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ANALYTICAL INVESTIGATIONS ON PROPERTIES OF REACTANTS [H_2 - AIR] AND PRODUCTS AT DIFFERENT EQUIVALENCE RATIO

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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.

The various properties of hydrogen (specific heat, thermal conductivity, kinematic viscosity, density, prandtl no.) have been calculated at various equivalence ratios at different temperatures. Graphs of these properties have been plotted. The software of various property of hydrogen and calculation of all properties was developed using the turbo C language.

KEYWORDS: Computer Simulation, Mathematical Model, Delayed Entry Technique, Hydrogen Fuel

INTRODUCTION

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.

CRITERIA FOR THE FUTURE FUEL SYSTEM

Many investigations and studies have led to the recognition that the creative scope of a future energy supply is large that there are energy supply options other than mere expansion of conventional energy sources. Discussion for one or the other option therefore has to be carefully prepared. The criteria for future fuel system are listed below:

TECHNOLOGY /ECOLOGY EFFICIENCY

Energy conversion efficiency (Primary energy to usable energy)

Type of primary energy

Raw material requirements, ability o be mined or recycle, possible use of or disposal of water.

Land requirements, effect on climate, ground water etc.

OPERATING EFFICIENCY

Specific energy costs.(at start-up, total lifetime, progressions)

Requisite up-front payments, type of costs.

Amortization times, break-even point etc.

ECONOMIC EFFICIENCY

Influence on economic structures

Effect on employment

Export potential, influence on balance of trade and output

Costs of prevention pr repair of ecological or societal damage

Repercussions on residential and transportation structures

SUPPLY ASSURANCE

Technical availability under normal operations, life-span etc

Potential dangers and safety in case of accidents

System flexibility under changing conditions (short and medium term, e.g. delivery, restrictions, long term, e.g. substitution of an energy carrier)

SOCIAL COMPATIBILITY

Expansion or restriction of development and room for manoeurve of potential entities, economic entities and the individual; Compatibility with democratic groundless

Compatibility with practice and principles of international trade and with interest of the trading partner

PROPERTIES OF HYDROGEN

Physical Properties

Hydrogen is a colorless and odorless gas. Its density is 0.0899 g/l (air is 14.4 times as dense). Hydrogen boils at -252.77°C. Liquid hydrogen has a density of 70.99 g/l. With these properties, hydrogen has the highest energy to weight ratio of all fuels. 1 kg of hydrogen contains the same amount of energy as 2.1 kg of natural gas or 2.8 kg of gasoline. The energy to volume ratio amounts to about 1/4 of that for petroleum and 1/3 of that for natural gas. Water consists of 11.2% hydrogen by weight. Hydrogen burns in air at concentrations in the range of 4 - 75% by volume (methane burns at 5.3 - 15% and propane at 2.1 - 9.5% concentrations by volume). The highest burning temperature of hydrogen of 2318 °C is reached at 29% concentration by volume, whereas hydrogen in an oxygen atmosphere can reach burning temperatures up to 3000°C (the highest reached burning temperature in air for methane is 2148°C and for propane 2385°C). The minimum required ignition energy required for a stoichiometric fuel/oxygen mixture is for hydrogen 0.02 mJ, for methane 0.29 mJ and for propane 0.26 mJ. Even the energy of a static electric discharge from the arcing of a spark is sufficient to ignite natural gas so it is largely irrelevant that hydrogen requires only a tenth of this energy for ignition. The temperatures for spontaneous combustion of hydrogen, methane and propane are 585°C, 540°C and 487°C respectively.

The explosive regions for hydrogen and methane lie in the ranges 13% - 59% and 6.3% - 14% respectively. The explosive range for hydrogen is clearly much greater, whereas methane is already explosive at a much lower concentration. The diffusion coefficient for hydrogen at 0.61 cm3/s is 4 times as high as that for methane. Hydrogen therefore mixes in air considerably faster than methane or petrol vapor, which is advantageous in the open but represents a potential disadvantage in badly ventilated interiors. Since both hydrogen and natural gas are lighter than air they rise quickly. Propane and petrol vapor are in contrast heavier than air and remain on the ground, leading to a higher likelihood of explosion.

ENVIRONMENTAL ADVANTAGES

The burning of hydrogen with air under appropriate conditions in combustion engines or gas turbines results in very low or negligible emissions. Trace hydrocarbon and carbon monoxide emissions, if at all generated, can only result from the combustion of motor oil in the combustion chamber of internal combustion engines. Nitrous oxide emissions increase exponentially with the combustion temperature. These can therefore be influenced through appropriate process control. As hydrogen offers more possibilities than other fuels, a distinct reduction in NOx emissions is possible compared to mineral oil and natural gas, provided that a lower combustion temperature is achieved (e.g. with a high air to fuel ratio). Particulate and sulfur emissions are completely avoided apart from small quantities of lubricant remnants.

The use of hydrogen in fuel cell propulsion systems with low temperature fuel cells (Membrane fuel cells: PEMFC) completely eliminates all polluting emissions. The only by-product resulting from the generation of electricity from hydrogen and oxygen in the air is de-mineralised water. Use of hydrogen in fuel cells at higher temperature levels causes up to 100 times fewer emissions compared with conventional power stations. If the hydrogen is obtained from methanol however, then the reforming process itself will result in carbon dioxide emissions.

Furthermore hydrogen offers the possibility, depending on production method, to drastically reduce or avoid emissions, especially carbon dioxide (CO2), in the whole fuel cycle. Using hydrogen as secondary energy carrier would allow the flexible introduction of the most diverse renewable energies into the fuel sector.

Since hydrogen is a secondary energy carrier, the complete fuel cycle from primary energy source to final application must be considered when judging the environmental relevance.

COMPOUNDS

Although pure Hydrogen is a gas we find very little of it in our atmosphere. Hydrogen gas is so light that uncombined Hydrogen will gain enough velocity from collisions with other gases that they will quickly be ejected from the atmosphere. On earth, hydrogen occurs chiefly in combination with oxygen in water, but it is also present in organic matter such as living plants, petroleum, coal, etc. It is present as the free element in the atmosphere, but only to the extent of less than 1 ppm by volume. The lightest of all gases, hydrogen combines with other elements – sometimes explosively -- to form compounds.

FORMS

Quite apart from isotopes, it has been shown that under ordinary conditions hydrogen gas is a mixture of two kinds of molecules, known as ortho- and para-hydrogen, which differ from one another by the spins of their electrons and nuclei.

Normal hydrogen at room temperature contains 25% of the para form and 75% of the ortho form. The ortho form cannot be prepared in the pure state. Since the two forms differ in energy, the physical properties also differ. The melting and boiling points of parahydrogen are about 0.1oC lower than those of normal hydrogen.

ISOTOPES

The ordinary isotope of hydrogen, H, is known as Protium, the other two isotopes are Deuterium (a proton and a neutron) and Tritium (a protron and two neutrons). Hydrogen is the only element whose isotopes have been given different names. Deuterium and Tritium are both used as fuel in nuclear fusion reactors. One atom of Deuterium is found in about 6000 ordinary hydrogen atoms.

Deuterium is used as a moderator to slow down neutrons. Tritium atoms are also present but in much smaller proportions. Tritium is readily produced in nuclear reactors and is used in the production of the hydrogen (fusion) bomb. It is also used as a radioactive agent in making luminous paints, and as a tracer.

GENERAL STRUCTURE

Atomic Number: 1

Group: 1

Period: 1

Series: Nonmetals

NAME IN OTHER LANGUAGES

- Latin: Hydrogenium
- Czech: Vodík
- Croatian: Vodik
- French: Hydrogéne
- German: Wasserstoft – r
- Italian: Idrogeno
- Norwegian: Hydrogen
- Portuguese: Hidrogênio
- Spanish: Hidrógeno
- Swedish: Väte

ATOMIC STRUCTURE

- Atomic Radius: 0.79Å
- Atomic Volume: 14.4cm3/mol

- Covalent Radius: 0.32Å
- Cross Section: 0.33barns
- Crystal Structure: Hexagonal
- Electron Configuration: 1s1
- Electrons per Energy Level: 1

SHELL MODEL

- Ionic Radius: 0.012Å
- Filling Orbital: 1s1
- Number of Electrons (with no charge): 1
- Number of Neutrons (most common/stable nuclide): 0
- Number of Protons: 1
- Oxidation States: 1
- Valance Electrons: 1s1

CHEMICAL PROPERTIES

- Electrochemical Equivalent: 0.037605g/amp-hr
- Electron Work Function:
- Electronegativity (Pauling): 2.2
- Heat of Fusion: 0.05868kJ/mol
- Incompatiblities: metals, oxidizing materials, metal oxides, combustible materials, halogens, metal salts, halo carbons
- Ionization Potential First: 13.598
- Valance Electron Potential (-eV): 1200

REGULATORY / HEALTH

- CAS Number
- 1333-74-0 Compressed gas
- UN/NA ID and ERG Guide Number
- UN1049 / 115 Compressed gasUN1966 / 115 Refrigerated liquid
- RTECS: MW8900000
- NFPA 704

Health: 1

Fire: 4

Reactivity: 0

Special Hazard:

- OSHA Permissible Exposure Limit (PEL)

  No limits set by OSHA

- OSHA PEL Vacated 1989

  No limits set by OSHA

- NIOSH Recommended Exposure Limit (REL)

  No limits set by NIOSH

COMBUSTION OF HYDROGEN

- Hydrogen burns in oxygen or air to form water.

  2 H2 + O2 ==> 2 H2O

- Oxygen will also burn in hydrogen.

- Hydrogen does not itself support combustion, as may be shown by passing a lighted taper into an inverted jar of hydrogen, when the taper is extinguished.

A mixture of hydrogen with oxygen or air explodes violently when kindled, provided either gas is not present in too large excess.

REACTION STOICHIOMETRY AND COMPUTATION OF MASS FRACTION AND PROPERTIES OF REACTANTS AND PRODUCTS

Stoichiometric Reaction for (ϕ < 1)

$$H_2 + \frac{1}{2\phi}[O_2 + 3.762N_2] \rightarrow (H_2O)_g + \frac{1}{2}\left(\frac{1-\phi}{\phi}\right)O_2 + \left(\frac{1.881}{\phi}\right)N_2$$

Mass Fractions of Reactants

Total mass of reactants m_r:

$$m_r = 2 + \left(\frac{1}{2\phi} \times 137.336\right)kg$$

$$= 2\left(\frac{\phi + 34.334}{\phi}\right)kg$$

Mass fraction of H_2; $X_{H_2,r}$

$$X_{H_2,r} = \frac{2}{m_r}$$

Mass fraction of O_2; $X_{O_2,r}$

$$X_{O_2,r} = \frac{16}{m_r \times \phi}$$

Mass fraction of N_2; $X_{N_2,r}$

$$X_{N_2,r} = \frac{52.668}{m_r \times \phi}$$

Mass Fraction of Products

Total mass of Products: m_p

$$m_p = 18 + (16)\left(\frac{1-\phi}{\phi}\right) + \frac{52.668}{\phi} kg$$

Mass fraction of H_2O; $X_{H_2O,p}$

$$X_{H_2O,p} = \frac{18}{m_p}$$

Mass fraction of O_2; $X_{O_2,p}$

$$X_{O_2,p} = \frac{16\left(\frac{1-\phi}{\phi}\right)}{m_p}$$

Mass fraction of N_2; $X_{N_2,p}$

$$X_{N_2,p} = \frac{52.668}{m_p \times \phi}$$

Stoichiometric Reaction for (ϕ = 1)

$$H_2 + \frac{1}{2}[O_2 + 3.762N_2] \rightarrow H_2O_g + 1.881N_2$$

Mass Fractions of Reactants

Total mass of reactants m_r

$$m_r = 2 + \left(\frac{1}{2}\phi \times 137.336\right) kg$$
$$= 70.668\, kg$$

Mass fraction of H_2; $X_{H_2,r}$

$$X_{H_2,r} = \frac{2}{70.668} = 0.0283$$

Mass fraction of O_2; $X_{O_2,r}$

$$X_{O_2,r} = \frac{16}{70.668} = 0.2264$$

Mass fraction of N_2; $X_{N_2,r}$

$$X_{N_2,r} = \frac{52.668}{70.668} = 0.7453$$

Mass Fraction of Products

Total mass of Products: m_p

$$m_p = 18 + (16)\left(\frac{1-\phi}{\phi}\right) + \frac{52.668}{\phi} kg$$

Mass fraction of H_2O; $X_{H_2O,p}$

$$X_{H_2O,p} = \frac{18}{m_p} = \frac{18}{70.668} = 0.2547$$

Mass fraction of O_2; $X_{O_2,r}$

$$X_{O_2,p} = \frac{16\left(\frac{1-\phi}{\phi}\right)}{m_p} = 0$$

Mass fraction of N_2; $X_{N_2,p}$

$$X_{N_2,p} = \frac{52.668}{70.668} = 0.7453$$

Stoichiometric Reaction for (ϕ > 1)

$$\phi H_2 + \frac{1}{2}[O_2 + 3.762 N_2] \rightarrow (H_2O)_g + (\phi - 1) H_2 + 1.881 N_2$$

Mass Fractions of Reactants

Total mass of reactants m_r

$$m_r = 2\phi + 68.668\,kg$$

Mass fraction of H_2; $X_{H_2,r}$

$$X_{H_2,r} = \frac{2\phi}{m_r}$$

Mass fraction of O_2; $X_{O_2,r}$

$$X_{O_2,r} = \frac{16}{m_r}$$

Mass fraction of N_2; $X_{N_2,r}$

$$X_{N_2,r} = \frac{52.668}{m_r}$$

Mass Fraction of Products

Total mass of Products: m_p

$$m_p = 18 + 2\times(\phi - 1) + 52.668\ kg$$

Mass fraction of H_2O; $X_{H_2O,p}$

$$X_{H_2O,p} = \frac{18}{m_p}$$

Mass fraction of H_2; $X_{H_2,p}$

$$X_{H_2,p} = \frac{2(\phi - 1)}{m_p}$$

Mass fraction of N_2; $X_{N_2,p}$

$$X_{N_2,p} = \frac{52.668}{m_p}$$

Specific Heat of Reactants

$$C_{p_r,T_r} = X_{H_2,r} C_{p_{H_2,T_r}} + X_{O_2,r} C_{p_{O_2,T_r}} + X_{N_2,r} C_{p_{N_2,T_r}}$$

Specific Heat of Products

$$C_{p_p,T_p} = X_{H_2,p} C_{p_{H_2,T_p}} + X_{O_2,p} C_{p_{O_2,T_p}} + X_{N_2,p} C_{p_{N_2,T_p}} + X_{H_2O,p} C_{p_{H_2O,T_p}}$$

Thermal Conductivity for Reactants

$$K_{r,T_r} = X_{H_2,r} K_{H_2,T_r} + X_{O_2,r} K_{O_2,T_r} + X_{N_2,r} K_{N_2,T_r}$$

Thermal Conductivity for Products

$$K_{p,T_p} = X_{H_2O,p} K_{H_2O,T_p} + X_{O_2,p} K_{O_2,T_p} + X_{N_2,p} K_{N_2,T_p} + X_{H_2,p} K_{H_2,T_p}$$

Density for Reactants

$$\rho_{r,T_r} = X_{H_2,r} \rho_{H_2,T_r} + X_{O_2,r} \rho_{O_2,T_r} + X_{N_2,r} \rho_{N_2,T_r}$$

Density for Products

$$\rho_{p,T_p} = X_{H_2O,p} \rho_{H_2O,T_p} + X_{O_2,p} \rho_{O_2,T_p} + X_{N_2,p} \rho_{N_2,T_p} + X_{H_2,p} \rho_{H_2,T_p}$$

Molecular Mass for Reactants

$$M_{eq,r} = X_{H_2,r} M_{H_2} + X_{O_2,r} M_{O_2} + X_{N_2,r} M_{N_2}$$

Gas Constant for Reactants

$$R_{eq,r} = \frac{R}{M_{eq,r}}$$

Molecular Mass for Products

$$M_{eq,p} = X_{H_2O,p} M_{H_2O} + X_{O_2,p} M_{O_2} + X_{N_2,p} M_{N_2} + X_{H_2,p} M_{H_2}$$

Gas Constant for Products

$$R_{eq,p} = \frac{R}{M_{eq,p}}$$

Specific Heat at Constant Volume for Reactants

$$C_{v_r,T_r} = R_{eq,r} - C_{p_r,T_r}$$

Specific Heat at Constant Volume for Products

$$C_{v_p,T_p} = R_{eq,p} - C_{p_p,T_p}$$

Specific Heat Ratio for Reactants

$$\gamma_{r,T_r} = \frac{C_{p_r,T_r}}{C_{v_r,T_r}}$$

Specific Heat Ratio for Products

$$\gamma_{p,T_p} = \frac{C_{p_p,T_p}}{C_{v_p,T_p}}$$

RESULTS & DISCUSSIONS

Results obtained using above analysis are given in Appendix 1 and graphs are plotted accordingly.

CONCLUSIONS

Usually Hydrogen-air engine are operated in a equivalence ratio range of 0.6 to 1.0 [1, 2] and hence all the physical properties of reactants and products are evaluated in the wider equivalence ratio range of 0.2 to 1.4 for simulation purpose.

The typical variations of specific heats only for reactants and products in the equivalence ratio range of 0.2 to 1.4 are depicted in Figure 1 to Figure 10, respectively as a function of temperature. The individual constituent properties are taken from Roshenow et. al. [61]. These properties of reactants and products are used as input parameters for digital simulation of Hydrogen-air engine.

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APPENDICES

Properties of Reactantas & Products at Different Eqivalence Ratios [ϕ = 0.2 To 1.4]

Table 1: Results of Equivalence Ratio ∅ = 0.2 [for Reactants]

equivalence ratio = 0.2 for reactant					
The coeff. of nitrogen is = 9.404762					
The total mass of reactants is = 345.333344					
The mass fraction of hydrogen is = 0.005792					
The mass fraction of oxygen is = 0.231660					
The mass fraction of nitrogen is = 0.762548					
Temp	**Sp.Heat**	**Cond.**	**Density**	**Vis.*10-6**	**Prandtl No.**
-128.9	1.087693	0.014172	2.446491	4.301892	0.754106
-17.8	1.086853	0.023729	1.38333	13.90143	0.728573
93.4	1.09388	0.031227	0.962008	22.99353	0.717597
204.4	1.110434	0.03854	0.740984	36.11834	0.715276
315.6	1.133793	0.045657	0.598794	51.69798	0.715873
426.7	1.159739	0.051981	0.497406	68.61603	0.716913
537.8	1.187114	0.058208	0.435318	86.60126	0.721952
538.9	1.213098	0.063597	0.370308	111.0352	0.734008
760	1.239083	0.068365	0.342097	128.4653	0.745295

Table 2: Results of Equivalence Ratio ∅ = 0.2 [for Products]

equivalence ratio = 0.2 for product					
Enter choice= 1 for equivalence ratio = 1					
and 2 for eq. ratio > 1 and 3 for eq. ratio < 1 =3					
The coeff. of nitrogen is = 9.405000					
The total mass of products is = 345.339996					
The mass fraction of water is = 0.052123					
The mass fraction of oxygen is = 0.185325					
The mass fraction of nitrogen is = 0.762553					
Temp	**Sp.Heat**	**Cond.*10-3**	**Density**	**Vis.*10-6**	**Prandtl No.**
100	1.072855	31.371567	0.924259	22.48089	0.700436
200	1.076804	38.645306	0.728589	33.62896	0.674324
300	1.097287	45.435432	0.60165	46.55	0.669895
400	1.121009	51.779495	0.511857	61.23127	0.674527
500	1.147937	57.53101	0.445255	77.49941	0.676471
600	1.174594	62.789375	0.394896	94.71409	0.690025
700	1.197827	67.430435	0.354699	114.2104	0.710424
800	1.216931	71.578568	0.320398	134.6563	0.715849
900	1.239055	75.158722	0.293363	156.3397	0.763378
1000	1.25209	78.348572	0.270039	179.7046	0.759523

Table 3: Results of Equivalence Ratio ∅ = 0.4 [for Reactants]

equivalence ratio = 0.4 for reactant					
The coeff. of nitrogen is = 4.702381					
The total mass of reactants is = 173.666672					
The mass fraction of hydrogen is = 0.011516					
The mass fraction of oxygen is = 0.230326					
The mass fraction of nitrogen is = 0.758157					
Temp	**Sp.Heat**	**Cond.**	**Density**	**Vis.*10-6**	**Prandtl No.**
-128.9	1.153177	0.014639	2.433376	4.462591	0.753846
-17.8	1.162188	0.024509	1.375911	14.31273	0.728507
93.4	1.170729	0.032263	0.956854	23.75998	0.717495
204.4	1.187476	0.039832	0.737013	37.28944	0.71505
315.6	1.210931	0.047185	0.595587	53.35518	0.715545
426.7	1.236958	0.053743	0.494737	71.00902	0.716597
537.8	1.264175	0.060095	0.432983	89.0024	0.721578
538.9	1.29024	0.065631	0.368328	114.6782	0.733622
760	1.316305	0.070534	0.340263	132.6499	0.744896

Table 4: Results of Equivalence Ratio ∅ = 0.4 [for Products]

equivalence ratio = 0.4 for product					
Enter choice= 1 for equivalence ratio = 1					
and 2 for eq. ratio > 1 and 3 for eq. ratio < 1 =3					
The coeff. of nitrogen is = 4.700000					
The total mass of products is = 197.599991					
The mass fraction of water is = 0.091093					
The mass fraction of oxygen is = 0.242915					
The mass fraction of nitrogen is = 0.665992					
Temp	**Sp.Heat**	**Cond.*10-3**	**Density**	**Vis.*10-6**	**Prandtl No.**
100	1.110002	31.148037	0.919583	22.41802	0.716563
200	1.108557	38.575001	0.724427	33.56963	0.686486
300	1.130933	45.588989	0.598245	46.54879	0.681332
400	1.156366	52.230949	0.508911	61.3251	0.68484
500	1.184737	58.348747	0.442668	77.72895	0.683053
600	1.212955	64.031662	0.392607	94.74029	0.694921
700	1.237597	69.149391	0.352668	114.7915	0.718219
800	1.258941	73.836235	0.318547	135.4899	0.724223
900	1.282553	77.958237	0.291729	157.5223	0.767405
1000	1.296828	81.772995	0.268486	181.1599	0.764686

Table 5: Results of Equivalence Ratio ∅ = 0.6 [for Reactants]

equivalence ratio = 0.6 for reactant					
The coeff. of nitrogen is = 3.134795					
The total mass of reactants is = 116.439857					
The mass fraction of hydrogen is = 0.017176					
The mass fraction of oxygen is = 0.229007					
The mass fraction of nitrogen is = 0.753816					
Temp	**Sp.Heat**	**Cond.**	**Density**	**Vis.*10-6**	**Prandtl No.**
-128.9	1.217918	0.0151	2.420411	4.621469	0.75359
-17.8	1.236669	0.02528	1.368576	14.71936	0.728441
93.4	1.246708	0.033287	0.951757	24.51774	0.717395
204.4	1.263645	0.04111	0.733088	38.44728	0.714826

315.6	1.287194	0.048696	0.592416	54.99361	0.715221
426.7	1.313301	0.055485	0.492097	73.3749	0.716284
537.8	1.340362	0.061961	0.430676	91.37634	0.721208
538.9	1.366507	0.067643	0.366371	118.2799	0.73324
760	1.392652	0.072678	0.338451	136.7871	0.744502

Table 6: Results of Equivalence Ratio ∅ = 0.6 [for Products]

equivalence ratio = 0.6for product					
Enter choice= 1 for equivalence ratio = 1					
and 2 for eq. ratio > 1 and 3 for eq. ratio < 1 =3					
The total mass of products is = 121.475998					
The mass fraction of water is = 0.148177					
The mass fraction of oxygen is = 0.087721					
The mass fraction of nitrogen is = 0.764102					
Temp	**Sp.Heat**	**Cond.*10-3**	**Density**	**Vis.*10-6**	**Prandtl No.**
100	1.188371	30.487631	0.880634	22.18219	0.738269
200	1.174232	37.942604	0.693657	33.24319	0.699749
300	1.195071	45.061718	0.572895	46.21164	0.692335
400	1.222052	51.862167	0.487348	61.0074	0.696114
500	1.252535	58.181118	0.424027	77.41839	0.702276
600	1.284	64.152939	0.37608	93.94023	0.71431
700	1.312142	69.60717	0.337716	114.6845	0.729635
800	1.336527	74.690254	0.305055	135.5131	0.735051
900	1.364235	79.217888	0.279274	157.5776	0.782166
1000	1.38392	83.62941	0.257108	181.6148	0.777519

Table 7: Results of Equivalence Ratio ∅ = 0.8 [for Reactants]

equivalence ratio= 0.8 for reactant					
The coeff. of nitrogen is = 2.351191					
The total mass of reactants is = 87.833336					
The mass fraction of hydrogen is = 0.022770					
The mass fraction of oxygen is = 0.227704					
The mass fraction of nitrogen is = 0.749526					
Temp	**Sp.Heat**	**Cond.**	**Density**	**Vis.*10-6**	**Prandtl No.**
-128.9	1.281907	0.015556	2.407596	4.778501	0.753336
-17.8	1.310285	0.026043	1.361326	15.12127	0.728376
93.4	1.321803	0.034299	0.94672	25.2667	0.717296
204.4	1.338928	0.042373	0.729209	39.59165	0.714605
315.6	1.362571	0.050189	0.589282	56.613	0.714901
426.7	1.388757	0.057207	0.489489	75.71328	0.715975
537.8	1.415664	0.063806	0.428394	93.72267	0.720843
538.9	1.441888	0.069632	0.364436	121.8398	0.732863
760	1.468112	0.074797	0.336659	140.8763	0.744112

Table 8: Results of Equivalence Ratio ∅ = 0.8 [for Products]

equivalence ratio = 0.8 for product
Enter choice= 1 for equivalence ratio = 1
and 2 for eq. ratio > 1 and 3 for eq. ratio < 1 =3
The coeff. of nitrogen is = 2.351250
The total mass of products is = 91.834999
The mass fraction of water is = 0.196004
The mass fraction of oxygen is = 0.087113

The mass fraction of nitrogen is = 0.716884					
Temp	**Sp.Heat**	**Cond.*10-3**	**Density**	**Vis.*10-6**	**Prandtl No.**
100	1.241089	30.114218	0.865344	22.06226	0.75749
200	1.218902	37.69878	0.681208	33.0991	0.71332
300	1.240782	45.026329	0.562656	46.11035	0.70466
400	1.269579	52.109684	0.478599	60.98711	0.707631
500	1.301831	58.778347	0.416432	77.50761	0.713204
600	1.335499	65.172112	0.369351	93.72288	0.723954
700	1.365796	71.103683	0.331659	115.1125	0.739201
800	1.39286	76.730988	0.299576	136.1796	0.744899
900	1.422963	81.808113	0.274274	158.5299	0.789745
1000	1.445241	86.891747	0.252494	182.9019	0.785424

Table 9: Results of Equivalence Ratio ∅ = 1.0 [for Reactants]

equivalence ratio = 1 for reactant					
The coeff. of nitrogen is = 1.880952					
The total mass of reactants is = 70.666664					
The mass fraction of hydrogen is = 0.028302					
The mass fraction of oxygen is = 0.226415					
The mass fraction of nitrogen is = 0.745283					
Temp	**Sp.Heat**	**Cond.**	**Density**	**Vis.*10-6**	**Prandtl No.**
-128.9	1.345179	0.016007	2.394925	4.933774	0.753085
-17.8	1.383075	0.026796	1.354158	15.51868	0.728311
93.4	1.396057	0.0353	0.94174	26.00727	0.717198
204.4	1.413368	0.043622	0.725373	40.72321	0.714387
315.6	1.437104	0.051665	0.586183	58.21425	0.714585
426.7	1.463368	0.058909	0.486909	78.02548	0.71567
537.8	1.490123	0.065629	0.426139	96.04273	0.720481
538.9	1.516425	0.071598	0.362524	125.3597	0.732491
760	1.542726	0.076892	0.334888	144.9196	0.743726

Table 10: Results of Equivalence Ratio ∅ = 1.0 [for Products]

equivalence ratio = 1 for product					
Enter choice= 1 for equivalence ratio = 1					
and 2 for eq. ratio > 1 and 3 for eq. ratio < 1 = 3					
The total mass of products is = 70.667999					
The mass fraction of water is = 0.254712					
The mass fraction of nitrogen is = 0.745288					
Temp	**Sp.Heat**	**Cond.*10-3**	**Density**	**Vis.*10-6**	**Prandtl No**
100	1.314438	29.535793	0.835002	21.86322	0.780394
200	1.280646	37.208611	0.65703	32.83586	0.728338
300	1.30225	44.7117	0.542746	45.86511	0.717716
400	1.332929	52.042145	0.461642	60.79812	0.720386
500	1.367354	59.019184	0.401755	77.38396	0.730074
600	1.40407	65.810844	0.35634	93.1538	0.740197
700	1.437532	72.19796	0.319906	115.2924	0.750942
800	1.467796	78.351677	0.288963	136.566	0.756471
900	1.501532	83.963417	0.26451	159.0942	0.802245
1000	1.528286	89.757217	0.243548	183.8772	0.797028

Table 11: Results of Equivalence Ratio ∅ = 1.2 [for Reactants]

equivalence ratio = 1.2 for reactant					
The coeff. of nitrogen is = 1.880952					
The total mass of reactants is = 71.066666					
The mass fraction of hydrogen is = 0.033771					
The mass fraction of oxygen is = 0.225141					
The mass fraction of nitrogen is = 0.741088					
Temp	**Cond.**	**Sp.Heat**	**Density**	**Vis.*10-6**	**Prandtl No.**
-128.9	1.407739	0.016452	2.382396	5.087298	0.752837
-17.8	1.455047	0.027541	1.34707	15.91161	0.728248
93.4	1.469475	0.036289	0.936815	26.73949	0.717101
204.4	1.48697	0.044856	0.72158	41.84203	0.714171
315.6	1.510797	0.053125	0.583119	59.79747	0.714272
426.7	1.537139	0.060593	0.484359	80.31164	0.715368
537.8	1.563743	0.067432	0.423908	98.33669	0.720124
538.9	1.590122	0.073542	0.360632	128.8401	0.732122
760	1.616501	0.078964	0.333136	148.9175	0.743345

Table 12: Results of Equivalence Ratio ∅ = 1.2 [for Products]

equivalence ratio = 1.2 for product					
Enter choice= 1 for equivalence ratio = 1					
and 2 for eq. ratio > 1 and 3 for eq. ratio < 1 =3					
The coeff. of nitrogen is = 1.881000					
The total mass of products is = 71.068001					
The mass fraction of water is = 0.253279					
The mass fraction of hydrogen is = 0.005628					
The mass fraction of nitrogen is = 0.741093					
Temp	**Sp.Heat**	**Cond.*10-3**	**Density**	**Vis.*10-6**	**Prandtl No.**
100	1.388331	30.575327	0.830673	22.64707	0.779934
200	1.354983	38.467888	0.653625	33.98047	0.728049
300	1.37667	45.929626	0.539934	47.43884	0.717399
400	1.407398	53.462521	0.459245	62.98547	0.720053
500	1.441664	60.805946	0.399644	79.74573	0.729673
600	1.478299	67.710686	0.354492	96.22054	0.73976
700	1.511776	74.211136	0.318248	119.118	0.750493

Table 13: Results of ∅ = 1.4 [for Reactants]

equivalence ratio = 1.4 for reactant					
The coeff. of nitrogen is = 1.880952					
The total mass of reactants is = 71.466667					
The mass fraction of hydrogen is = 0.039179					
The mass fraction of oxygen is = 0.223881					
The mass fraction of nitrogen is = 0.736940					
Temp	**Sp.Heat.**	**Cond**	**Density**	**Vis.*10-6**	**Prandtl No.**
-128.9	1.469599	0.016893	2.370008	5.239104	0.752591
-17.8	1.526213	0.028278	1.340061	16.30015	0.728185
93.4	1.542071	0.037268	0.931946	27.46353	0.717006
204.4	1.559748	0.046077	0.717829	42.94832	0.713957
315.6	1.583666	0.054568	0.580089	61.36297	0.713963
426.7	1.610084	0.062257	0.481837	82.57221	0.715069
537.8	1.636539	0.069215	0.421703	100.6049	0.71977
538.9	1.662994	0.075465	0.358762	132.2814	0.731757
760	1.68945	0.081013	0.331404	152.8705	0.742968

Table 14: Results of ∅ = 1.4 [for Products]

equivalence ratio 1.4 for product					
Enter choice= 1 for equivalence ratio = 1					
and 2 for eq. ratio > 1 and 3 for eq. ratio < 1 3					
The coeff. of nitrogen is = 1.881000					
The total mass of products is = 71.468002					
The mass fraction of water is = 0.251861					
The mass fraction of hydrogen is = 0.011194					
The mass fraction of nitrogen is = 0.736945					
Temp	**Sp.Heat**	**Cond.*10-3**	**Density**	**Vis.*10-6**	**Prandtl No.**
100	1.461397	31.603226	0.826392	23.42214	0.779478
200	1.428487	39.71307	0.650258	35.11225	0.727763
300	1.450256	47.133923	0.537154	48.99497	0.717085
400	1.481034	54.867001	0.456875	65.14834	0.719724
500	1.515142	62.572712	0.397556	82.08106	0.729275
600	1.551697	69.589256	0.352665	99.25295	0.739329
700	1.585189	76.201775	0.316608	122.9008	0.750049

Table 15: Properties of Hydrogen [1, 5]

International Symbol		H2
Molecular weight		2.016
Specific gravity of gas at 32 F and 1 aim (air = 1)		0.06950
Specific volume at 70 F and 1 atm, cu ft/lb		192.0
Density of gas at 70 F and 1 atm, Ib/cu ft		0.005209
Density of gas at boiling point and 1 atm, Ib/cu ft		0.084
Density of liquid at boiling point and 1 arm, Ib/cu ft		4.428
Liquid/gas ratio		
(liquid at boiling point, gas at 70 F and 1 atm),vol/vol		1/850.1
Boiling point at 1 atm		- 423.0 F
Freezing point at 1 atm		- 434.6 F
Critical temperature		- 399.91 F
Critical pressure, psia		190.8
Triple point		-434.56F at 1.0414 psia
Latent heat of vaporization at boiling point, Btu/lb		192.7
Specific heat, *Cp*, at 70 F. Btu/(lb)(°F)		3.416
Specific heat, Cu. at 70 F. Btu/(lb)(°F)		2.430
Ratio of specific heats, *Cp/Cu*, at 70 F		1.41
Heat of combustion, Btu/cu ft		
	Gross	325
	Net	275
Solubility in water at 60 F. vol/1 vol of water		0.019
Weight per gallon, liquid, at boiling point, lb		0.5920

Results of Reactants at Different Equivalence Ratios [ϕ = 0.2 TO 1.4]

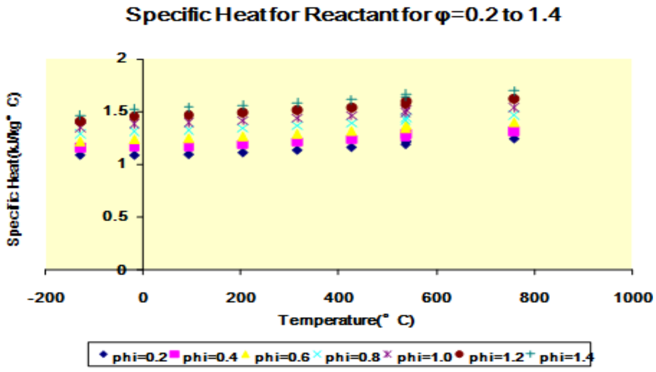


Figure 1: Specific Heat v/s Temperature for Reactants for ϕ = 0.2 to 1.4

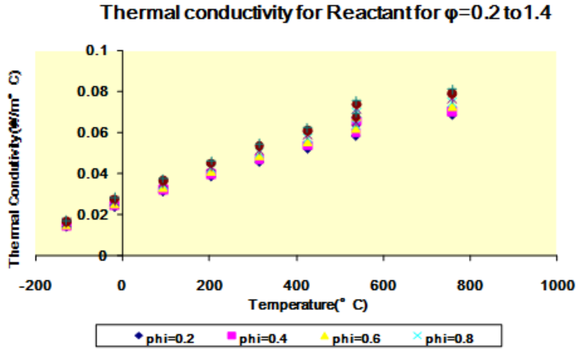


Figure 2: Thermal Conductivity v/s Temperature for Reactants for ϕ = 0.2 to 1.4

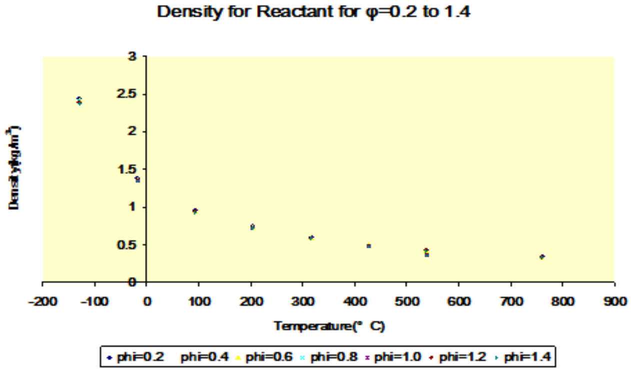


Figure 3: Density v/s Temperature for Reactants for ϕ = 0.2 to 1.4

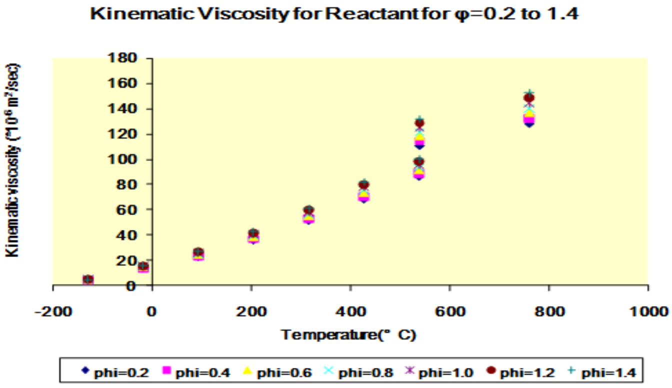


Figure 4: Kinematics Viscosity v/s Temperature for Reactants for ϕ = 0.2 to 1.4

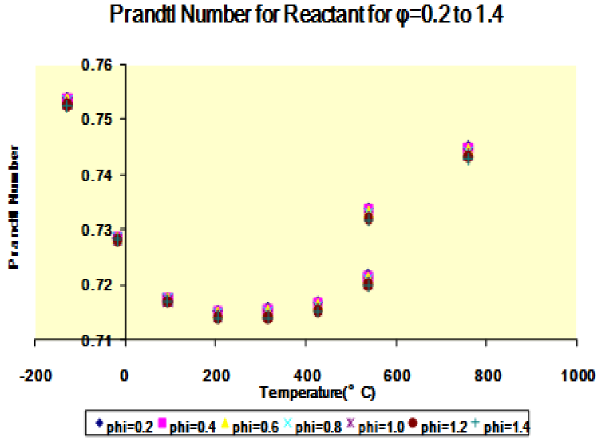
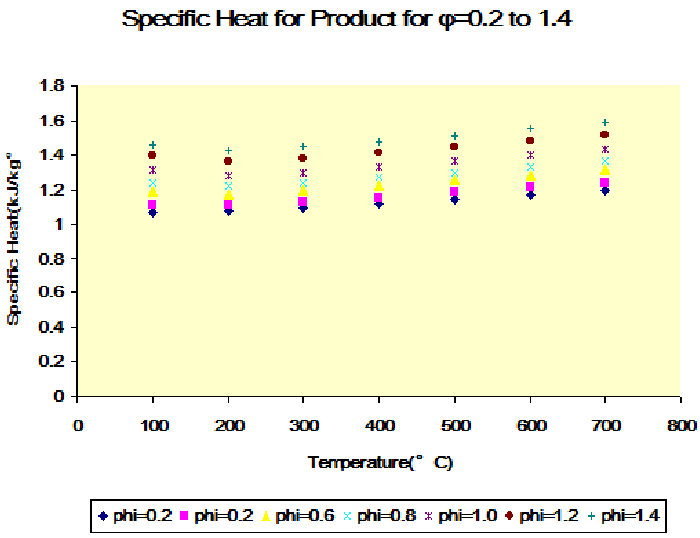


Figure 5: Prandtl No. v/s Temperature for Reactants for ϕ = 0.2 to 1.4

RESULTS OF THE PRODUCTS AT DIFFERENT EQUIVALENCE RATIOS [ϕ = 0.2 TO 1.4]



Specific Heat v/s Temperature for Products for ϕ = 0.2 To 1.4¶

Figure 6: Specific Heat v/s Temperature for Products for ϕ = 0.2 To 1.4

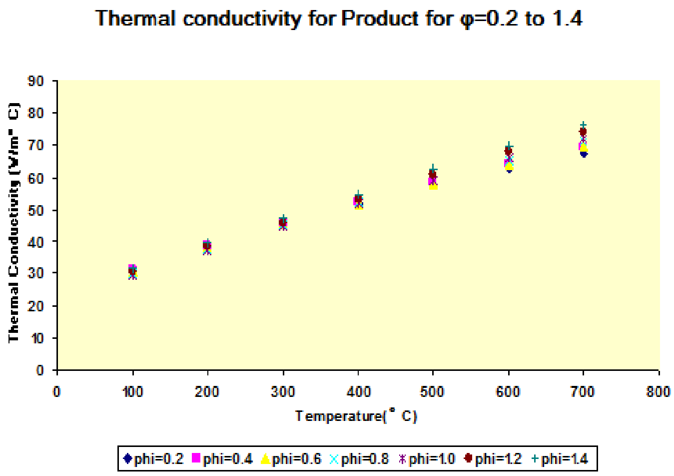


Figure 7: Thermal Conductivity v/s Temperature for Products for ϕ = 0.2 to 1.4

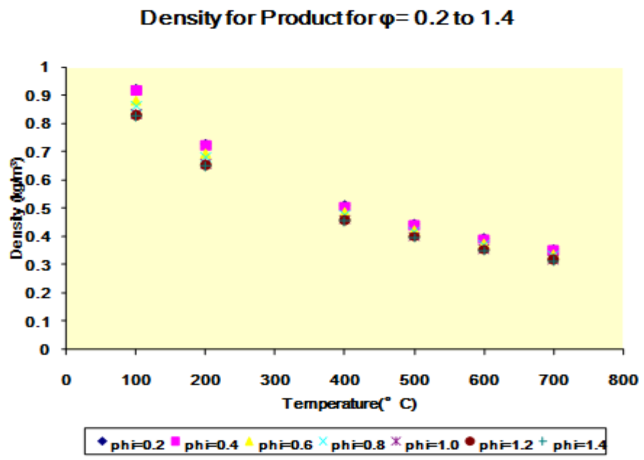


Figure 8: Density v/s Temperature for Products for ϕ = 0.2 to 1.4

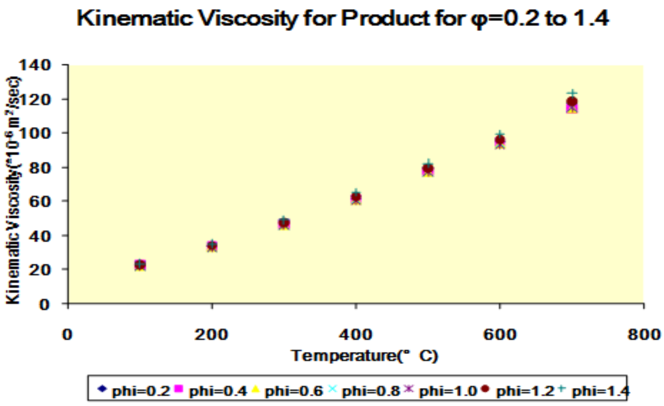


Figure 9: Kinematics Viscosity v/s Temperature for Products for ϕ = 0.2 to 1.4

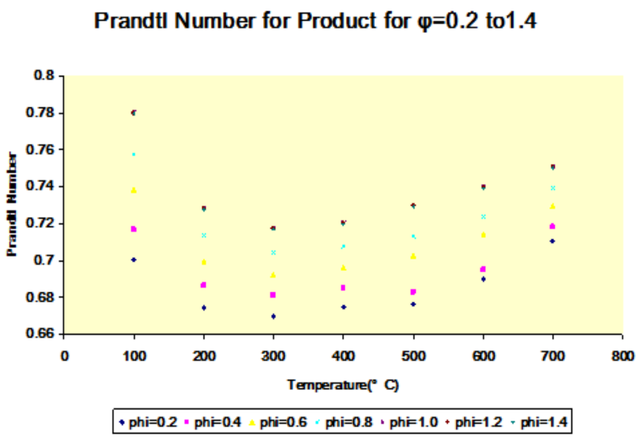


Figure 10: Prandtl No. v/s Temperature for Products for ϕ = 0.2 to 1.4

MASS FRACTION OF REACTANT DIFFERENT EQUIVALENCE RATIOS

Table 16: Mass Fraction of Reactant at Different Equivalence Ratios

Φ	H_{2r}	O_{2r}	N_{2r}	Total Reactant[Kg/mole]
0.2	0.005792	0.2316	0.7625	345.33
0.4	0.01151	0.2303	0.7581	173.66

0.6	0.0171	0.229	0.7538	116.43
0.8	0.0227	0.2277	0.7459	87.8333
1	0.0283	0.2264	0.7452	70.6666
1.2	0.0337	0.2251	0.741	71.0666
1.4	0.03917	0.2238	0.7369	71.466

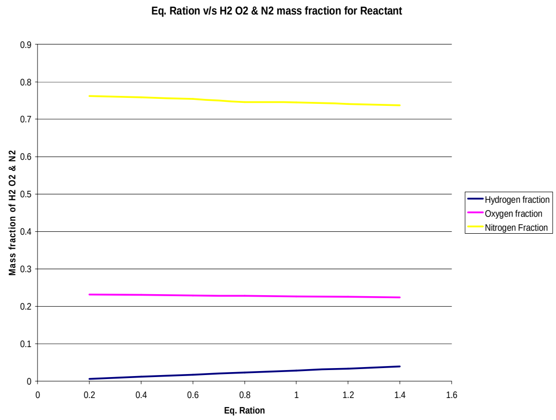


Figure 11: Variation of Mass Fraction of H2, O2 & N2 with Respect to Different Equivalence Ratio for Reactant

MASS FRACTION OF PRODUCT AT DIFFERENT EQUIVELENCE RATIOS

Table 17: Mass Fraction of Product at Different Equivalence Ratios

Φ	H_2O_p	O_{2p}	N_{2p}	H_{2p}	Total Product[Kg/mole]
0.2	0.05212	0.1853	0.7625	0	345.33
0.4	0.091	0.2429	0.6659	0	173.66
0.6	0.1481	0.0877	0.7641	0	116.43
0.8	0.196	0.0871	0.7168	0	87.8333
1	0.2547	0	0.7452	0	70.6666
1.2	0.2532	0	0.741	0.005628	71.0666
1.4	0.2518	0	0.7369	0.0111	71.466

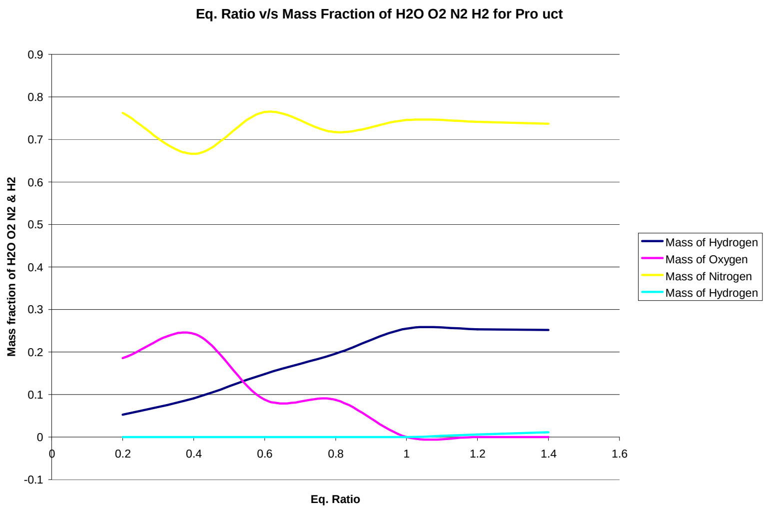


Figure 12: Variation of Mass Fraction of H_2O, H2, O2 & N2 with Respect to Different Equivalence Ratio for Product