Combustion modeling of IC engine using methane gas as a fuel: A Review

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Abstract- *Combustion model of engine is defined as a physically based description of the engine combustion process, which predicts the mass burning rate and the flame geometry as functions of engine design and operating variables. The methane gas is considered as a fuel in this study. The single oxidation of methane with oxygen to form carbon dioxide and water vapor is taken in to use. Prediction of turbulent flame speed at different equivalence ratio and engine speed is carried out in FLUENT software. Turbulent flame speed for C.I and S.I engine can be predicted by using non-premixed combustion, premixed Combustion and partially premixed combustion models. For that, it is necessary to understand the concept of non-premixed combustion, premixed combustion and partially premixed combustion models. Understanding of spark ignition, flame kernel developments, and flame propagation in spark-ignition engines and ability to model the critical aspects of these processes.*

I. INTRODUCTION

Turbulent flame speed for C.I and S.I engine can be predicted by using non-premixed combustion, premixed Combustion and partially premixed combustion models. For that, it is necessary to understand the concept of non-premixed combustion, premixed combustion and partially premixed combustion models.

Non-premixed combustion

In non-premixed combustion, fuel and oxidizer enter the reaction zone in distinct streams. This is in contrast to premixed systems, in which reactants are mixed at the molecular level before burning. An example of non premixed combustion includes diesel engines, aircraft gas turbines, coal furnaces, and pool fires.

Premixed combustion

In premixed combustion, fuel and oxidizer are mixed at the molecular level prior to ignition. Combustion occurs as a flame front propagating into the unburnt reactants. An example of premixed combustion includes petrol (S.I) engines, lean burn gas turbines, household burners, and bunsen burner (blue flame regime).

Partially premixed combustion

Partially premixed combustion model is based on the non-premixed combustion model and the premixed combustion model. An example of partially premixed combustion includes direct injection (DI) petrol engines and aircraft gas turbines.

Includes hypothesis of the model and analysis. Hypothesis includes flame structure, species diffusion, chemical species involved, and chemical equilibrium. The methane gas is taken as fuel and single oxidation of methane with oxygen to form carbon dioxide and water vapor is considered. Pressure, temperature and volume at the different strokes are calculated by analysis of the engine cycle. This chapter also includes setup and solution procedure for premixed combustion models.

II. LITERATURE REVIEW

Sunil U. S. Moda[1] has done computational investigation of heavy fuel feasibility in a gasoline direct injection spark ignition engine. A computational model has been developed to explore the feasibility of heavy fuel in a gasoline direct injection spark ignition engine. A geometrical model identical to that of the Pontiac Solstice 2008 is developed using ANSYS Gambit 2.4. To generate high-quality meshes and to accurately represent the piston motion, dynamic layering and local re-meshing techniques are utilized. A parametric study is performed on injection timing and particle size in order to determine the engine operating characteristics using diesel fuel instead of gasoline. As the diesel is a heavy fuel it vaporizes slowly and it has a lower auto ignition time. So, the gasoline operating conditions will not suit the diesel operating conditions. To tackle this problem a parametric study is needed to find out the operating conditions suitable for diesel in a DISI engine. However, doing experimental parametric study is very expensive and time taking. They used ANSYS Fluent to investigate the heavy fuel feasibility in Pontiac Solstice 2008 engine which is a direct injection spark ignition engine. The strategies used in their work involve control surface modeling, flow volume meshing, validating computational models in combustion simulation, and parametric study on injection time and droplet size using heavy fuel. Results demonstrate that it is feasible to use diesel fuel in DISI engine and get a similar performance as that of gasoline fuel.

Rashid Ali and Dr Nafis Ahmad - have done the modeling of turbulent flame velocity for spark ignition engines. The model reported a thorough hypothetical study on fire speed in sparkle ignition motor for iso-octane air blend. The model created is a zero-dimensional thermodynamic model. PC recreations have been performed for the turbulent fire speed of premixed fire. The correlation has been made between the fire speed got from the present model to the hypothetical and test fire speeds that are accessible in the writing for the extensive variety of motor working parameters, for example, leeway stature, thickness proportion, proportionality proportion fire span, motor pace and unburnt blend temperature. The correlation demonstrates a decent assention between the fire speed acquired from the present model with the test and hypothetical fire speed.

Muhsin M. Ameen and R.V. Ravikrishna [2] proposed an EDC based turbulent premixed integrating so as to burn model the lucid fire model with the adjusted vortex scattering idea, and relating the fine structure mass division to the fire surface thickness. To begin with, exploratory consequences of turbulent fire speed accessible from writing are contrasted and the anticipated results at distinctive turbulence intensities to accept the fire surface thickness model. It is watched that the model has the capacity anticipate the turbulent smoldering speeds precisely. At that point a thorough acceptance is done using information on a turbulent lifted methane fire issuing into a vitiated co-stream Nitty gritty correlation of temperature and species focuses in the middle of test and reenactment is performed at diverse statures of the fire In general, the model is found to anticipate both the spatial variety and top estimations of the scalars at different statures satisfactorily.

J. Helie and A Trouve [3] have built up a changed reasonable fire model to portray turbulent fire engendering in blends with variable piece. direct infusion flash ignition motors highlight both substantial and little scale spatial varieties in unburned blend structure. Alterations of the reasonable fire model (CFM) are proposed in the study to represent the impacts of variable blend quality on the essential premixed fire, too concerning the arrangement of an auxiliary non-premixed response zone downstream of the premixed fire. The space of legitimacy of the present adjustments is confined to the instance of little varieties in blend quality, without the extra intricacy of premixed fire eradication. In this improved however fairly bland setup, two profoundly distinctive circumstances are anticipated: for varieties in blend quality around mean stoichiometric conditions, unmixedness tends to have a net negative effect on the turbulent fire speed; interestingly, for varieties in blend quality near as far as possible, unmixedness tends to have a net positive effect on the turbulent fire speed. While highlighting a limited area of legitimacy, the proposed alterations to the CFM set the premise for future advancements and are appropriate specifically for an expansion of the model to the instance of burning with events of premixed fire elimination.

Combustion Modeling Theory

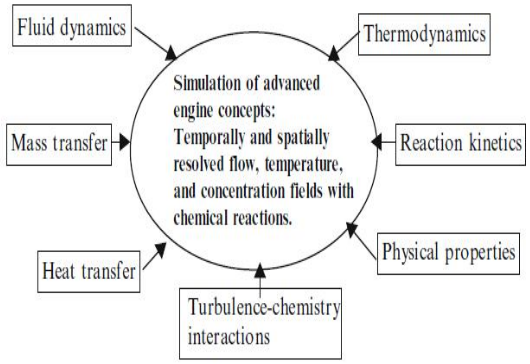
The fundamental source of power in an internal combustion engine is the combustion of the charge. The combustion generates the heat and pressure which is extracted during the expansion stroke and converted into crankshaft torque. Improving the effectiveness of the combustion in an IC engine will directly improve engine performance. Factors affecting the combustion in an internal combustion engine include:

- Fuel properties, including air to fuel ratio, fuel vaporization and fuel chemistry.
- Air properties, including air temperature and pressure, and quantity of residual exhaust gases from previous strokes.
- Gas motion factors, including charge velocity and turbulence during combustion.
- Ignition factors, including spark plug design, spark energy and spark duration.
- Geometric factors, including combustion chamber geometry, spark plug location and
- Combustion chamber wall temperatures.

Modeling of Combustion Processes in IC Engines

Numerical models are useful tools for studying combustion processes inside an engine as well as for assisting in the design of advanced engines. It presents the various physical models needed for simulation of I.C engines. Due to the complexity of interactions among the different processes involved in an engine, a detailed model may demand impractically large time to compute. Advancements in both computational fluid dynamics (CFD) and various sub models have been made in the last two decades, and large-scale simulations using parallel computers are now run.

The amount of time required to calculate detailed chemistry can be quite severe. An estimate of required times depend upon time scales with the total number of grid cells used in CFD. In engine CFD, grid cells are used to resolve the



details of the flow field, with each cell storing values of local temperature, velocity, pressure, and chemical composition.

Modeling Premixed Combustion [2]

In premixed combustion, fuel and oxidizer are mixed at the molecular level prior to ignition. Combustion occurs as a flame front propagating into the unburnt reactants. Examples of premixed combustion include aspirated internal combustion engines, lean-premixed gas turbine combustors, and gas-leak explosions .Premixed combustion is much more difficult to model than non-premixed combustion. The reason for this is that premixed combustion usually occurs as a thin, propagating flame that is stretched and contorted by turbulence. For subsonic flows, the overall rate of propagation of the flame is determined by both the laminar flame speed and the turbulent eddies. The laminar flame speed is determined by the rate that species and heat diffuse upstream into the reactants and burn. To capture the laminar flame speed, the internal flame structure would need to be resolved, as well as the detailed chemical kinetics and molecular diffusion processes. Because practical laminar flame thicknesses are of the order of millimeters or smaller, resolution requirements are usually unaffordable The effect of turbulence is to wrinkle and stretch the propagating laminar flame sheet, increasing the sheet area and, in turn, the effective flame speed. The large turbulent eddies tend to wrinkle and corrugate the flame sheet, while the small turbulent eddies, if they are smaller than the laminar flame thickness, may penetrate the flame sheet and modify the laminar flame structure.Non-premixed combustion, in comparison, can be greatly simplified to a mixing problem. The essence of premixed combustion modeling lies in capturing the turbulent flame speed, which is influenced by both the laminar flame speed and the turbulence.In premixed flames, the fuel and oxidizer are intimately mixed before they enter the combustion device Reaction then takes place in a combustion zone that separates unburnt reactants and burnt combustion products. Partially premixed flames exhibit the properties of both premixed and diffusion flames. They occur when an additional oxidizer or fuel stream enters a premixed system, or when a diffusion flame becomes lifted off the burner so that some premixing takes place prior to combustion

The turbulent premixed ignition model, includes the arrangement of a vehicle mathematical statement for the response progress variable. The conclusion of this mathematical statement is taking into account the meaning of the turbulent fire speed.

Propagation of the Flame Front

In numerous mechanical premixed frameworks, ignition happens in a flimsy fire sheet. As the fire front moves, ignition of unburnt reactants happens, changing over unburnt premixed reactants to smoldered items. The premixed ignition demonstrate in this way considers the responding stream field to be partitioned into locales of smoldered and unburnt species, isolated by the fire sheet. For calculation of impeccably premixed turbulent ignition, it is common practice to characterize the progress variable c (for unburned gas c = 0 and for the product gas c = 1. The transport equation is as following

$$\frac{\partial \bar{\rho}\tilde{c}}{\partial t} + \frac{\partial}{\partial x_j}\left(\bar{\rho}\tilde{u}_j\tilde{c}\right) = -\frac{\partial y}{\partial x}\left(\overline{\rho u_j'' c''}\right) + \bar{\rho}\tilde{W}$$

Where

t = time,

x_j and u_j the coordinate and flow velocity component respectively.

ρ = the gas density

$\tilde{W}$ = mean rate of product creation

Reynolds averages denoted by overbears as well as the farve average such as $\bar{\rho}\,\tilde{c} = \overline{\rho c}$ are used where $c'' = c - \tilde{c}$ and $c' = c = \bar{c}$.

Farve averaging

Let be any dependent variable. This variable can be decomposed into a mean part and a fluctuating part using a density weighted average in the following way:

$$\tilde{\emptyset} = \frac{\int_T \rho(t)\,\emptyset(t)dt}{\int_T \rho(t)dt} = \frac{\overline{\rho\emptyset}}{\bar{\rho}}$$

Where overbars (e.g) denote averages using the Reynolds decomposition.

Auxiliary relation include

$$\overline{\rho \emptyset''} = 0$$
$$\overline{\rho \emptyset''} = \bar{\rho}\tilde{\emptyset} = \overline{\rho \emptyset}$$

Favre averaging is utilized as a part of compressible stream to discrete turbulent vacillations from the mean-stream. Much of the time it is not important to utilize Favre averaging however, since turbulent variances frequently don't prompt any critical changes in thickness. All things considered Reynolds averaging system can be utilized. Just in exceedingly compressible streams and hypersonic streams it is important to perform the more unpredictable Favre averaging.

Turbulent Flame Speed

- The way to the premixed burning model is the forecast of Ut, the turbulent popularity speed typical to the mean surface of the fire. The turbulent fire velocity is impacted by the accompanying:
- laminar fire speed, which is, thusly, controlled by the fuel focus, temperature, and sub-atomic dissemination properties, and also the point by point synthetic energy
- Flame front wrinkling and stretching by large eddies, and flame thickening by small eddies.

The turbulent flame speed is computed by

$$U_t = A(u')^{3/4} U_l^{1/2} \alpha^{-1/4} l_t^{1/4}$$
$$U_t = Au' \left(\frac{\tau_t}{\tau_c}\right)^{1/4}$$

Where

A = model constant

u' = RMS (root-mean-square) velocity (m/s)

U_l = laminar flame speed (m/s)

α = k/cp = molecular heat transfer coefficient of unburnt mixture (thermal difusivity) (m^2/s)

l_t = turbulence length scale (m)

$\tau_t = l_t / u^1$ turbulence time scale (s)

The turbulence length scale is computed from

$$l_t = C_D \frac{(u')^3}{\epsilon}$$

ϵ = is the turbulence dissipation rate.

The model is in view of the suspicion of harmony little scale turbulence inside the laminar fire, bringing about a turbulent fire speed expression that is absolutely as far as the expansive scale turbulent parameters. The default estimation of 0.52 for An is prescribed, and is suitable for most premixed flares. The default estimation of 0.37 for Compact disc ought to likewise be suitable for most premixed flares.

Laminar Flame Speed

Laminar fire rate is a property of a flammable blend. It is the pace at which an un-extended laminar fire will proliferate through a calm blend of unburned reactants. The laminar fire velocity can be indicated as steady, or as a client characterized capacity. A third choice shows up for non-adiabatic premixed and somewhat remixed flares and is taking into account the connection proposed by Meghalchi and Keck [23]

$$U_l = U_{l,ref}\left(\frac{T_u}{T_{u,ref}}\right)^{\gamma}\left(\frac{\rho_u}{\rho_{u,ref}}\right)^{\beta}$$

T_u and p_u are the unburnt reactant temperature and pressure ahead of the flame, $T_{u,ref}$ = 298K and $p_{u,ref}$ = 1atm.

The reference laminar flame speed, $U_{l,ref}$, is calculated from

$$U_{1,ref} = C_1 + C_2(\emptyset - C_3)^2$$

Where $\emptyset$ is the equivalence ratio ahead of the flame front, and C_1, C_2 and C_3 are fuel specified constants. The exponents α and β are calculated from,

$$\gamma = 2.18 - 0.8(\emptyset - 1)$$
$$\beta = -0.16 + 0.22(\emptyset - 1)$$

Limitations of the Premixed Combustion Model

The following limitations apply to the premixed combustion model:

- The premixed ignition model is not accessible with the thickness based solver. So weight based solver ought to be taken into utilization.
- The premixed ignition model is substantial just for turbulent, subsonic streams. These sorts of blazes are called deflagrations. Blasts, additionally called explosions, where the burnable blend is touched off by the warmth behind a stun wave, can be demonstrated with the limited rate model utilizing the thickness based solver.

The premixed combustion model cannot be used in conjunction with the pollutant (that is, soot and NOx) models. However, a perfectly premixed system can be modeled with the partially premixed model, which can be used with the pollutant models. It is not possible to use the premixed combustion model to simulate reacting discrete-phase particles, because these would result in a partially premixed system. Only inert particles can be used with the premixed combustion model.

III. CONCLUSION

Reproduction of single chamber four stroke flash ignition motor of magnificence bicycle for premixed burning model has been done in Familiar using so as to program methane gas as fuel. Deduced in this model is that turbulent fire pace increments with expansion in identicalness proportion, turbulent fire rate increments with increment in motor pace. Turbulent fire velocity is higher at bay side contrast with outlet side.

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