CFD ANALYSIS OF BIOFUEL (CNSL BLENDED WITH DIESEL) RUN DIESEL ENGINE

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Abstract

The world is confronted with the twin crises of fossil fuel depletion and environmental degradation. The indiscriminate extraction and consumption of fossil fuels have led to a reduction in petroleum reserves. Petroleum based fuels are obtained from limited reserves. These finite reserves are highly concentrated in certain regions of the world. Therefore, those countries not having these resources are facing a foreign exchange crisis, mainly due to the import of crude petroleum oil. Hence it is necessary to look for alternative fuels, which can be produced from resources available within the country.

The present paper investigates the use of the Cashew Nut Shell Liquid (CNSL) Biodiesel as a Alternative Fuel through experimental analysis of engine performance & CFD analysis.

In this study, biodiesel derived from CNSL blended with diesel have been chosen for testing and analysis. Several engine performance tests and CFD analysis have been carried out and initial results have been tabulated. The experiments disclose that the use of blends of CNSL and diesel as a fuel reduces the overall diesel consumption and hence dependency on diesel. Among the blends tested against diesel (B10, B15, B20), the blend B20 (20% CNSL and 80% Diesel) proved to be superior, displaying better engine performance characteristics, in comparison with diesel and the other blends.

Keyword: *Cashew Nut Shell Liquid (CNSL), blend of ethanol with biofuels, Engine Performance Characteristics, CFD Analysis***.**

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1.INTRODUCTION TO BIODIESEL

The predicted shortage of fossil fuel has encouraged the search for substitutes for petroleum derivatives. This search has resulted in an alternative fuel called "biodiesel". Bio-diesel is an alternative to petroleum-based fuels derived from vegetable oils, animal fats, and used waste cooking oil including triglycerides. Since the petroleum crises in 1970s, the rapidly increasing prices and uncertainties concerning petroleum availability, a growing concern of the environment and the effect of greenhouse gases during the last decades, has revived more and more interests in the use of biodiesel as a substitute of fossil fuels [1]. Bio-diesel production is a very modern and technological area for researchers due to the relevance that it is winning everyday because of the increase in the petroleum prices and the environmental advantages biodiesel offers over diesel. Accordingly, many researchers around the world have dealt with these issues and in many cases devised unique solutions. Countless legislative and regulatory efforts around the world have helped pave the way toward the widespread application of the concept [2].

2.BIODIESEL

The major components of vegetable oils and animal fats are triacylglycerols (TAG; often also called triglycerides). Chemically, TAG are esters of fatty acids (FA) with glycerol (1,2,3-propanetriol; glycerol is often also called glycerine). The TAG of vegetable oils and animal fats typically contain several different FA. Thus, different FA can be attached to one glycerol backbone. The different FA that are contained in the TAG comprise the FA profile (or FA composition) of the vegetable oil or animal fat. Because different FA have different physical and chemical properties, the FA profile is probably the most important parameter influencing the corresponding properties of a vegetable oil or animal fat. [2].

3.HISTORY OF BIODIESEL

The use of vegetable oils as alternative fuels has been around for one hundred years when the inventor of the diesel engine Rudolph Diesel first tested peanut oil, in his compression-ignition engine. In the 1930s and 1940s vegetable oils were used as diesel fuels from time to time, but usually only in emergency situations. In 1940 first trials with vegetable oil methyl and ethyl esters were carried out in France and, at the same time, scientists in Belgium were using palm oil ethyl ester as a fuel for buses.

Not much was done until the late 1970s and early 1980s, when concerns about high petroleum prices motivated extensive experimentation with fats and oils as alternative fuels. Bio-diesel (mono alkyl esters) started to be widely produced in the early 1990s and since then production has been increasing steadily. In the European Union (EU), bio-diesel began to be promoted in the 1980s as a means to prevent the decline of rural areas while 3 responding to increasing levels of energy demand. However, it only began to be widely developed in the second half of the 1990s [1].

Objectives:

The objectives of the study are:

- To evaluate the performance analysis of compression ignition engine fuelled with different blends of biodiesel extracted from methyl esters.
- To compare optimized biodiesel and diesel performance and emission characteristics.
- CFD Analysis Of Biofuel (CNSL Blended With Diesel) Run Diesel Engine
- Use of the Cashew Nut Shell Liquid (CNSL) Biodiesel As a Alternative Fuel for transportation sector.

Review of Related Literature

A lot of work has been done on Performance Analysis of Diesel Engine Using Cashew Nut Shell Liquid (CNSL) Biodiesel. Limited amount of work is done on the Performance Analysis and CFD analysis of combustion of Diesel Engine Using Cashew Nut Shell Liquid (CNSL) blended with ethanol as a Alternative Fuel.

In India, the high content of glycerin and free fatty acid in CSNL prevents their use in biodiesel preparation. But through fuel production process optimization (by blending of ethanol), CSNL oils are affordable for biodiesel production. Cost associated with biodiesel is reduced due to the low cost of the CSNL oils (approximately Rs 25 per liter).

Research Methodology

To meet the main aim and the specific objectives of the study a quantitative research methodology study along with a comprehensive literature review were employed. A lot of work has been done on transesterification of edible & Non edible oils. Limited amount of work is done on Cashew Nut Shell Liquid (CNSL). Limited amount of work has been done on the engine performance analysis and CFD combustion analysis fuelled with biodiesel derived from CNSL and CNSL mixed with ethonal.

4.BIODIESEL PREPRATION METHODOLOGY

Biodiesel preparation

- Cashew Nut Shell Liquid (CNSL) was blended with diesel in three different proportions creating three different blends of one litre each.
- All blends were made using a magnetic stirrer in which the different percentages by volume of CNSL and diesel were stirred continuously for 7-8 hours and then allowed to stand for at least 3-4 hours to ensure no separation of the constituents occurred.
- Blend B10 was obtained by mixing 10% by volume of CNSL (100 ml) with 90% by volume of diesel (900ml), Blend B15 was obtained by mixing 15% by volume of CNSL (150 ml) with 85% by volume of diesel (850 ml), Blend B20 was obtained by mixing 20% by volume of CNSL (200 ml) with 80% by volume of diesel (800 ml), respectively.

5. ROPERTIES OF THE SAMPLES TESTED

Table 1 Properties Of Samples Tested

Blend Ratio	Specific Gravity	Dynamic Viscosity Centipoises	Flash point °C	Fire Point °C	pH	Calorific Value KJ/Kg
Diesel	0.85	4.450	96	117	8-9	45000
5%	0.900	4.560	120	135	6.6	43670
10%	0.908	5.619	118	128	6.6	42058
15%	0.912	5.643	105	122	6.5	42000
20%	0.920	6.550	103	118	6.4	43976
25%	0.936	7.786	101	113	6.4	42824
100%	1.024	116.66	-	-	5.6	37969

6.ENGINE SPECIFICATIONS

MAKE: KIRLOSKAR
CAPACITY: 3.7kw
COMPRESSION RATIO: 16.5:1
CYLINDER BORE: 80mm
STROKE: 110mm
CYLINDER CAPACITY: 553cc
COOLING: water cooled
LOADING: Eddy Current Dynamometer
MAKE: Power MAG
SPEED: 1500RPM
EXCITATION VOLTAGE: 80V

7.RESULT ANALYSIS AND DISCUSSION

On the basis of experiments carried out so far tables have been made for the performance and emission characteristics for each of the blends tested on the diesel engine. Using these tables CFD analysis have been plotted to give a better idea of each blend is in comparison to conventional diesel.

The engine is run at a speed of 1500RPM and is loaded using an Eddy Current Dynamometer.

8.ENGINE PERFORMANCE TEST

Performance Tables

The time required to consume 10cc of the fuel for different blends at different loads is measured along with the exhaust gas temperature and air flow rate.

Table 2. PERFORMANCE CHARACTERISTICS – DIESEL

SL.NO	TORQUE (N-M)	TIME TO CONSUME 10 CC (SECONDS)	EXHAUST GAS TEMPERATURE (DEGREES C)	AIR FLOW RATE (m^3/Hr)
1	**0**	**95.28**	**174**	**14.1**
2	**5**	**70.34**	**238**	**13.8**
3	**10**	**54.35**	**314**	**13.8**
4	**15**	**43.44**	**394**	**13.8**
5	**20**	**34.25**	**499**	**13.8**

Table 3. PERFORMANCE CHARACTERISTICS – B10

SL.NO	TORQUE (N-M)	TIME TO CONSUME 10 CC (SECONDS)	EXHAUST GAS TEMPERATURE (DEGREES C)	AIR FLOW RATE (m^3/Hr)
1	0	102.41	174	14.1
2	5	73.81	232	13.8
3	10	55.16	305	13.8
4	15	42.90	395	13.8
5	20	35.94	498	13.4

Table 4 PERFORMANCE CHARACTERISTICS – B15

SL.NO	TORQUE (N-M)	TIME TO CONSUME 10 CC (SECONDS)	EXHAUST GAS TEMPERATURE (DEGREES C)	AIR FLOW RATE (m^3/Hr)
1	0	98.41	178	13.8
2	5	74.03	232	13.8
3	10	55.25	310	13.8

Table 5 PERFORMANCE CHARACTERISTICS – B20

SL.NO	TORQUE (N-M)	TIME TO CONSUME 10 CC (SECONDS)	EXHAUST GAS TEMPERATURE (DEGREES C)	AIR FLOW RATE (m^3/Hr)
1	0	93.87	172	14.1
2	5	70.06	238	13.8
3	10	55.41	304	13.8

4	15	44.50	379	13.8	4	15	43.94	391	13.8
5	20	35.01	490	13.4	5	20	34.82	519	13.4

9.CFD ANALYSIS

The meshing of the domain has been done using ANSYS WORKBENCH. The Mesh has been generated through the Automatic Method that results in a uniform grid constituting of tetrahedral elements.

In FLUENT, the complete set of the nonlinear partial differential equations is discretized in each control volume via the divergence theorem to construct algebraic equations for the discrete dependent variables and conserved scalars. A Gauss-Seidel linear equation solver is used in conjunction with an algebraic multigrid (AMG) method to solve the resultant scalar system of equations for the dependent variable in each cell. We employed the segregated solver to solve sequentially the momentum balance and mass conservation equations. The coupling between velocity and pressure is achieved through the Semi-Implicit Method for Pressure-Linked Equations (SIMPLE) algorithm.[15]

There are two kinds of solvers available in FLUENT:

- Pressure based
- Density based

The pressure based solvers take pressure and momentum as primary variables. There are two algorithms available with pressure based solver, namely:

- Segregated Solver: Solves for pressure correction and momentum sequentially.
- Coupled Solver: Solves pressure and momentum simultaneously

The density based coupled solver solves equations of continuity, momentum and energy in a vector form.

11.PROCEDURE

1. The Piston model is initially created using SolidWorks 2014
2. This model is then imported to ANSYS Workbench
3. A suitable mesh is generated and the relevant inlet and outlet ports are identified
4. The appropriate conditions for the solver are entered viz.:

➢ Energy Equation = ON
➢ Viscous Flow = k – epsilon
➢ Radiation = P1
➢ Species = Non – premixed condition

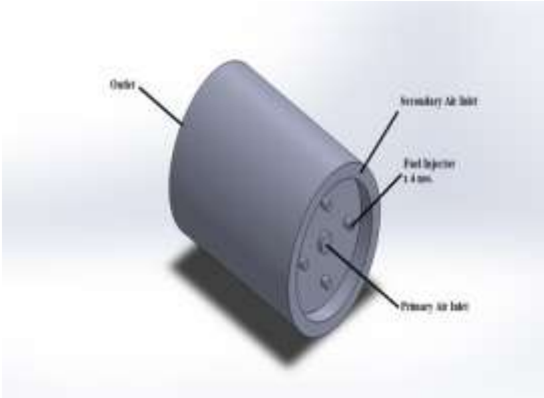
Energy Equation: determines if energy was supplied before entering domain or if there is an energy source present in the domain (in this case, the fuel).
Viscous Flow: determines the fluidity of the media present in the domain. ‘k-epsilon’ model is used since the molecular viscosity is low and the fluid is very turbulent due to combustion and subsequent release of energy.
Radiation: determines the material of domain, whether it is a black body, white body, or grey body. ‘P1’ implies a grey body i.e. mid-level absorption and emission.
Species: determines whether the fluid is uniform, consists of multiple streams that are mixed beforehand or after entering the domain. ‘Non-premixed condition’ enables us to input air and fuel in 2 separate streams with varied flow rates to best mimic combustion in a piston.

5. Each blend was quantified by mass fractions of species in the CFD model.
6. Using a MatLab program, the mass flow rates of the fuel and air are computed and results implemented in the model.
7. As diesel is composed almost entirely of saturated and aromatic hydrocarbons, we expressed the fuel mixture in terms of mass fraction of CH_4 (Σmass fractions = 1).

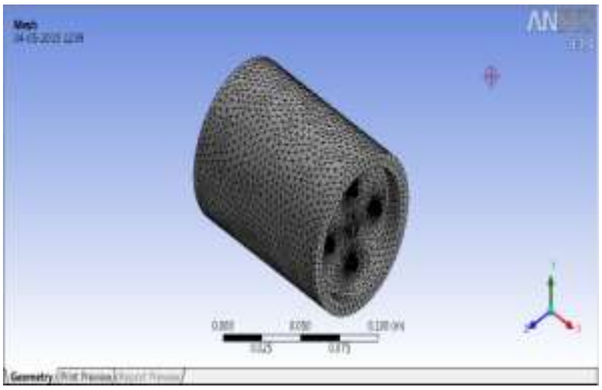
12.PISTON DIMENSIONS

- Bore = 85 mm
- Stroke = 110 mm
- Fuel Injectors = 5 mm dia x 4 nos.
- Primary Air = 10 mm dia

PISTON MODEL



PISTON MESH



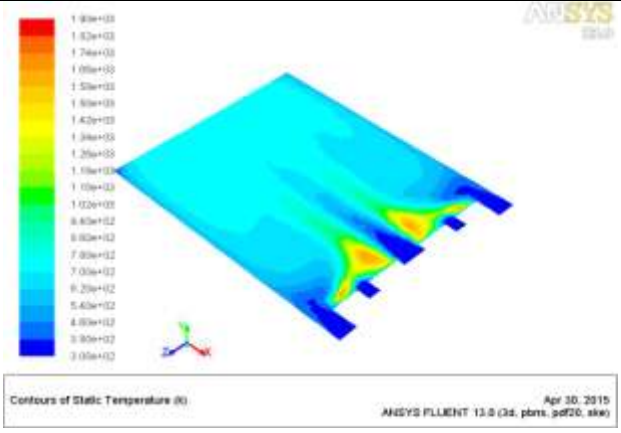
Mesh Details:

- We generated a patch conforming tetrahedron automatic mesh which discretises the domain into 20253 nodes and 107403 elements
- The maximum face size is 4.0608e-3
- The minimum face size is 4.30608e-5

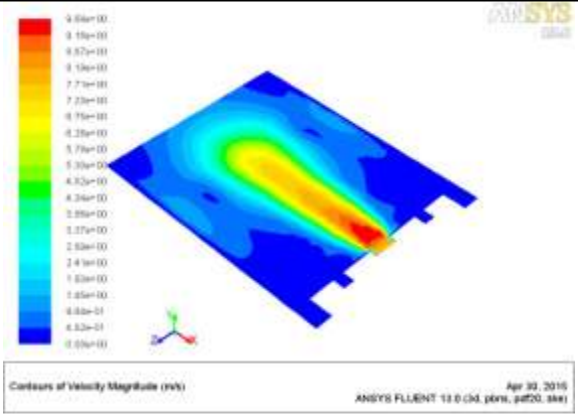
Using Ansys Software, the temperature contour, Velocity Contour, OH Mass Fraction Contour and O_2 Mass Fraction Contour CFD simulation has done for different blends B10, B15 & b20 respectively. [16]

B10 BLEND (10% CNSL and 90% Diesel)

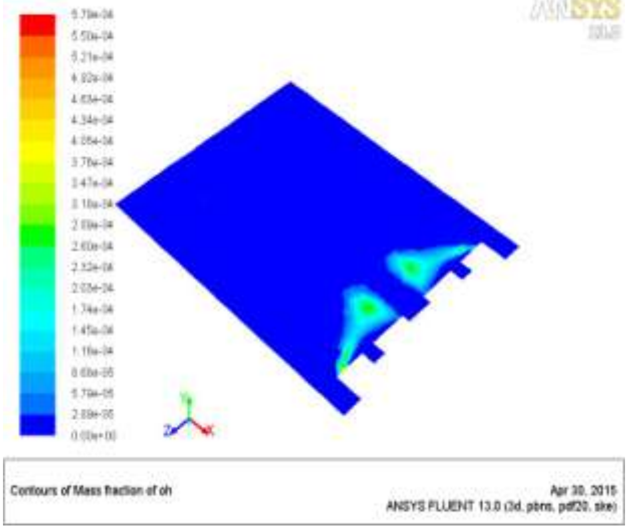
Fuel Species Mass Fractions:	Mass Flow Rates:
• CH_4 = 0.9	• Fuel Injector = 1.3196e-5 kg/s
• N_2 = 0.079	• Primary Air = 7.1978e-4 kg/s
• O_2 = 0.021	• Secondary Air = 2.39925e-4 kg/s



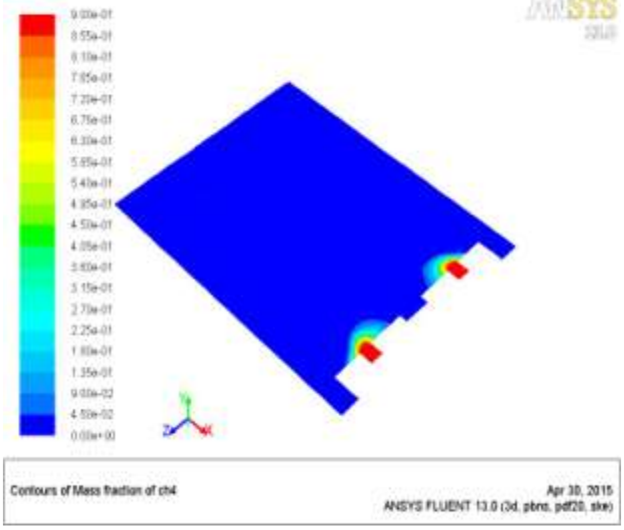
B10 Temperature Contour



B10 Velocity Contour



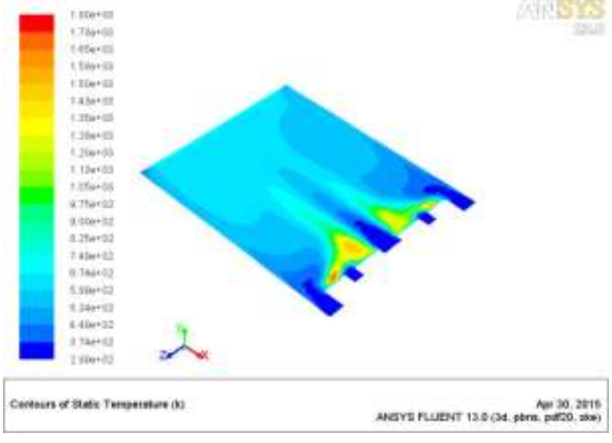
B10 OH Mass Fraction Contour



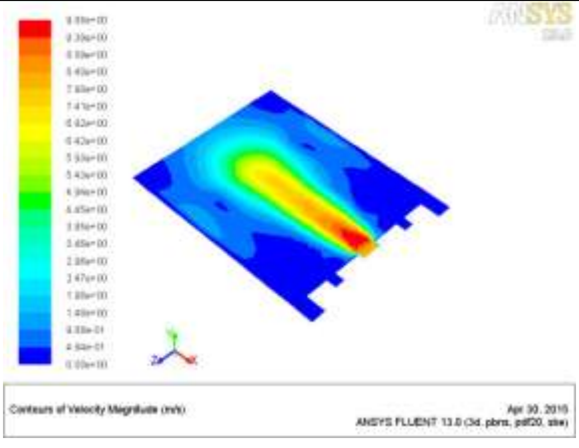
B10 CH_4 Mass Fraction Contour

B15 BLEND (15% CNSL and 85% Diesel)

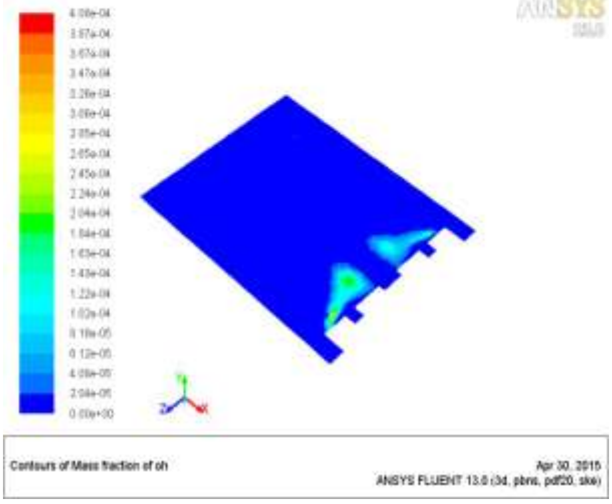
Fuel Species Mass Fractions:	Mass Flow Rates:
• CH_4 = 0.85 • N_2 = 0.1185 • O_2 = 0.0315	• Fuel Injector = 1.3482e-5 kg/s • Primary Air = 7.3539e-4 kg/s • Secondary Air = 2.4513e-4 kg/s



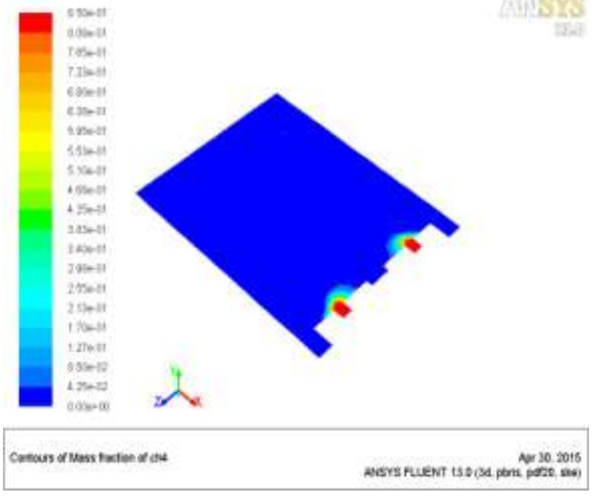
B15 Temperature Contour



B15 Velocity Contour



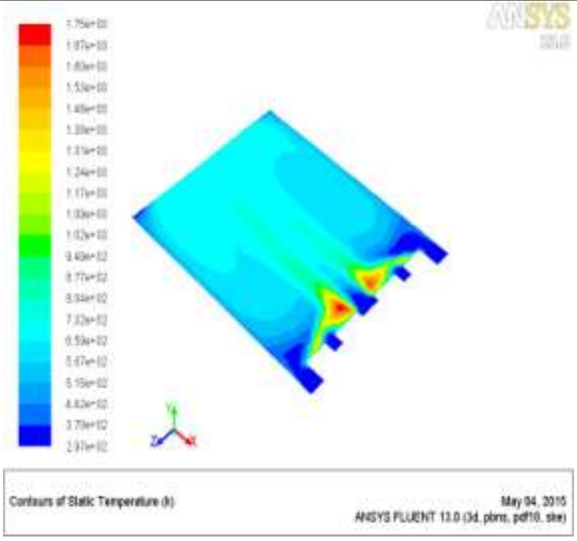
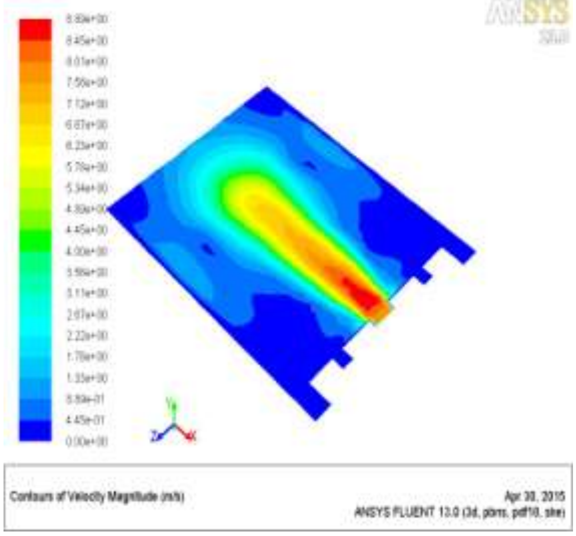
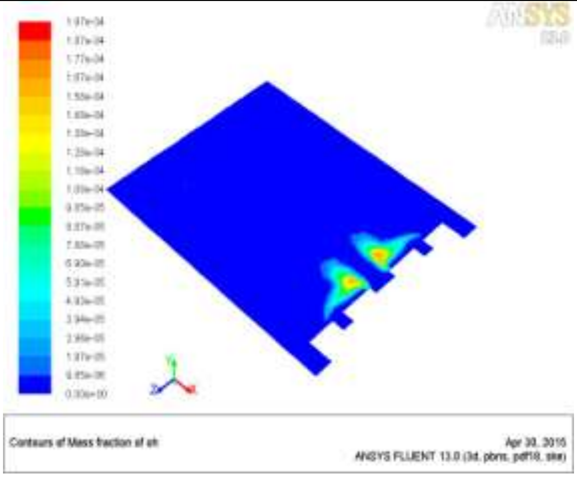
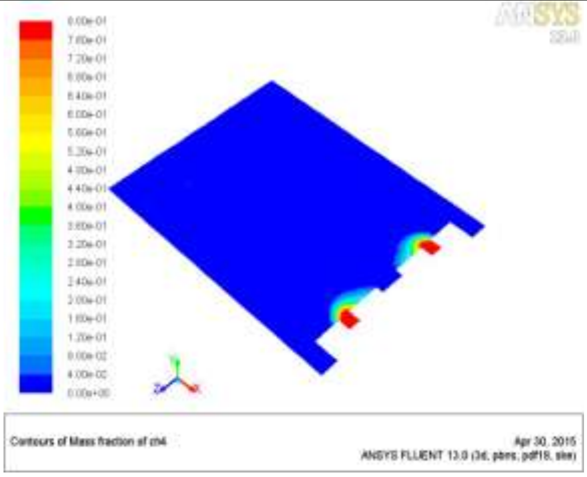
B15OH Mass Fraction Contour



B15 CH_4 Mass Fraction Contour

B15 BLEND (20% CNSL and 80% Diesel)

Fuel Species Mass Fractions:	Mass Flow Rates:
• CH_4 = 0.8 • N_2 = 0.158 • O_2 = 0.042	• Fuel Injector = 1.2831e-5 kg/s • Primary Air = 6.9986e-4 kg/s • Secondary Air = 2.3329e-4 kg/s

 B20 Temperature Contour	 B20 Velocity Contour
 B20 OH Mass Fraction Contour	 B20 CH_4 Mass Fraction Contour

13.OBSERVATIONS AND INFERENCE

1. All blends show complete combustion of biodiesel
2. This is evidenced by the mass fraction of CH4 i.e. there are no remnants of the fuel left in the piston at the end of combustion
3. This indicates less knocking and good combustion efficiency
4. The mass fraction of O2 shows there is surplus supply of air that ensures good combustion as well as easy exhaust of flue gases
5. The temperature contours help us visualise the flame propagation through the piston during combustion of the fuel
6. Higher temperature regimes at the flame front generally indicate better combustion characteristics

7. The mass fraction of OH serves as a good indicator of combustion since this by-product is relatively easy to form (low enthalpy of formation)
8. Thus, the B20 Blend, with highest concentration of OH species and high temperature regimes is ideally suited for use as corroborated by the mathematical model

14.CONCLUSION

1. Testing of B5, B10, B15 and B20 Blends reveals they would be ideal substitutes for conventional mineral based fuel
2. As evidenced by the mathematical as well as CFD analysis, the B20 Blend is superior to the other blends
3. Testing of B25 Blend was halted due to its high viscosity. Pre-heating may be necessary to counter this problem, but this will add to the expenditure
4. The Cost Benefit Analysis validates the monetary benefit of using the B20 Blend, saving Rs. 4.58364 per litre of unmixed diesel
5. The ease of access to CNSL makes this blend a viable option, furthering the need, importance and effectiveness of biofuels

15.FUTURE WORK

- Biofuels ensure utilisation of agricultural wastes such as husks, shells, roots etc.
- GM crops grown specifically for biofuels
- Although it is unlikely that biofuels will completely replace conventional fossil fuels, the blends will help retain this fast exhausting energy resource
- Application of CFD analysis for differential density fuel separation (fractional distillation)
- Analysis of flow over and through porous body suspended in fluid container

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