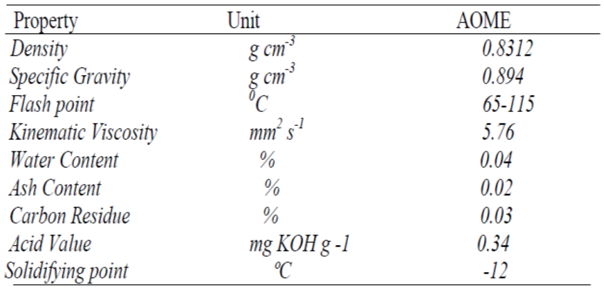


Fig.2. Transesterification of oil to biodiesel. R_{1-3} is hydrocarbon groups.

Biodiesel is a proven fuel. Technology for producing and using biodiesel has been known for more than 50 years (*Yusuf Chisti, 2007*). The table shows the properties of algal oil which are nearly equivalent to the petro-diesel oil.

Table I. Properties of AOME*



Property	Unit	AOME
Density	*g cm^{-3}*	*0.8312*
Specific Gravity	*g cm^{-3}*	*0.894*
Flash point	*^{0}C*	*65-115*
Kinematic Viscosity	*mm^{2} s^{-1}*	*5.76*
Water Content	*%*	*0.04*
Ash Content	*%*	*0.02*
Carbon Residue	*%*	*0.03*
Acid Value	*mg KOH g -1*	*0.34*
Solidifying point	*℃*	*-12*

III. GOVERNING EQUATIONS

A. *Species Transport Equations*

The local mass fraction of each species, *Yi*, through the solution of a convection-diffusion equation for the i^{th} species is given by the conservation equation:

$$\frac{\partial}{\partial t}(\rho Y_i) + \nabla \cdot (\rho \vec{v} Y_i) = -\nabla \cdot \vec{J}_i + R_i + S_i$$

Where J_i is the diffusion flux of species *i*, which arises due to gradients of concentration and temperature and R_i is the net rate of production of species *i* by chemical reaction and S_i is the rate of creation by addition from the dispersed phase.

B. *Mass Diffusion In Laminar Flows*

The dilute approximation, also called Fick’s law to model mass diffusion due to concentration gradients, under which the diffusion flux can be written as

$$\vec{J}_i = -\rho D_{i,m} \nabla Y_i - D_{T,i} \frac{\nabla T}{T}$$

$D_{i,m}$ is the mass diffusion coefficient for species *i* in the mixture, and $D_{T,i}$ is the thermal (Soret) diffusion coefficient.

C. *Mass Diffusion In Turbulent Flows*

In turbulent flows, ANSYS FLUENT computes the mass diffusion as following:

$$\vec{J}_i = -\left(\rho D_{i,m} + \frac{\mu_t}{\mathrm{Sc}_t}\right) \nabla Y_i - D_{T,i} \frac{\nabla T}{T}$$

where Sc_t is the turbulent Schmidt number (where μ_t is the turbulent viscosity and Dt is the turbulent diffusivity). The default Sc_t is 0.7.

D. *Treatment Of Species Transport In The Energy Equation*

For many multicomponent mixing flows, the transport of enthalpy due to species diffusion is given by

$$\nabla \cdot \left[\sum_{i=1}^{n} h_i \vec{J}_i\right]$$

The Lewis number

$$\mathrm{Le}_i = \frac{k}{\rho c_p D_{i,m}}$$

k is the thermal conductivity.

E. *Diffusion at Inlets*

The net transport of species at inlets consists of both convection and diffusion components. The convection component is fixed by the inlet species mass fraction. The diffusion component, however, depends on the gradient of the computed species field at the inlet.

F. *The Generalized Finite-Rate Formulation for Reaction Modeling*

Laminar finite-rate model: The effect of turbulent fluctuations is ignored, and reaction rates are determined by Arrhenius kinetic expressions.

- Eddy-dissipation model: Reaction rates are assumed to be controlled by the turbulence, so expensive Arrhenius chemical kinetic calculations can be avoided. The model is computationally cheap, but, for realistic results, only one or two step heat-release mechanisms should be used.
- Eddy-dissipation-concept (EDC) model: Detailed Arrhenius chemical kinetics can be incorporated in turbulent flames. Note that detailed chemical kinetic calculations are computationally expensive.

G. *The Eddy-Dissipation Model*

In premixed flames, the turbulence slowly mixes cold reactants and hot products into the reaction zones, where reaction occurs rapidly. In such cases, the combustion is said to be mixing-limited, and the complex and often unknown, chemical kinetic rates can be safely neglected. The eddy-dissipation model is given by:

$$R_{i,r} = \nu'_{i,r} M_{w,i} A \rho \frac{\epsilon}{k} \min_{\mathcal{R}} \left(\frac{Y_{\mathcal{R}}}{\nu'_{\mathcal{R},r} M_{w,\mathcal{R}}} \right)$$

$$R_{i,r} = \nu'_{i,r} M_{w,i} A B \rho \frac{\epsilon}{k} \frac{\sum_P Y_P}{\sum_j^N \nu''_{j,r} M_{w,j}}$$

Where YP is the mass fraction of any product species, P

YR is the mass fraction of a particular reactant, R
A is an empirical constant equal to 4.0
B is an empirical constant equal to 0.5

IV. EXPERIMENT

For analysis and estimation of NO_x emissions in an aircraft, an axisymmetric geometry of a combustor (GE DLN, Maughan et al.,1994) is considered.

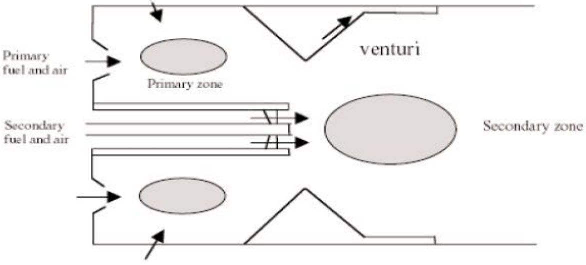


Fig.3. GE DLN combustor

The grid used in this simulation is generated using Gambit. Analysis is formed using Fluent. Cells are clustered close to the corner to capture expansion of flow. Premixed fuel-air is used in this combustor. The operating mode is lean-lean as the primary and secondary zones operate at low equivalence ratio and it also can raise turbine output to base load. The venturi prevents flashback as it accelerates as it has a converging – diverging geometry. The combustor operable temperature considered is in the range of 1500-1700 k. The equivalence ratio (Φ) of algal oil is 0.91. Mixture of algal oil and air is used.

A. Boundary Conditions

Zone-Air Inlet
    Velocity magnitude=0.5m/s
    Turbulence Intensity= 10%
    Temperature=350k
Zone- Fuel Inlet
    Velocity= 80m/s
    Turbulence Intensity= 10%
    Temperature= 350k
Zone- Outlet
    Backflow Turbulent Intensity=10%
    Temperature=350k

V.RESULT

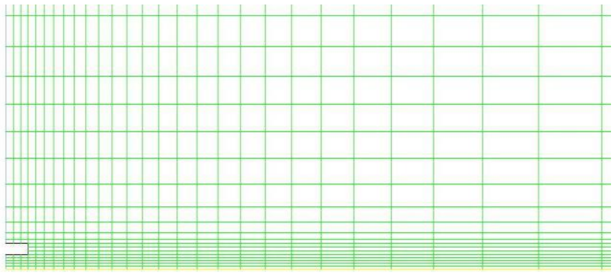


Fig.4. Grid

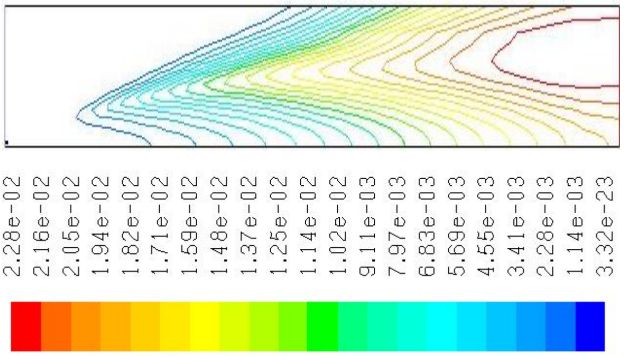


Fig.5. Mass fraction of NO_x contours

The contour of mass fraction shows that formation of NO_x is high at the exit of the combustor when compared to combustion zone. This is because in the combustor the temperature is being maintained in the range of low NO_x emission.

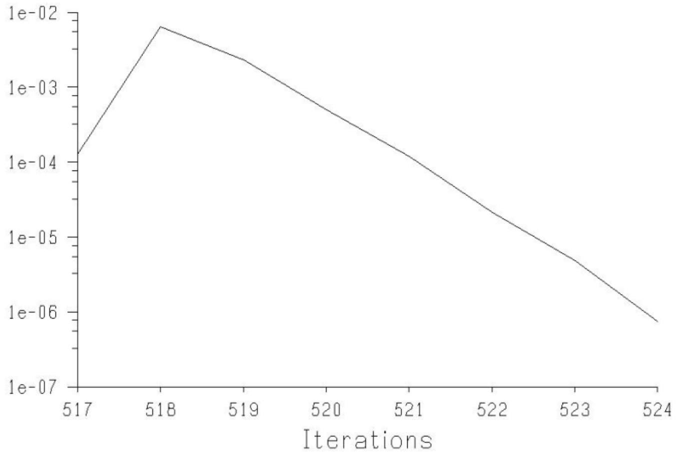


Fig.6. NO_x residuals Iterations

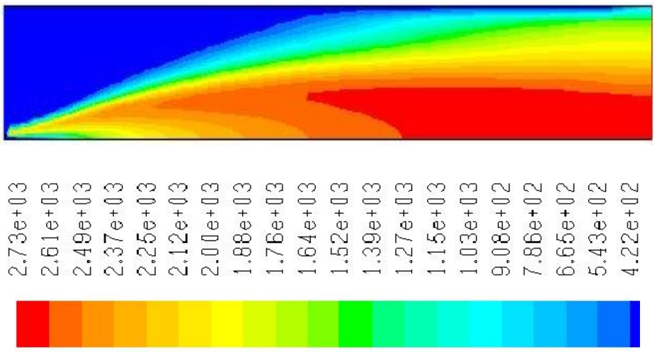


Fig.7. Static Temperature (k) contours

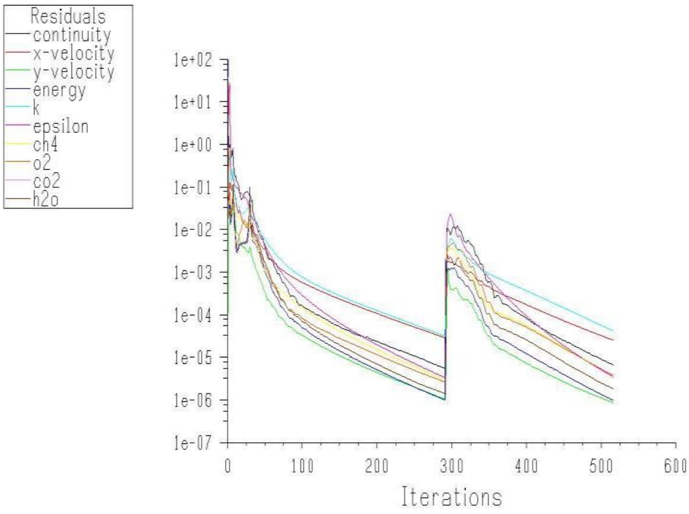


Fig.8.Residuals v/s Iterations

The premixed fuel-air is combusted in the combustor. The contours show that the temperature is high in the combustion zone.

VI.CONCLUSION

This paper is a work on NO_x emissions in aircraft engines using algal oil. This paper shows that in thermally stable combustors the NO_x emissions are low compared to high temperature varying combustors. It also supports algal oil as the best alternate fuel to fossil fuels which are costlier and much pollution causing fuels.

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