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HEAT TRANSFER PERFORMANCE AND CFD ANALYSIS OF COMBUSTION CHAMBER USED IN IC ENGINE

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ABSTRACT: Internal combustion engines are seen every day in automobiles like trucks, and buses and other power generation purposes. The name internal combustion refers also to gas turbines except that the name is usually applied to reciprocating internal combustion (I.C.) engines like the ones found in everyday automobiles. There are basically two types of I.C. ignition engines, those which need a spark plug, and those that rely on compression of a liquid. Spark ignition engines take a mixture of fuel and air, compress it, and ignite it with help of a spark plug.

In this thesis, the combustion chamber is designed according to the IC engine specifications and analyzed for its heat transfer rate using Finite Element analysis software ANSYS and calculate emissions . Modeling will be done in CREO parametric software. CFD analysis to determine the pressure drop, velocity and heat transfer coefficient and to finding the emissions (O_2, N2) of ethane and methane (mass fraction, mole fraction and mole concentration of methane and ethane).

Key words: combustion chamber, emissions, CFD analysis.

1.INTRODUCTION: The diesel engine (also known as a compression-ignition or CI engine), named after Rudolf Diesel, is an internal combustion engine in which ignition of fuel is done after spraying it into the combustion chamber where air is compressed into elevated temperature and pressure due to mechanical compression (adiabatic compression). Diesel engines work by compressing only the air. This increases the air temperature inside the cylinder to such a high degree that atomized diesel fuel that is injected into the combustion chamber ignites spontaneously. While in a gasoline engine i.e a SI engine a suitable mixture of air and fuel is induced into the combustion chamber with the help of a carburetor and the ignition is done by a spark plug . In diesel engines, glow plugs (combustion chamber pre-warmers) may be used to aid starting in cold weather, or when the engine uses a lower compression-ratio, or both. The original diesel engine operates on the "constant pressure" cycle of gradual combustion and produces no audible knock.

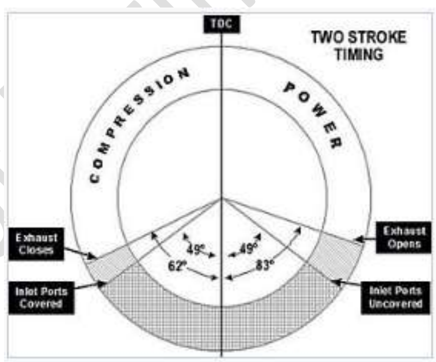

Fig 1.1 Detroit Diesel timing

OPERATING PRINCIPLE: Diesel internal combustion engine differs from the gasoline powered Otto cycle by using highly compressed hot air to ignite the fuel rather than using a spark plug (compression ignition rather than spark ignition).

In the true diesel engine, only air is initially introduced into the combustion chamber. The air is then compressed with a compression ratio typically between 15:1 and 23:1. This high compression causes the temperature of the air to rise. At about the top of the compression stroke, fuel is injected directly into the compressed air in the combustion chamber. This may be into a (typically toroidal) void in the top of the piston or a pre-chamber depending upon the design of the engine. The fuel injector ensures that the fuel is broken down into small droplets, and that the fuel is distributed evenly. The vapour is then ignited by the heat from the compressed air in the combustion chamber, the droplets continue to vaporize from their surfaces and burn, getting smaller, until all the fuel in the droplets has been burnt. Combustion occurs at a substantially constant pressure during the initial part of the power stroke. The start of vaporization causes a delay before ignition and the characteristic diesel knocking sound as the vapour reaches ignition temperature and causes an abrupt increase in pressure above the piston.

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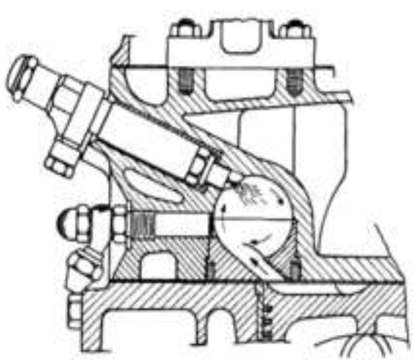
Major Advantages

- Diesel engines have several advantages over other internal combustion engines:
- Diesel fuel has higher energy density and a smaller volume of fuel is required to perform a specific amount of work.
- Diesel engines inject the fuel directly into the combustion chamber, have no intake air restrictions apart from air filters and intake plumbing and have no intake manifold vacuum to add parasitic load and pumping losses resulting from the pistons being pulled downward against intake system vacuum. Cylinder filling with atmospheric air is aided and volumetric efficiency is increased for the same reason.
- Heavier fuels like diesel fuel have higher cetane ratings and lower octane ratings, resulting in increased tendency to ignite spontaneously and burn completely in the cylinders when injected. Increased compression ratios create higher combustion chamber temperatures to ignite the injected fuel. Higher compression ratios increase pumping losses as more work is required to compress intake air to a smaller volume, but pumping loss increases are offset by increased power and efficiency. Increasing compression ratios in spark-ignition engines requires higher octane fuels that are harder to ignite and burn completely and/or advanced spark timing to avoid pre-ignition, knocking and resulting performance losses and engine damage. Power gains from increased compression ratios are reduced in spark-ignition engines while the pumping losses remain comparable to similar compression ratio increases in diesel engines.

1.2 INJECTION

The process of introducing the fuel charge in to the combustion chamber with required pressure with the help of various injectors and the process is done by various methods.

1.2.1 Indirect Injection



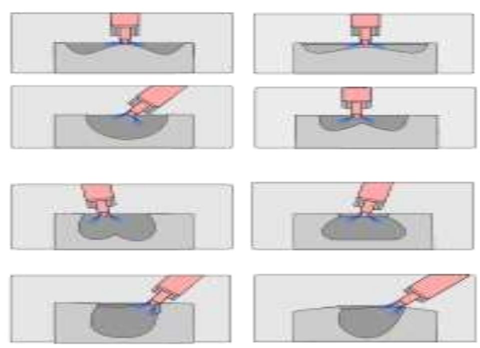


Fig .1.2 Ricardo Comet indirect injection chamber

Fig1.3. Direct injection chamber

An indirect diesel injection system (IDI) engine delivers fuel into a small chamber called a swirl chamber, pre combustion chamber, pre chamber or ante-chamber, which is connected to the cylinder by a narrow air passage. Generally the goal of the pre chamber is to create increased turbulence for better air / fuel mixing. This system also allows for a smoother, quieter running engine, and because fuel mixing is assisted by turbulence, injector pressures can be lower. Most IDI systems use a single orifice injector. The pre-chamber has the disadvantage of lowering efficiency due to increased heat loss to the engine's cooling system, restricting the combustion burn, thus reducing the efficiency by 5–10%.. IDI engines are also more difficult to start and usually require the use of glow plugs. IDI engines may be cheaper to build but generally require a higher compression ratio than the DI counterpart. IDI also makes it easier to produce smooth, quieter running engines with a simple mechanical injection system since exact injection timing is not as critical. Most modern automotive engines are DI which have the benefits of greater efficiency and easier starting; however, IDI engines can still be found in the many ATV and small diesel applications.

1.2.2 Direct Injection: Different types of piston bowls direct injection diesel engines inject fuel directly into the cylinder. Usually there is a combustion cup in the top of the piston where the fuel is sprayed. Many different methods of injection can be used.

Electronic control of the fuel injection transformed the direct injection engine by allowing much greater control over the combustion.

EMISSIONS

Since the diesel engine uses less fuel than the petrol engine per unit distance, the diesel produces less carbon dioxide (CO_2) per unit distance. Recent advances in production and changes in the political climate have increased the availability and awareness of biodiesel, an alternative to petroleum-derived diesel fuel with a much lower net-sum emission of CO_2, due to the absorption of

CO_2 by plants used to produce the fuel. However, the use of waste vegetable oil, sawmill waste from managed forests in Finland, and advances in the production of vegetable oil from algae demonstrate great promise in providing feed stocks for sustainable biodiesel that are not in competition with food production.

DEFINATIONS

Mass fraction (weight fraction) and percent by mass (percent by weight) are measurements of the concentration of a solution. Mass fraction (weight fraction) is the ratio of the mass of one component of a solution to the total mass of the solution.

Mole fraction is another way of expressing the concentration of a solution or mixture. It is equal to the moles of one component divided by the total moles in the solution or mixture.
a = the component that is being identified for mole fraction
Mole fraction is used in a variety of calculations, but most notably for calculating partial pressures.

$$\text{Mole Fraction } (\chi_a) = \frac{\text{moles of a}}{\text{total moles}}$$

2. PROBLEM DESCRIPTION: In this thesis, the combustion chamber is designed according to the IC engine specifications and analyzed for its heat transfer rate using Finite Element analysis software ANSYS and calculate emissions . Modeling will be done in CREO parametric software. CFD analysis to determine the pressure drop, velocity and heat transfer coefficient and to finding the emissions (O_2, N2) of methane and ethane (mass fraction, mole fraction and mole concentration of methane and ethane).

3. LITERATURE REVIEW

Arka Ghosh B. Tech. (Mechanical Engineering), SRM University, Kattankulathur, T.N., India [1] – 603203 CI engines are widely used in stationary as well as mobile applications. Stationary applications include typical gen-set, etc. and mobile applications include heavy automobiles, forestry equipments, etc. as well as other applications in day-to-day life. Since the turbulence is necessary for better mixing and the fact that it can be controlled by shape of the combustion chamber, makes this review paper necessary. This paper re-visits and draws on the essentials of combustion chamber, their design, influence in combustion process, timing, etc. This paper is meant to emphasize research on newer designs requirement for combustion chambers. CI engines find widespread applications due to their robustness, high compression ratio and hence high thermal efficiency and usage of non-volatile fuel generally diesel oil.

Nagasundaram.S1, Nester Ruban.J2 [2] Design and Analysis of an Internal Combustion Engine Piston Head to Increase the Torque on Crankshaft The in-cylinder air motion in internal combustion engines is one of the most important factors controlling the combustion process combustion efficiency of CI engine and emissions especially NOx can be controlled by creating turbulence, by designing intake system, by designing combustion chamber. A good swirl promotes fast combustion to improve the efficiency. So in the present work a study about the influence of air swirl in the combustion chamber upon the performance and emission of a diesel engine is studied. The intensification of the swirl is studied on the crown of the piston by three different configurations of Models are, Mitsubishi, Pan and Shallow Hasselman. CFD analysis is carried out on a diesel engine using different configuration pistons which is four stroke engine cylinder air cooled and constant speed. Performance parameters such as turbulent kinetic energy and turbulent intensity and turbulent dissipation are calculated. CREO is parametric used for design and Ansys IC Engine Solver 15.0 is used for analysis.

4 INTRODUCTION TO CAD: Computer-aided design (CAD) is the use of computer systems (or workstations) to aid in the creation, modification, analysis, or optimization of a design. CAD software is used to increase the productivity of the designer, improve the quality of design, improve communications through documentation, and to create a database for manufacturing. CAD output is often in the form of electronic files for print, machining, or other manufacturing operations. The term **CADD** (for Computer Aided Design and Drafting) is also used.

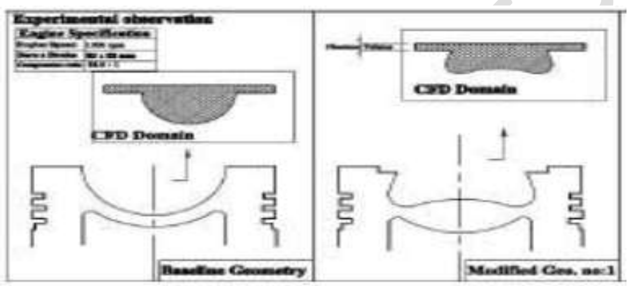
INTRODUCTION TO CREO: PTC CREO, formerly known as Pro/ENGINEER, is 3D modeling software used in mechanical engineering, design, manufacturing, and in CAD drafting service firms. It was one of the first 3D CAD modeling applications that used a rule-based parametric system. Using parameters, dimensions and features to capture the behavior of the product, it can optimize the development product as well as the design itself.

4.1 Table Representing Engine specification

Parameter	Magnitude
Engine Speed	1550 rpm
Mass Flow Rate	0.00111055 kg/s
Spray Cone Angle	55 Deg.
Start Crank Angle	360 Deg.
Stop crank Angle	720 Deg.

4.2 Table Representing Input parameter of CFD domain

Parameter	Magnitude
Crank shaft speed	1550 rpm
Crank radius	56 mm
Bore	85 mm
Stroke	85 mm
Fuel	Diesel $C_{10}H_{26}$



4.1 ORIGINAL MODEL **4.2 MODIFIED MODEL**

Figures shows required combustion chamber of original and modified model

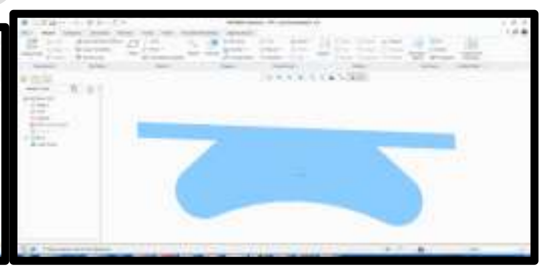


Fig 4 .3 Original model of combustion chamber **Fig 4.4 Required combustion chamber**

Figure shows required combustion chamber profile that should be in closed loops then its convert into 3D surface by using fill option in CREO

5. INTRODUCTION TO FEA: Finite element analysis is a method of solving, usually approximately, certain problems in engineering and science. It is used mainly for problems for which no exact solution, expressible in some mathematical form, is available. As such, it is a numerical rather than an analytical method. Methods of this type are needed because analytical methods cannot cope with the real, complicated problems that are met with in engineering. For example, engineering strength of materials or the mathematical theory of elasticity can be used to calculate analytically the stresses and strains in a bent beam, but neither will be very successful in finding out what is happening in part of a car suspension system during cornering.

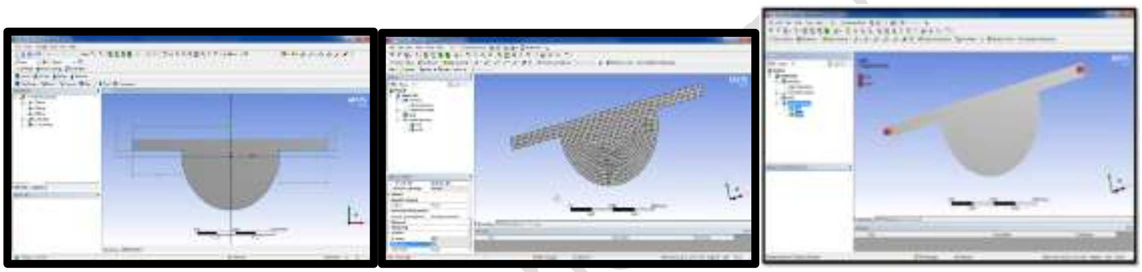
COMBUSTION CHAMBER: Computational methodology and Boundary condition For CFD analysis viscous standard k-e RNG standard model is enabled for considering volumetric reaction and eddy dissipation. Domain is subjected to motion of piston suitable boundary condition for piston, cylinder, fluid and cylinder walls. Combustion process in a C.I engine involves the transient injection of finely atomized liquid fuel into the air at high temperature and pressure. Boundary condition location of the injector, size of the injector, injection temperature and pressure, mass flow rate are having significant effect in diesel combustion modeling. The injection mass flow rate parameters and Engine specifications are given below Table 1 Engine specification Parameter Magnitude Engine Speed 1550 rpm Mass Flow Rate 0.00111055 kg/s Spray Cone Angle 55 Deg. Start Crank Angle 360 Deg. Stop crank Angle 720 Deg.

Table 5.1 Engine specification

Parameter	Magnitude
Engine Speed	1550 rpm
Mass Flow Rate	0.00111055 kg/s
Spray Cone Angle	55 Deg.
Start Crank Angle	360 Deg.
Stop crank Angle	720 Deg.

5.1Imported model

The geometry of the C.I engine is modeled in CREO software. that file is converted into IGES format to import in ANSYS software. The model of combustion chamber is saved in IGES format which can be directly imported into ANSYS workbench. The model imported to ANSYS workbench



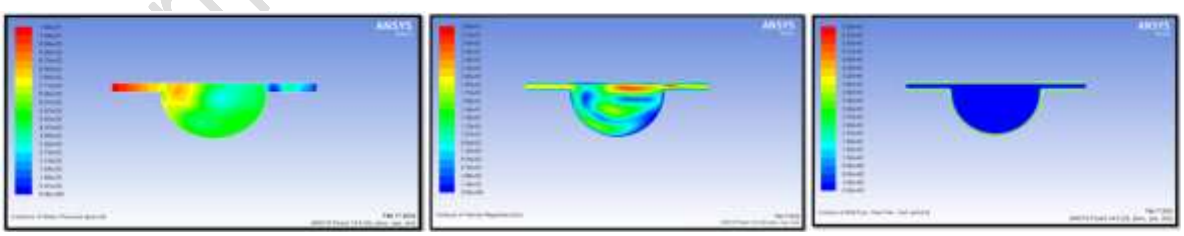
(a) (b) (c)

Fig (a) Imported CFD domain combustion chamber original model shows in fluid flow fluent

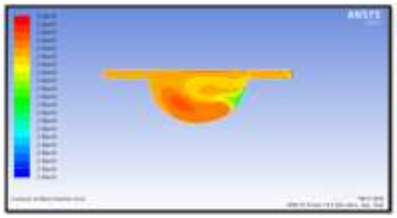
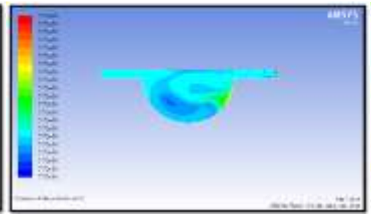
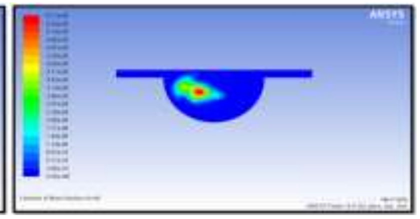
Fig (b) Model with 859 numbers of nodes and 781 numbers of tetrahedral elements.

Fig (c) Inlet and outlet conditions

Boundary conditions are a required component of the mathematical model. Boundaries direct motion of flow. Specify fluxes into the computational domain, e.g. mass, momentum, and energy. Fluid and solid regions are represented by cell zones. Material and source terms are assigned to cell zones. Boundaries and internal surfaces are represented by face zones. Boundary data are assigned to face zones.



(d) (e) (f)

(g) (h) (i)

Fig (d) Fluid – Methane + Air Pressure Fig (g) Mass fraction of O_2

Fig (e) Velocity of Methane Fig (h) Mass fraction of N_2

Fig (f) Heat transfer coefficient of Methane Fig (i) Mass fraction of CH_4

5.2 MODIFIED MODEL OF COMBUSTION CHAMBER : The modified geometry of the C.I engine is modeled in CREO software. That file is converted into IGES format to import in ANSYS software. The model of combustion chamber is saved in IGES format which can be directly imported into ANSYS workbench. The model imported to ANSYS workbench

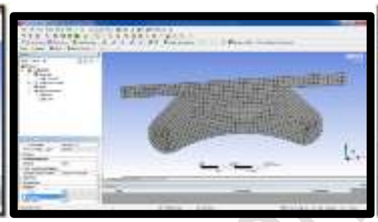




Fig 5.2.1 Modified model Fig 5.2.2 Meshed model Fig 5.2.3 Inlet and outlet conditions

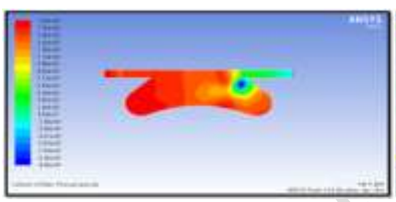
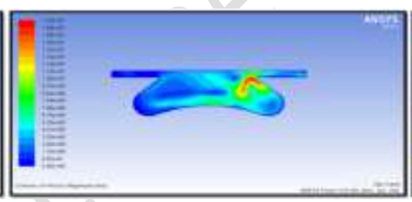
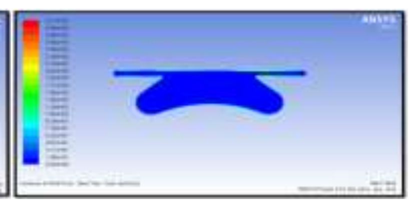




Fig 5.2.4 Fluid – Methane + Air Pressure Fig 5.2.5 Velocity Fig 5.2.6 Heat transfer coefficient

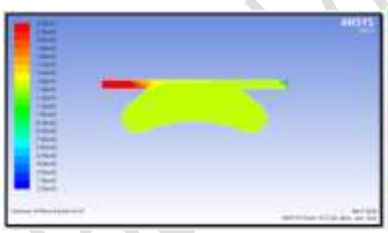
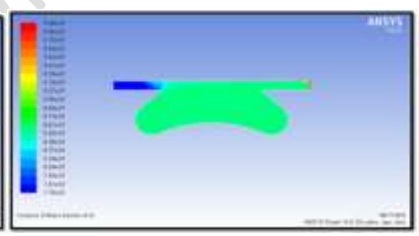
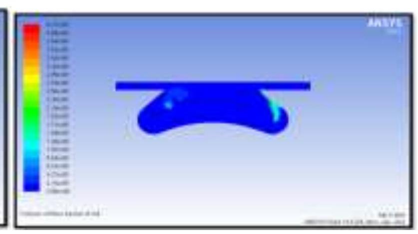




Fig 5.2.7 Mass fraction of O_2 Fig 5.2.8 Mass fraction of N_2 Fig 5.2.9 Mass fraction of CH_4

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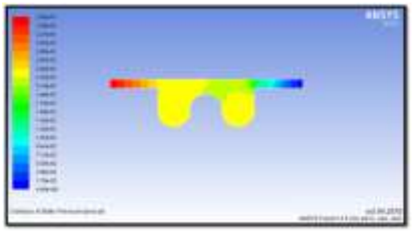
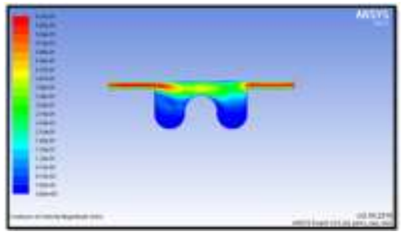
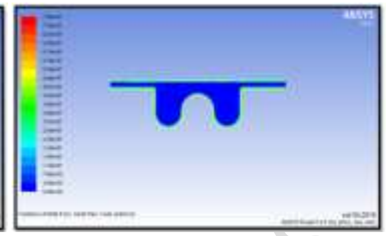
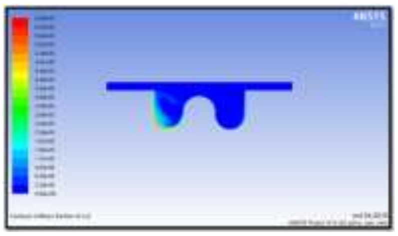
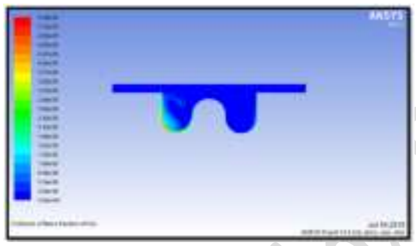
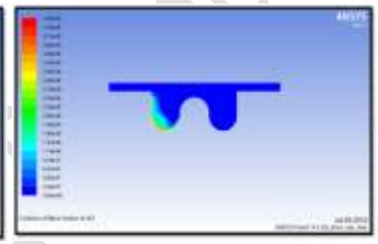
3rd MODEL

FLUID – METHANE + AIR

Pressure **Velocity** **Heat transfer coefficient**

Mass fraction of CO_2 **Mass fraction of H_2O** **Mass fraction of CH_4**

6 RESULTS AND DISCUSSIONS The present work is to compare the various parameters like pressure velocity heat transfer: coefficient mass fraction for the fuels methane and ethane in the modified combustion chamber and for original models.

6.1 Table comparing the values of Methane and Ethane for Original and Modified Models

Variable		**Modified Model**		**Original Model**	
		Methane(CH_4) + air	**Ethane(C_2H_6) + air**	**Methane(CH_4) + air**	**Ethane(C_2H_6) + air**
Pressure(Pa)		1.84e+02	9.62e-02	1.09e-01	1.38e-01
Velocity (m/s)		1.76e+01	2.58e-01	2.88e-01	3.44e-01
Heat transfer coefficient (w/m^2-k)		3.11e+02	6.37e+01	6.00e+01	6.00e+01
Mass	**O_2**	2.30e-01	2.30e-01	2.30e-01	2.30e-01
	N_2	9.98e-01	7.72e-01	7.70e-01	7.70e-01
	CH_4/ C_2H_6	4.27e-08	1.38e-09	5.71e-09	6.00e-09
Mole	**O_2**	2.08e-01	2.7e-01	2.07e-08	2.07e-01
	N_2	9.17e-01	7.93e-01	7.93e-01	7.93e-01
	CH_4/ C_2H_6	3.16e-08	1.32e-09	1.03e-08	5.75e-09
Mass concentration	**O_2**	8.76e-03	8.43e-03	8.43e-03	8.43e-03
	N_2	3.80e-02	3.22e-02	3.22e-02	3.22e-02
	CH_4/ C_2H_6	1.31e-09	5.37e-11	4.17e-10	2.34e-10

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Result table 3rd model

Variables		METHANE+AIR	ETHANE+AIR	DIESEL+ AIR
Pressure(Pa)		$3.56e^{-01}$	$3.43e^{-01}$	$3.37e^{-01}$
Velocity (m/s)		$6.10e^{-01}$	$6.30e^{-01}$	$6.32e^{-01}$
heat transfer coefficient(w/m2-k)		$7.68e^{+01}$	$7.68e^{+01}$	$7.68e^{+01}$
Mass fraction	CO_2	$6.55e^{-05}$	$3.53e^{-05}$	$2.39e^{-05}$
	H_2O	$5.39e^{-05}$	$3.04e^{-05}$	$1.92e^{-05}$
	$CH_4/C_2H_6/C_{10}H_{22}$	$4.58e^{-06}$	$3.13e^{-06}$	$2.73e^{-06}$
Mole fraction	CO_2	$1.17e^{-05}$	$8.18e^{-06}$	$1.48e^{-05}$
	H_2O	$2.35e^{-05}$	$2.17e^{-05}$	$2.58e^{-05}$
	$CH_4/C_2H_6/C_{10}H_{22}$	$3.07e^{-06}$	$2.36e^{-06}$	$4.11e^{-07}$
Molar concentration	CO_2	$1.63e^{-07}$	$1.14e^{-07}$	$2.07e^{-07}$
	H_2O	$3.28e^{-07}$	$3.78e^{-07}$	$3.60e^{-07}$
	$CH_4/C_2H_6/C_{10}H_{22}$	$4.29e^{-08}$	$3.29e^{-08}$	$5.74e^{-09}$

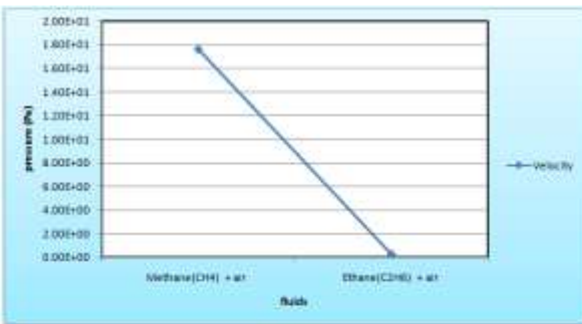

Fig. 6.1 Pressure variation in modified model for Methane and Ethane

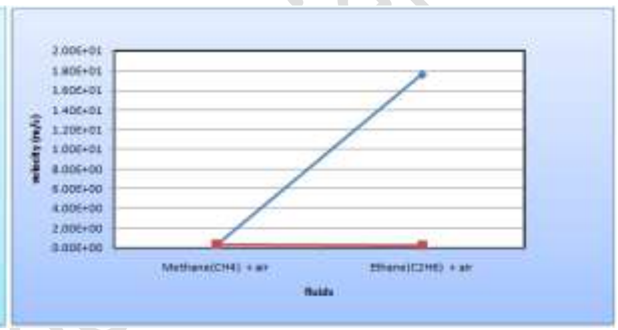

Fig. 6.2 Velocity for Methane v/s Ethane

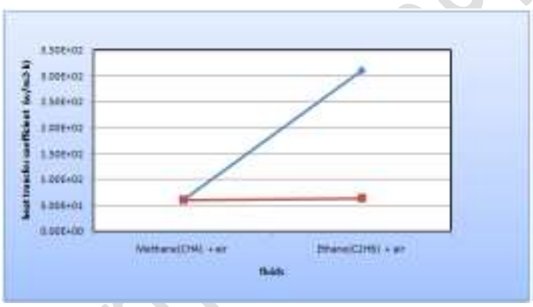

Fig. 6.3 Heat transfer coefficient for Methane v/s Ethane

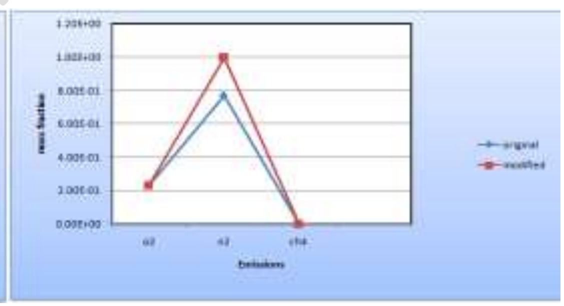

Fig. 6.4 Mass fraction for original v/s modified model

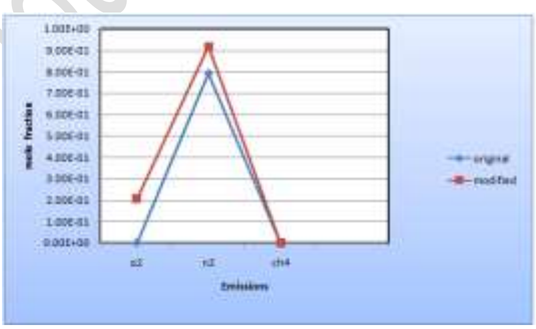

Fig. 6.5 Mole fractions for original v/s modified model

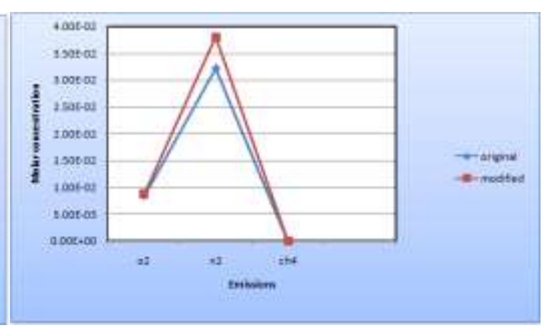

Fig. 6.6 Figure representing pressure variation for original v/s modified model

Fluid- Ethane +Air

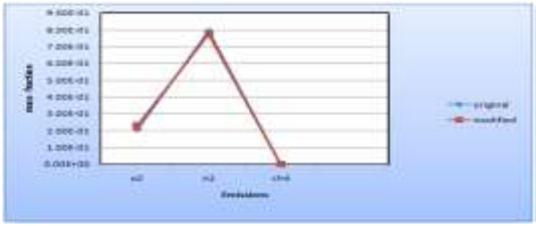

Fig. 6.7 Mass fraction for original v/s modified model

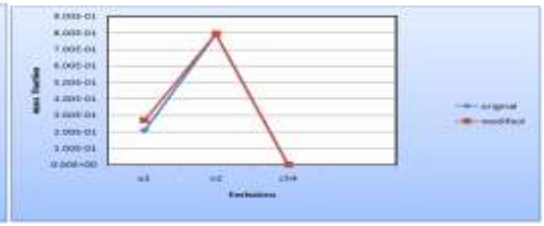

Fig. 6.8 Mole fraction for original v/s modified Model

Discussions:

From the above **Tabel:6.1** it is observed that Modified geometry for methane + air combination, velocity increases by 2.1 % when compared to existed geometry due to shape. Therefore, it is observed that the existed geometry is suited for industrial use but for less formation of .Modified geometry results in higher velocity compared to the existed geometry .

Tabel: 6.1 show Heat transfer coefficients for methane and ethane fluids. The maximum heat transfer coefficients for methane is 3.11e+02 and ethane is 6.37e+01 . Hence modified model using methane +air as a combination has high heat transfer coefficient

ii) Mass concentrations for the modified model for O2, N2 concentration are more for methane and ethane when compared with original model.

CONCLUSION

In this thesis, the combustion chamber is designed according to the IC engine specifications and analyzed for its heat transfer rate using Finite Element analysis software ANSYS and calculate emissions . Modeling will be done in CREO parametric software. CFD analysis to determine the pressure drop, velocity and heat transfer coefficient and to finding the emissions (O_2, N2) of methane and ethane (mass fraction, mole fraction and mole concentration of methane and ethane). By observing the CFD analysis of combustion chamber the original model have emission of methane and ethane for original and modified model. Compare with the combustion chamber models the mass concentration value and heat transfer coefficient value is more for modified model of combustion chamber. And when we compare the fluids of combustion chamber the mass concentration of methane value is more.

So it can be concluded the combustion chamber modified model and fluid methane+ air combination fluid is better performance.

FUTURE SCOPE

In interior ignition motors, fumes gas distribution (EGR) is a nitrogen oxide (NO.x) discharges decrease system utilized in oil/gas and diesel motors. EGR works by recalculating a bit of a motor's fumes gas back to the motor chambers.

1. The combustion chamber can be designed as Rankine profile by varying the dimensions uniformly in all axes.
2. Number of variation and the different injection pressure of nozzle may be considered for the different profile combustion chamber.
3. A variety of fuel may be used to study the affect of chamber profile variation in performance parameters of engine and vibrations.
4 EGR with turbochargers may be used for the studies of performances and vibrations of engine with the above combination.
5. Artificial Neural Network, Genetic Algorithms and Surface Response Method may be used to identify the influential factor/parameters.
6. Heat release rate, turbulence parameters, thermodynamic properties and flow field variables to be calculated from simulation for different profile with normal as well as EGR conditions.

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DESIGN AND ANALYSIS OF C.I ENGINE COMBUSTION CHAMBER USING CFD

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