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Simulation of Combustion Process with Delayed Entry Technique Using Discrete Approach for Hydrogen Fuelled Engine

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ABSTRACT -- ***The rapidly increasing worldwide demand for energy and the progressive depletion of fossil fuels has led to an intensive research for alternative fuels which can be produced on a renewable basis. Hydrogen in the form of energy will almost certainly be one of the most important energy components of the early next century. Hydrogen is a clean burning and easily transportable fuel. Most of the pollution problems posed by fossil fuels at present would practically disappear with Hydrogen since steam is the main product of its combustion. This Paper deals with the modeling of Suction and Compression Processes for Hydrogen Fuelled S.I.Engine and also describes the safe and backfire free Delayed entry Technique. A four stroke, Multicylinder, Naturally aspirated, Spark ignition engine, water cooled engine has been used to carrying out of investigations of Suction Process. The Hydrogen is entered in the cylinder with the help of Delayed Entry Valve. This work discusses the insight of suction process because during this process only air and Hydrogen enters in to cylinder, which after combustion provides power. Simulation is the process of designing a model of a real system and conduction experiment with it, for the purpose of understanding the behavior of the design. The advent of computers and the possibilities of performing numerical experiments may provide new way of designing S.I.Engine. In fact stronger interaction between Engine Modelers, Designers and Experimenters may results in improved engine design in the not-to-distant future. A computer Programme is developed for analysis of suction and Compression processes. The parameter considered in computation includes engine speed, compression ratio, ignition timing, fuel-air ratio and heat transfer. The results of computational exercise are discussed in the paper.***

KEYWORDS: Computer simulation, Mathematical model, Suction Process, Delayed Entry Technique, Hydrogen Fuel

INTRODUCTION

Internal Combustion Engines are those engines in which combustion of fuels takes place inside the engine and hence the chemical energy is converted in to thermal energy, which is further converted into mechanical work. The present acute shortage of conventional fuels has necessitated the need for alternate fuel research. Hydrogen, which can be produced from natural gas or water, is proved to be a practical and potential alternate fuel for the I.C. Engine. The replacement of hydrocarbons by Hydrogen in automotive vehicles is expected to results in a considerable reduction in environmental pollution, since the harmful emission of unburned hydrocarbons and oxides of nitrogen are either avoided or minimized. With Hydrogen as a fuel, the engine exhaust is free from carbon monoxide and hydrocarbon emission, except very small quantities, which may be due to the combustion of lubricating oil. Further it does not contain sulfur, lead compounds or smoke and is virtually odorless. When Hydrogen-air combustion takes place in an I.C. engine cylinder, the only product of combustion are water vapour and oxides of nitrogen and the engine will be pollution free.

It has been proved that the higher thermal efficiency of Hydrogen engine can offset the higher production cost. With only minor modifications, the conventional diesel cycle engine can be operated efficiently using Hydrogen as fuel with atmospheric air supplying the necessary oxygen.

PROPERTIES OF HYDROGEN

Table 1. Shows that main combustion properties of Hydrogen provide its use as an IC engine fuel. A low fuel conversion rate is problem with gaseous-fueled engines run with high amounts of excess air. The low quenching distance of Hydrogen offers improvement in this matter. Hydrogen flames can easily penetrate into difficult chamber zones and reach the unburnt mixtures than that of fossil fuels. Optimized Hydrogen engines can be run at higher compression ratio than that with unleaded gasoline. It makes Hydrogen powered engines 15-25 % more efficient than gasoline engines.

Table 1: Properties of Hydrogen

Description	Hydrogen
Laminar flame speed	1.96 m/sec
Theoretical flame Temperature	2140 °C
Minimum ignition energy	0.02 MJ
Quenching distance	0.6 mm
Normalized flame emmisivity	1
Normal Boiling Point	20.27 K
Auto ignition temperature	858 K
Burning velocity	265 to 325 cm/sec

LITERATURE SHOWCASE

Beauties of Hydrogen were recognized as early as in 1820. In 1820, W.Cecil [1] read a paper before Cambridge philosophical society on "The Application of Hydrogen gas to produce a motive power in Machinery ".
Then after an elapse of century,. Ricardo [1] published in the "Report of the Empire Motor Fuel Committee" a very instructive paper on experiments carried out with Hydrogen and air used as a promoter with Petrol and Kerosene. He noticed that with a rich mixture pained by backfire, Ennen [2] in Germany, in 1933 dealt successfully with the backfire problem by injecting Hydrogen directly in to the cylinder, but the knocking persisted. King[3] made valuable contribution on the subject of pre-ignition and combustion knock in Hydrogen engine. He found that any particulate matter provides hot spot for pre-ignition and the combustion knock is an inherent property of near stoichiometric Hydrogen-air mixture due to the extremely high flame velocity.
The major conclusions derived from the available literature are as follows:
Any existing engine can be converted to Hydrogen fuelled engine with minor modifications.
The part load & thermal efficiencies of H_2 fuelled engine are higher than gasoline air engine.
Hydrogen induction technique is easier to adopt as compared to Hydrogen injection technique.
Emission levels of H_2 - air engine are far less than that of gasoline – air engine if equivalence ratio is not exceeded 0.6 in H_2 - air engine (i.e. Lean operation)
Equivalence ratio more than 0.6 results in back fire problems. If H_2 – air engine has to be operated in the range of 0.6 to 1.0-equivalence ratio, we have to go for EGR or water induction or delay entry technique to achieve backfire free operation and lower NOx emission.
The reported optimum spark advance for H_2 – air engine lies in between 7^o to 12^o BDC.
The optimum compression ratio lies in between 8 to 12 for H_2 – air engine.

AIM OF THE PRESENT WORK

The aim of the present work is to model suction and Compression Processes in Hydrogen fueled Engine and by that improve fuel economy and govern power capacity of the engine. And also to describe the safe and backfire free H_2 fuelled engine using Delayed Entry Technique.

COMBUSTION PROCESS

Combustion is a chemical reaction in which H2 combines with oxygen liberating heat energy and causing an increase in temperature of gases. Conditions necessary for combustion are, presence of combustible mixture and source of initiating the process. In spark ignition engine spark is introduced to ignite the air-fuel mixture by 20 °-30 ° before TDC so that ignition lag is compensated. For Hydrogen fuelled engine this spark advance is in a narrow range of 5 to 7 ° btdc [1, 2, 6] and due to high burning velocity of Hydrogen-air mixture, combustion may be assumed to be instantaneous. However there may exist dissociation and hence, in present work the heat release is assumed to be instantaneous and the disassociation with NO and OH formation is considered which is described below.

Stoichiometry of Reactions

$$xH_2 + y(O_2 + 3.762 \times N_2) = aO_2 + bN_2 + cH_2 + dH_2O + eOH + fNO \qquad (4.21)$$

---------Reactants--------- -------------------Products-----------------

where,
a = moles of O_2 = nO_2
b = moles of N_2 = nN_2
c = moles of H_2 = nH_2

d = moles of H_20 = nH_2O
e = moles of OH = nOH
f = moles of NO = nNO

Conservation of Atoms [from mass balance]

1. No. of atoms of H_2 in reactants = No. of atoms of H_2 in products

$$2x = n = (2c + 2d + e) \qquad (4.22)$$

2. No. of atoms of O_2 in reactants = No. of atoms of O_2 in products

$$2y = l = (2a + e + d + f) \qquad (4.23)$$

3. No. of atoms of N_2 in reactants = No. of atoms of N_2 in products

$$2 \times 3.762 \times y = m = 2b + f \qquad (4.24)$$

Chemical Equilibrium

$$\frac{1}{2}H_2 + \frac{1}{2}O_2 \rightleftarrows OH$$

$$K_{P1} = \frac{P_{OH}}{\left(P_{H_2} \times P_{O_2}\right)^{1/2}} \qquad (4.25)$$

$$H_2 + \frac{1}{2}O_2 \rightleftarrows H_2O$$

$$K_{P2} = \frac{P_{H_2O}}{\left(P_{H_2} \times P_{O_2}^{1/2}\right)} \qquad (4.26)$$

$$\frac{1}{2}N_2 + \frac{1}{2}O_2 \rightleftarrows NO$$

$$K_{P3} = \frac{P_{NO}}{\left(P_{N_2} \times P_{O_2}\right)^{1/2}} \qquad (4.27)$$

The partial pressure of any constituent is given from Dalton's law of partial pressure as,

$$P_j = \left(\frac{n_j}{\sum n_j}\right) \times P_e \qquad (4.28)$$

$$\sum n_j = a + b + c + d + e + f = z = \text{Total No.of Moles of Products} \qquad (4.29)$$

Pe = Equilibrium pressure (total)

$$K_{p1} = K_{n1} = \frac{\left(nOH \times \frac{P_e}{z}\right)}{\left(nH_2 \times \frac{P_e}{z}\right)^{1/2} \times \left(nO_2 \times \frac{P_e}{z}\right)^{1/2}} \qquad (4.30)$$

$$= \frac{nOH}{\left(nH_2\right)^{1/2} \times \left(nO_2\right)^{1/2}}$$

$$K_{p1} = K_{n1} = \frac{e}{(c \times a)^{1/2}}$$

$$e = K_{n1} \times (c \times a)^{1/2} \qquad (4.31)$$

$$K_{p2} = K_{n2} = \frac{\left(nH_2O \times \frac{P_e}{z}\right)}{\left(nH_2 \times \frac{P_e}{z}\right) \times \left(nO_2 \times \frac{P_e}{z}\right)^{1/2}} \qquad (4.32)$$

$$= \frac{nH_2O}{(nH_2) \times (nO_2)^{1/2}} \times \left(\frac{P_e}{z}\right)^{1/2}$$

$$K_{p2} = K_{n2} = \frac{d}{(c \times a)^{1/2} \times \left(\frac{P_e}{z}\right)^{1/2}}$$

$$d = K_{n2} \times (c \times a)^{1/2} \times \left(\frac{P_e}{z}\right)^{1/2} \qquad (4.33)$$

$$K_{p3} = K_{n3} = \frac{\left(nNO \times \frac{P_e}{z}\right)}{\left(nN_2 \times \frac{P_e}{z}\right)^{1/2} \times \left(nO_2 \times \frac{P_e}{z}\right)^{1/2}} \qquad (4.34)$$

$$= \frac{nNO}{(nN_2) \times (nO_2)^{1/2}}$$

$$K_{p3} = K_{n3} = \frac{f}{(a \times b)^{1/2}}$$

$$f = K_{n3} \times (a \times b)^{1/2} \qquad (4.35)$$

Energy Balance

$$E_i = E_j \qquad (4.36)$$

$$\sum_i \left[h_{fo} + h_{Ti}\right]_i - \sum n_i \times R \times T_i = \sum_j \left[h_{fo} + h_{T_e}\right]_j - \sum n_j \times R \times T_e \qquad (4.37)$$

Thus, there are seven non-linear equations i.e. six for constituents [eq. (4.21) to eq. (4.23)] and [eq. (4.30) to eq. (4.32)] and one for temperature [eq. 4.37]. These set of non-linear equation is solved using iterative technique where in the equilibrium constants and enthalpies are taken from JANAF Tables [68].

$$P_e \times V_e = \sum n_j \times R \times T_e \qquad (4.38)$$

$$P_i \times V_i = \sum n_i \times R \times T_i \qquad (4.39)$$

For constant volume combustion

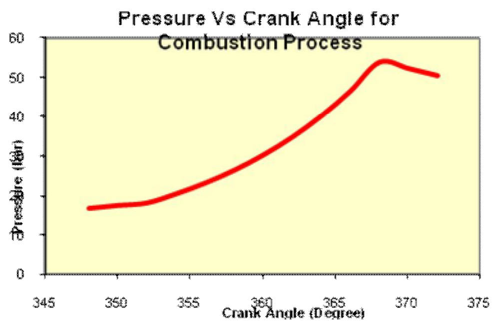
$$\frac{P_e}{P_i} = \frac{\sum n_j \times T_e}{\sum n_i \times T} \qquad (4.40)$$

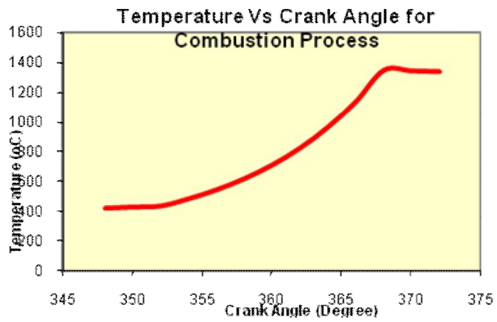
Thus, Pe i.e. pressure at the end of the combustion process can be calculated from the above equation.

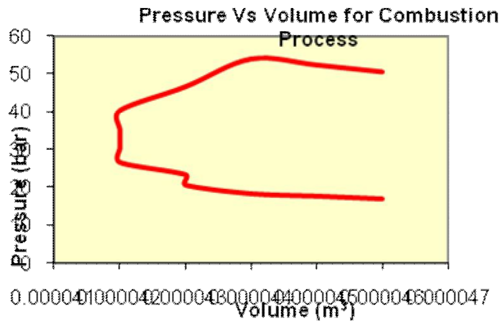
RESULTS & DISCUSSION OF THE MODEL

Parameters	Ideal Cycle	Discrete approach
P_3	105.110 bar	50.5909bar
T_3	3458 K	1341.17 K
η	64.32 %	47.60 %
Ikw	119.80 kW	96.3274 kW
Bkw	101.83 kW	81.87 kW

Results of the Combustion Process







The result from the above fig of the combustion process indicates that there is a rapid increase in pressure as well as temperature. The pressure and temperature at the end of the combustion considering dissociation are 50.591bar and 1341.2K, respectively.

CONCLUSION

The peak pressure and temperature obtained with discrete and differential approach are of the order of 50.590 bar and 1341.17 K and 36.515 bar and 1408.25 K respectively. The peak temperature achieved with discrete approach is slightly lower than that achieved with differential approach which clearly establishes the influence of dissociation.

The overall efficiency obtained with discrete approach for equivalence ratio of unity is 47.60% while that with differential approach is 38.39%. This shows that both approaches gives quite close results. Further, the efficiency levels obtained are higher than that of the gasoline-air engine which is quite in tune with the experimental results obtained by various researchers who have concluded that the efficiency level of H_2-air engine are about 50% higher than gasoline-air en

The authors feel that the Delayed Entry Technique is designed for the backfire ree operation will become an essential feature of future H_2 fuelled engines. It is also felt that this valve can be used on any gas engine for utmost safe operation.

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