# A Quasi One-dimensional Simulation of a Combustor for Micro Gas Turbine Engine Using different NGV-Ethanol Fuelled Modes

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***Abstract***

This work is to numerically study combustion in silo combustor type of micro gas turbine engine using different NGV-Ethanol fuelled modes. The simulation applied chemical equilibrium method where the fuel mixture is specified by the way of its C-H-O-N values and curve-fit coefficients are employed to simulate air and fuel data along with frozen composition. The study described performance parameters, pressure and temperature profile data on the effect of mole ratio of the NGV-Ethanol-mixture (100:0, 90:10, 80:20, 70:30), equivalence ratio (0.6-1.0), pressure ratio (3.0-4.0), and engine speed (40000-120000 RPM).In this study, the silo combustor was simulated on the variation of the ignition length (premixed zone) 0.10, 0.15 m and burning length (primary zone) 0.10, 0.15 m. The calculated data is then showed to plot the changing performances and pressure-temperature profile.

***Keywords****:* NGV-Ethanol, equilibrium, Simulation, Thermodynamic Modeling and Olikara and Borman.

## 1. Introduction

The technology to generated power from micro gas turbine engines is new technology and compared with the piston engines of the efficiency and cost-effective for production power. The advantages of micro gas turbine engine are smaller and more efficient, depending on the purpose of the work (electric power and heat power). Generally, it will be used as backup power only. However, this technology is very expensive. Determined from Claire [1], he found that pay back periods and internal rate of return (IRR) is not satisfactory in the size range of 30-100 kWh as following lifetimes of the system, when fossil fuel prices rise and demand. So, if micro gas turbine is the common choice for co-generation of heat and power from fossil fuel and ethanol. Instead of the one fossil fuel micro gas turbine engines may be used. These alternatives promise a significant reduction of the cost and Possibility of using alternate fuels.

This paper aims to develop a simple, modified some empirical and accurate silo combustor simulation model without the need as great deal of computational power or knowledge of precise silo combustor geometrical data. So, the model is based on the classical two-zone approach on primary zone, wherein parameters like heat transfer from the general combustion chamber, blowby, energy loss and heat release rate are also considered. The calculated data are performance with respect to equivalence ratios, pressure ratio, engine speed and pressure-temperature profiles with respect to combustor length respectively.

## 2. Modeling and analysis

### 2.1 The Mathematical of a Silo Combustor

The mathematical of a silo type gas turbine combustor was applicable in the same details for constant volume spark ignition engine and is based on the thermodynamic analysis of the ideal fuel-air cycle. The method is assumed that the fuels and air are supplied from a perfect system and mixed completely. From the first law of thermodynamics, the open system can be modified as following equations from Lefebvre and Lefebvre [2] that shown in Fig 1.

$$\Delta U = Q - W - (H_L) + (H_a) \tag{1}$$

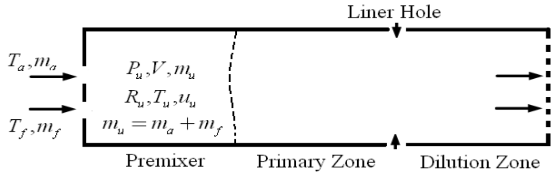



**Fig 1** Constant volume for a silo combustor

This Eq.1 shows the change of internal energy $U$ of a system is equal to the difference between the heat $Q$ from fuels, work generated by the system $W$, heat loss $H_L$ and the enthalpy $H_a$ of the *air inlet passed* the *dilution holes* which applied to the constant volume. Taking the derivative of Eq. 1 as the function of the length $L(x)$ yields as

$$mc_V \frac{dT}{dL} + c_V T \frac{dm}{dL} = \frac{dQ}{dL} - P\frac{dV}{dL} - \frac{\dot{m}_l c_p T}{v} + \left(\frac{\dot{m}_a c_{p,a} T}{v}\right) \tag{2}$$

Where $m$ is the total mass of system $\dot{m}_l$ is the instantaneous leakage or blow-by rate and is assumed to be always out of the linner, $\dot{m}_a$ is mass rate of air inlet passed the dilution holes, $P$ is the average pressure, $V$ is a constant volume in the linner and v is average gases velocity that assumed from relative engine speed and turbulent flame front speed during combustion.

### 2.2 Thermodynamic properties

The specific heat change as the function of the length in equation (2) indicates the enthalpy change with respect to temperature and pressure, which was obtained from curve fitted polynomial equation. Table 1 shows the thermodynamics properties expressed as a function of length, pressure and temperature. Where, Lewis [4] has represented the thermodynamic properties of fuels and air Ferguson [3] proposed the thermodynamic properties of air and combustion products.

**Table 1** Thermodynamic properties

| |
|---|
| Internal energy, volume, entropy, enthalpy [3] |
| $\frac{du}{dL} = \left(c_P - \frac{Pv}{T}\frac{\partial \ln v}{\partial \ln T}\right)\frac{dT}{dL} - v\left(\frac{\partial \ln v}{\partial \ln T} + \frac{\partial \ln v}{\partial \ln P}\right)\frac{dP}{dL}$ <br> $\frac{dv}{dL} = \frac{v}{T}\frac{\partial \ln v}{\partial \ln T}\frac{dT}{dL} - \frac{v}{P}\frac{\partial \ln v}{\partial \ln P}\frac{dP}{dL}$ <br> $\frac{ds}{dL} = \left(\frac{C_P}{T}\right)\frac{dT}{dL} - \frac{v}{T}\frac{\partial \ln v}{\partial \ln T}\frac{dP}{dL}, \left(\frac{\partial h}{\partial T}\right)_P = C_P$ |
| Fuels [4] |
| $\frac{c_P}{R} = a_0 + b_0 T + c_0 T^2$ <br> $\frac{h}{RT} = a_0 + \frac{b_0}{2}T + \frac{c_0}{3}T^2 + \frac{d_0}{T}$ <br> $\frac{s^0}{R} = a_0 \ln T + b_0 T + \frac{c_0}{2}T^2 + e_0$ |
| Air and Combustion product [4] |

$$\frac{c_P}{R} = a_1 + a_2T + a_3T^2 + a_4T^3 + a_5T^4$$
$$\frac{h}{RT} = a_1 \ln T + \frac{a_2}{2}T + \frac{a_3}{3}T^2 + \frac{a_4}{4}T^3 + \frac{a_5}{5}T^4 + \frac{a_6}{T}$$
$$\frac{s^0}{R} = a_1 \ln T + a_1 T + \frac{a_3}{3}T^2 + \frac{a_4}{4}T^3 + \frac{a_5}{4}T^4 + a_7$$

In the primary zone, we consider the temperature in the term of unburned ($T_u$) and burnt mixture ($T_b$) as separate open systems. Recalling Eq.2 and combining all the derivatives of thermodynamic properties will enable the pressure and temperature to be expressed as a function of length, pressure, unburned gas temperature and burned gas temperature.

$$\frac{dP}{dL}, \frac{dT_b}{dL}, \frac{dT_u}{dL} = f_1(L, P, T_b, T_u) \tag{3}$$

Modified algorithm from Ferguson [3] as following the arbitrary heat release conditions and solving the above equations with appropriate input data enable determination of the indicated work, enthalpy and heat loss throughout the system since indicated work, enthalpy and heat loss can be expressed as a function of pressure and temperature.

$$\frac{dP}{dL} = \frac{A+B+C}{D+E} \tag{4}$$

$$\frac{dT_b}{dL} = \frac{-h\left(\frac{\pi b^2}{2} + \frac{4V}{b}\right)x^{1/2}(T_b - T_w)}{vmc_{Pb}x} + \frac{v_b}{c_{Pb}}\left(\frac{\partial \ln v_b}{\partial \ln T_b}\right)\left(\frac{A+B+C}{D+E}\right) + \frac{h_u - h_b}{xc_{Pb}}\left[\frac{dx}{dL} - (x - x^2)\frac{C}{v}\right] \tag{5}$$

$$\frac{dT_u}{dL} = \frac{-h\left(\frac{\pi b^2}{2} + \frac{4V}{b}\right)\left(1 - x^{1/2}\right)(T_u - T_w)}{vmc_{Pb}(1-x)} + \frac{v_u}{c_{Pu}}\left(\frac{\partial \ln v_u}{\partial \ln T_u}\right)\left(\frac{A+B+C}{D+E}\right) \tag{6}$$

From the derivatives of Eq. (4–6) let us defined the constant term with respect to the combination of the thermodynamic properties equations are:

$$A = \frac{1}{m}\left(\frac{dV}{dL} + \frac{VC}{v}\right) \tag{7}$$

$$B = h\frac{\left(\frac{dV}{dL} + \frac{VC}{v}\right)}{vm}\left[\frac{v_b}{c_{Pb}}\frac{\partial \ln v_b}{\partial \ln T_b}x^{1/2}\frac{T_b - T_w}{T_b} + \frac{v_u}{c_{Pu}}\frac{\partial \ln v_u}{\partial \ln T_u}\left(1 - x^{1/2}\right)\frac{T_b - T_w}{T_b}\right] \tag{8}$$

$$C = -(v_b - v_u)\frac{dx}{dL} - v_b\frac{\partial \ln v_b}{\partial \ln T_b}\frac{h_u - h_b}{c_{Pb}T_b}\left[\frac{dx}{dL} - \frac{(x - x^2)C}{v}\right] \tag{9}$$

$$D = x\left[\frac{v_b^2}{c_{Pb}T_b}\left(\frac{\partial \ln v_b}{\partial \ln T_b}\right)^2 + \frac{v_b}{P}\frac{\partial \ln v_b}{\partial \ln P}\right] \tag{10}$$

$$E = (1 - x)\left[\frac{v_u^2}{c_{Pu}T_u}\left(\frac{\partial \ln v_u}{\partial \ln T_u}\right)^2 + \frac{v_u}{P}\frac{\partial \ln v_u}{\partial \ln P}\right] \tag{11}$$

### 2.3 Chemical Equilibrium with the Fuel mixture.

The basis of the equilibrium combustion products with fuel mixture model $C_\alpha H_\beta O_\gamma N_\delta$ is a solution to the atom balance equations from the chemical reaction equation of fuel and air forming and The subscript *1*,2&*3* represent the One of the fuel, the fuel in the second and third respectively. This mixture equation is given in Eq.12 for the condition of equivalence ratio $\phi$, where $n_1$ through $n_{11}$ are mole fractions of the product species, $e$ is the molar fuel-air ratio required to react with one mole of air. This process based on the work of modified Ferguson [3] as given below

$$\begin{aligned} &\varepsilon\phi(1 - c_1)C_{\alpha1}H_{\beta1}O_{\gamma1}N_{\delta1} + \\ &\varepsilon\phi(c_1)\left(c_2C_{\alpha2}H_{\beta2}O_{\gamma2}N_{\delta2} + c_3C_{a3}H_{\beta3}O_{\gamma3}N_{\delta3}\right) \\ &+ \begin{matrix}0.21O_2\\0.79N_2\end{matrix} \rightarrow \begin{matrix} n_1CO_2 + n_2H_2O + n_3N_2 + n_4O_2 \\ + n_5CO + n_6H_2 + n_7H + n_8O \\ + n_9OHn_{10}NO + v_{11}N \end{matrix} \end{aligned} \tag{12}$$

Where $c_1$ is the molar ratio of multi-fuel having the condition ($0 < c_1 < 1$). $c_2, c_3$ are the fuel in the second and third which having the condition($c_2 + c_3 = 1$). There is the conservation of 4 atoms, C,H,O and N from mixture equation, so atom balancing can be written,

$$\text{C} \quad \varepsilon\phi(1-\chi_1)\alpha1 + \varepsilon\phi\chi_1\chi_2\alpha2 + \varepsilon\phi\chi_1\chi_3\alpha3 = (y_1 + y_5)N \tag{13}$$

$$\text{H} \quad \varepsilon\phi(1-\chi_1)\beta1 + \varepsilon\phi\chi_1\chi_2\beta2 + \varepsilon\phi\chi_1\chi_3\beta3 = (2y_2 + 2y_6 + y_7 + y_9)N \tag{14}$$

$$\text{O} \quad \varepsilon\phi(1-\chi_1)\gamma1 + \varepsilon\phi\chi_1\chi_2\gamma2 + \varepsilon\phi\chi_1\chi_3\gamma3 + 0.42 = (2y_1 + y_2 + 2y_4 + y_5 + y_8 + y_9 + y_{10})N \tag{15}$$

$$\text{N} \quad \varepsilon\phi(1-\chi_1)\delta1 + \varepsilon\phi\chi_1\chi_2\delta2 + \varepsilon\phi\chi_1\chi_3\delta3 + 1.58 = (2y_3 + y_{10} + y_{11})N \tag{16}$$

Where, $N$ is the total number of moles and *y* is the mole fraction. Thus, the total number of mole fraction must be equal to one and this gives:

$$\sum_{i=1}^{11} y_i - 1 = 0 \tag{17}$$

The expression for atom balance of each equation can be eliminated by dividing Eq. 14-16 by equation 3. The equation can be written as next equation.

$$2y_2 + 2y_6 + y_7 + y_9 - [d_1(y_1 + y_5)] = 0 \tag{18}$$

$$2y_1 + y_2 + 2y_4 + y_5 + y_8 + y_9 + y_{10} - [d_2(y_1 - y_5)] = 0 \tag{19}$$

$$2y_2 + y_{10} + y_{11} - [d_3(y_1 + y_5)] = 0 \tag{20}$$

$$d_1 = \frac{(1-\chi_1)\beta 1 + \chi_1\chi_2\beta 2 + \chi_1\chi_3\beta 3}{(1-\chi_1)\alpha 1 + \chi_1\chi_2\alpha 2 + \chi_1\chi_3\alpha 3} \qquad d_2 = \frac{(1-\chi_1)\gamma 1 + \chi_1\chi_2\gamma 2 + \chi_1\chi_3\gamma 3 + \dfrac{0.42}{\varepsilon\phi}}{(1-\chi_1)\alpha 1 + \chi_1\chi_2\alpha 2 + \chi_1\chi_3\alpha 3}$$

$$d_3 = \frac{(1-\chi_1)\delta 1 + \chi_1\chi_2\delta 2 + \chi_1\chi_3\delta 3 + \dfrac{1.58}{\varepsilon\phi}}{(1-\chi_1)\alpha 1 + \chi_1\chi_2\alpha 2 + \chi_1\chi_3\alpha 3}$$

Eqs (17-20) have 11 unknowns ($y_1, y_2, y_3 .... y_{11}$), therefore in order to solve for these 11 unknowns other 7 more equations are needed which may be derived from the consideration of equilibrium among products. The equilibrium constant can be related to the partial pressure of the reactants and products. And the partial pressure of a component is defined relative to the total pressure and the mole faction, thus the equilibrium constant can be rewritten as Table 2.

**Table 2** The dissociation effect

| | |
|---|---|
| $CO_2 \leftrightarrow CO + \frac{1}{2}O_2$ | $K_1 = \dfrac{y_5 y_4^{1/2} P^{1/2}}{y_1}$ |
| $H_2 + \frac{1}{2}O_2 \leftrightarrow H_2O$ | $K_2 = \dfrac{y_2}{y_4^{1/2} y_6 P^{1/2}}$ |
| $\frac{1}{2}H_2 + \frac{1}{2}O_2 \leftrightarrow OH$ | $K_3 = \dfrac{y_9}{y_4^{1/2} y_6^{1/2}}$ |
| $\frac{1}{2}H_2 \leftrightarrow H$ | $K_4 = \dfrac{y_7 P^{1/2}}{y_6^{1/2}}$ |
| $\frac{1}{2}O_2 \leftrightarrow O$ | $K_5 = \dfrac{y_8 P^{1/2}}{y_4^{1/2}}$ |
| $\frac{1}{2}N_2 \leftrightarrow N$ | $K_6 = \dfrac{y_{11} P^{1/2}}{y_3^{1/2}}$ |
| $\frac{1}{2}O_2 + \frac{1}{2}N_2 \leftrightarrow NO$ | $K_7 = \dfrac{y_{10}}{y_4^{1/2} y_3^{1/2}}$ |

Equilibrium constant in Table 3, $K_1$ through $K_7$ are curve fitted Lewis [4] and their expressions are of the from,

$$K_P = \exp\left(\Delta a_1(\ln T - 1) + \frac{\Delta a_2 T}{2} + \frac{\Delta a_3 T^2}{6} + \frac{\Delta a_4 T^3}{12} + \frac{\Delta a_5 T^4}{20} - \frac{\Delta a_6}{T} + \Delta a_7\right) \tag{22}$$

Through algebraic manipulations, the ten equations can be reduced into four equations with four unknowns. The equations are nonlinear and solved by using the Newton method. Each of these may be expanded in Taylor's series $f_j(y_3, y_4, y_5, y_6) = 0$ where $j = 1,2,3,4$ (neglecting the second order and higher order) as,

$$f_j + \frac{\partial f_j}{\partial y_3}\Delta y_3 + \frac{\partial f_j}{\partial y_4}\Delta y_4 + \frac{\partial f_j}{\partial y_5}\Delta y_5 + \frac{\partial f_j}{\partial y_6}\Delta y_6 = 0 \tag{23}$$

Functions $f_j$ are evaluated from the solution of interested functions (Eq.17 through Eq.20) the independent set of derivatives is obtained by solution of matrix equation that results from differentiating with respect to mole faction. The above can be arranged as set of linear equations in the matrix form,

$$\left[\frac{\partial f_i}{\partial y_i}\right][\Delta y] - [-f] = 0 \tag{24}$$

This set of linear equations can then be solved for $y_3, y_4, y_5, y_6$ and iterative procedures undertaken until the corrections are less than a specified tolerance ($\delta$). For convenience, defining following partial derivatives and defining the constant values for a simple studied and the Jacobian of solution are given as Table 3

**Table 3** constant values,the Jacobian of solution

| | |
|---|---|
| $D_{ij} = \dfrac{\partial y_i}{\partial y_i} \dfrac{i = 1,2,7,8,9,10,11}{j = 3,4,5,6}$ | |
| $D_{14} = \dfrac{\partial y_1}{\partial y_4} = \dfrac{1}{2}\dfrac{c_1 y_5}{y_4^{1/2}}$, $D_{24} = \dfrac{\partial y_2}{\partial y_4} = \dfrac{1}{2}\dfrac{c_2 y_6}{y_4^{1/2}}$, | $D_{84} = \dfrac{\partial y_8}{\partial y_4} = \dfrac{1}{2}\dfrac{c_5}{y_4^{1/2}}$, $D_{94} = \dfrac{\partial y_9}{\partial y_4} = \dfrac{1}{2}\dfrac{c_3 y_6^{1/2}}{y_4^{1/2}}$ |
| $D_{15} = \dfrac{\partial y_1}{\partial y_5} = c_1 y_4^{1/2}$, $D_{26} = \dfrac{\partial y_2}{\partial y_6} = c_2 y_4^{1/2}$, | $D_{76} = \dfrac{\partial y_7}{\partial y_6} = \dfrac{1}{2}\dfrac{c_4}{y_6^{1/2}}$, $D_{96} = \dfrac{\partial y_9}{\partial y_6} = \dfrac{1}{2}\dfrac{c_3 y_4^{1/2}}{y_6^{1/2}}$ |
| $D_{103} = \dfrac{\partial y_{10}}{\partial y_3} = \dfrac{1}{2}\dfrac{c_7 y_4^{1/2}}{y_3^{1/2}}$, $D_{104} = \dfrac{\partial y_{10}}{\partial y_4} = \dfrac{1}{2}\dfrac{c_7 y_3^{1/2}}{y_4^{1/2}}$, | $D_{113} = \dfrac{\partial y_{11}}{\partial y_3} = \dfrac{1}{2}\dfrac{c_6}{y_3^{1/2}}$ |
| $\dfrac{\partial f_1}{\partial y_3} = 1 + D_{103} + D_{113}$ | $\dfrac{\partial f_2}{\partial y_3} = 0$ |
| $\dfrac{\partial f_1}{\partial y_4} = D_{14} + D_{24} + 1 + D_{84} + D_{104} + D_{94}$ | $\dfrac{\partial f_2}{\partial y_4} = 2D_{24} + D_{94} - d_1 D_{14}$ |
| $\dfrac{\partial f_1}{\partial y_5} = D_{15} + 1$ | $\dfrac{\partial f_2}{\partial y_5} = -d_1 D_{15} - d_1$ |
| $\dfrac{\partial f_1}{\partial y_6} = D_{26} + 1 + D_{76} + D_{96}$ | $\dfrac{\partial f_2}{\partial y_6} = 2D_{26} + 2 + D_{76} + D_{96}$ |
| $\dfrac{\partial f_3}{\partial y_3} = D_{103}$ | $\dfrac{\partial f_4}{\partial y_3} = 2 + D_{103} + D_{113}$ |
| $\dfrac{\partial f_3}{\partial y_4} = 2D_{14} + D_{24} + 2 + D_{84} + D_{94} + D_{104} - d_2 D_{14}$ | $\dfrac{\partial f_4}{\partial y_4} = D_{104} - d_3 D_{14}$ |
| $\dfrac{\partial f_3}{\partial y_5} = 2D_{15} + 1 - d_2 D_{15} - d_2$ | $\dfrac{\partial f_4}{\partial y_5} = d_3 D_{15} - d_3$ |
| $\dfrac{\partial f_3}{\partial y_6} = D_{26} - D_{96}$ | $\dfrac{\partial f_4}{\partial y_6} = 0$ |

Eq.24 may be solved using by Gauss elimination. The second approximation is then

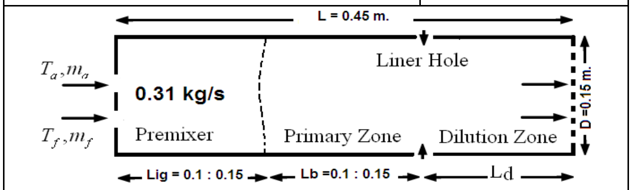
$\{y\}_{k+1} = \{y\}_k + \{\delta\}_k \quad y = 3,4,5,6$. The process of forming the jacobian, solving Eq.24 and calculating new values for $\{y\}$ is repeated until a stop criterion is met, results in the molar concentrations of the 11 product species, as shown in paramust [5].

### 2.5 Model setup

The combustor specification is shown in Table 4.

**Table 4** The specifications for Simulation

| | |
|---|---|
| Total Mass Flow Rate | 0.31 kg/s |
| Total Silo Combustor length (L) | 0.45 m |
| Silo Chamber diameter (D) | 0.15 m |
| Ignition length (premixedz, Lig) | 0.10, 0.15 m. |
| Burning length (primary, Lb) | 0.10, 0.15 m. |
| NGV-Ethanol fuel mode by mole faction | 100:0, 90:10, 80:20, 70:30 |
| Equivalence Ratio $\phi$ | 0.6-1.0 |
| Pressure Ratio (Pin/Pambient) | 3.0-4.0 |
| Engine Speed (RPM) | 40000-120000 |




A study of gases as models of internal combustion engines is useful for qualitatively illustrating some of the important parameters influencing combustor performances, that is, the work output $w_{CV}$ from fuel-air cycle. In theoretical of control volume, the combustor performances can be calculated by meaning of the indicated values which the following definitions are done by the gas. That is thermal efficiency and the indicated mean effective pressure.

Thermal Efficiency)

$$\eta = \frac{w_{CV}[1+\phi F_s(1-f)]}{\phi F_s a_0(1-f)} \tag{29}$$

The indicated mean effective pressure (IMEP)

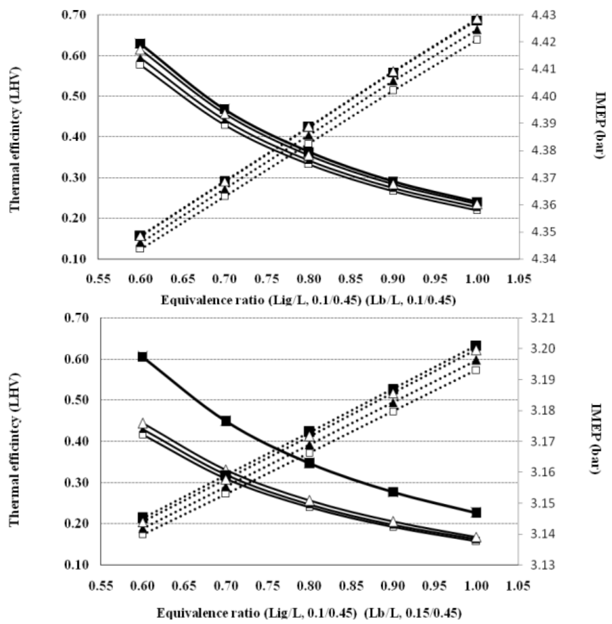
$$IMEP = \frac{w_{CV}[1+\phi F_s(1-f)]}{V} \tag{30}$$

Where, the stoichiometric fuel-air ratio by mass is $F_s$, residual fraction is $f$, available energy of fuel is $a_c$ (LHV), and V is the constant volume silo combustor $V = LD$.

## 4. Results and Discussions

### 4.1 Effect of Equivalence ratio on performance parameters

This simulation test was run at 40000 rpm and pressure ratio 3.5. The silo combustor specifications ($L_{ig}$:$L_b$) to be used as following 0.10:0.10, 0.10:0.15 and 0.15:0.10 while using different equivalence ratio ($f$) are 0.6, 0.7, 0.8, 0.9 and 1.0 respectively. The results indicate that as the IMEP rises and thermal efficiency starts to decrease exponentially as the equivalence ratio increases. In case, a specification of 0.10:0.10 was chosen for the following simulation since others gives a rather low performance. These are showed in Fig. 2.



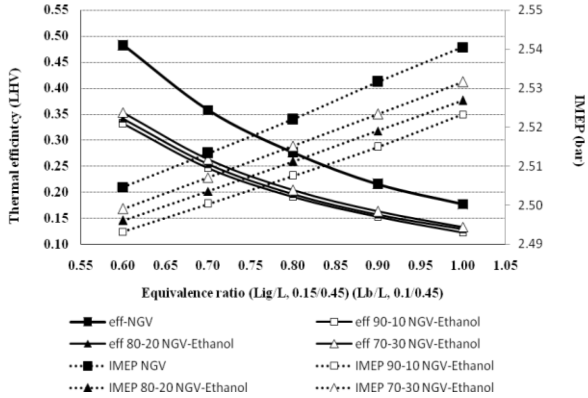
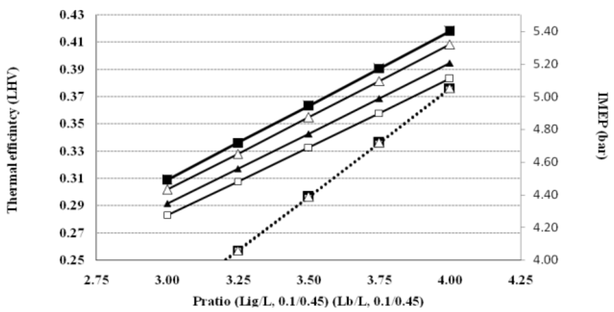



**Fig 2** Thermal efficiency, IMEP-Equivalence ratio

### 4.2 Effect of Pressure ratio on Performance Parameters

This simulation test was run at 40000 rpm and equivalence ratio 0.8. The silo combustor specifications ($L_{ig}$:$L_b$) to be used as following 0.10:0.10, 0.10:0.15 and 0.15:0.10 while using different pressure ratio (Pratio) are 3.00, 3.25,3.50,3.75 and 4.00 respectively. The results indicate that as the IMEP rises and thermal efficiency starts to increases exponentially as the pressure ratio increases. In case, these IEMP curves are almost the same values of NGV-ethanol fueled and 0.10:0.10 was chosen for high performances. These are showed in Fig. 3.



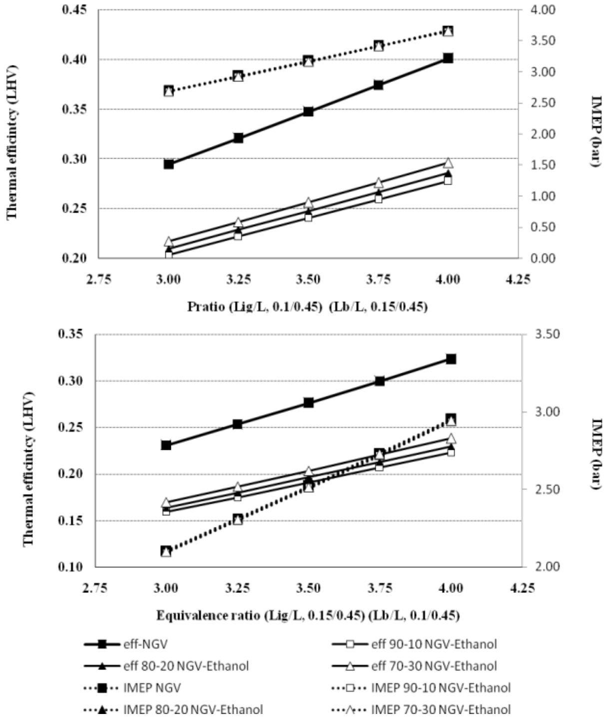
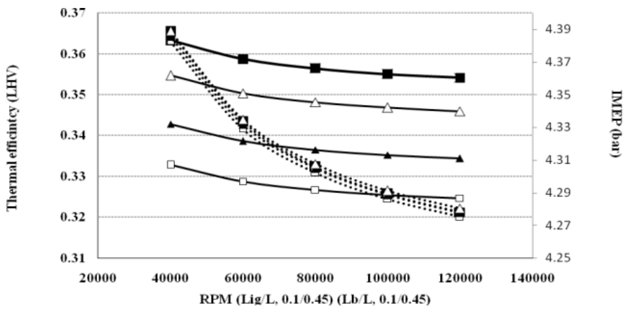




**Fig 3** Thermal efficiency,IMEP-Pressure ratio

### 4.3 Effect of Engine Speed on Performance Parameters

This simulation test was run at equivalence ratio 0.8 and pressure ratio 3.5. The silo combustor specifications ($L_{ig}$:$L_b$) to be used as following 0.10:0.10, 0.10:0.15 and 0.15:0.10 while using different engine speed (RPM) are 40000, 60000, 80000, 100000 and 120000 respectively. The results indicate that as the IMEP and thermal efficiency starts to decrease exponentially as the engine speed increases. In case, these IEMP are almost the same values and 0.10:0.10 was chosen for high performances as showed in Fig. 4.



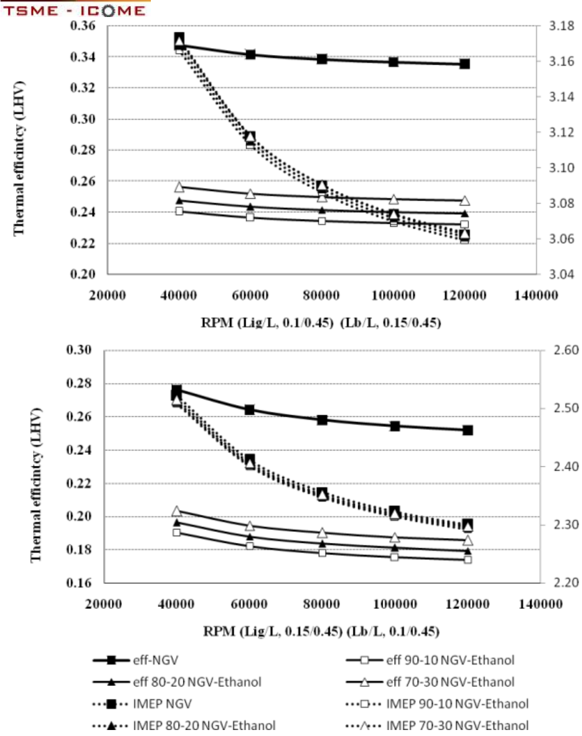
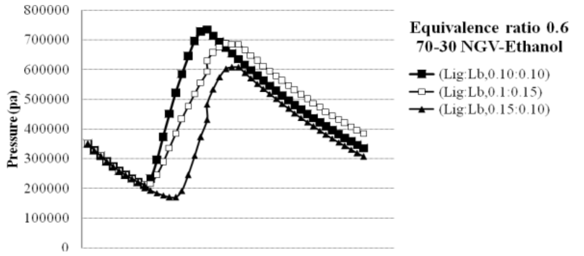



**Fig 4** Thermal efficiency,IMEP-Engine Speed

### 4.4 Effect of Equivalence ratio on pressure-temperature profiles

This simulation test was run at engine speed 40000 RPM and pressure ratio 3.5. The silo combustor specifications ($L_{ig}$:$L_b$) to be used in the simulation as following 0.10:0.10, 0.10:0.15 and 0.15:0.15 respectively. The results indicate that as the equivalence ratio increases, pressures and temperature gives the value that is not the appropriate design predictions. These are low-pressure and high temperature. These are showed in Fig. 5.



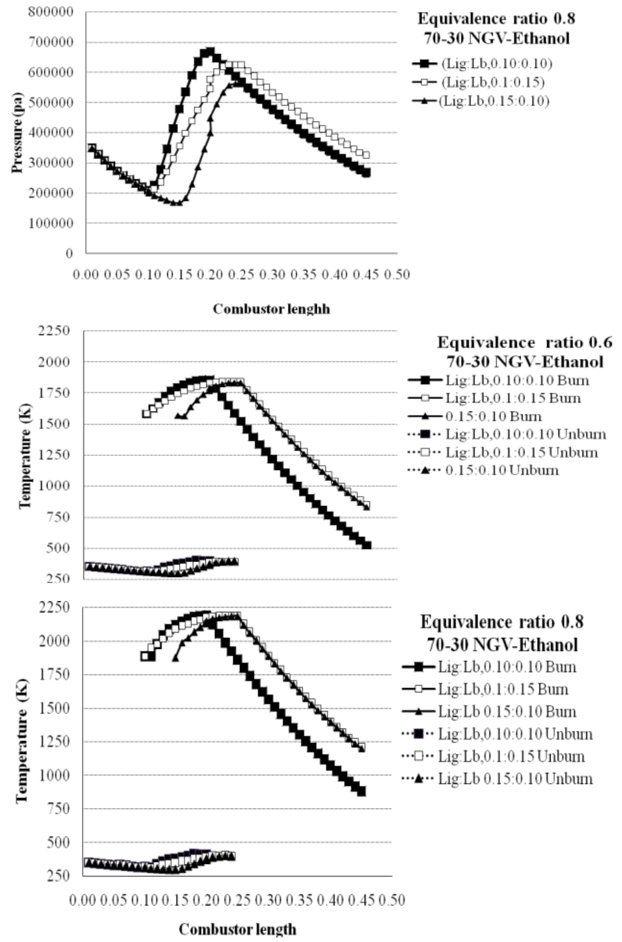




**Fig 5** Pressure-Temperature-Equivalence Ratio

### 4.5 Effect of Pressure ratio on pressure-temperature profiles

This simulation test was run at equivalence ratio 0.8 and engine speed 40000 RPM. The silo combustor specifications ($L_{ig}$:$L_b$) to be used in the simulation as following 0.10:0.10, 0.10:0.15 and 0.15:0.15 respectively. The results indicate that as the pressure rises as the pressure ratio increases, but, temperatures are almost the same values. In case, high pressure ratio was chosen for the appropriate design predictions. These are showed in Fig. 6.

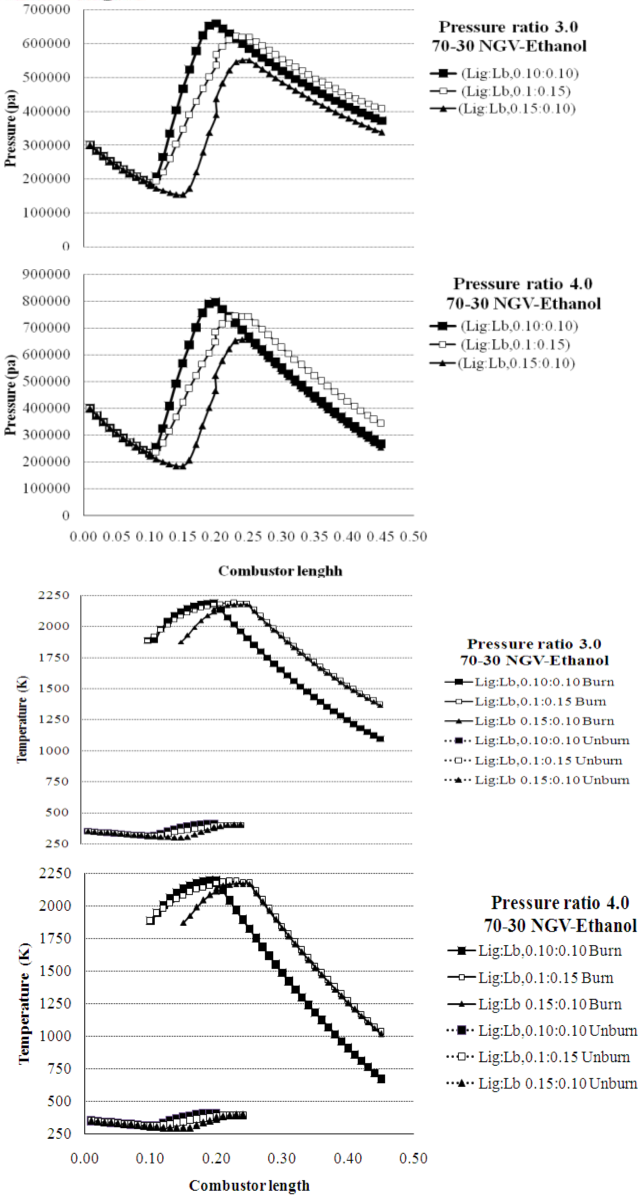



**Fig 6** Pressure-Temperature-Pressure ratio

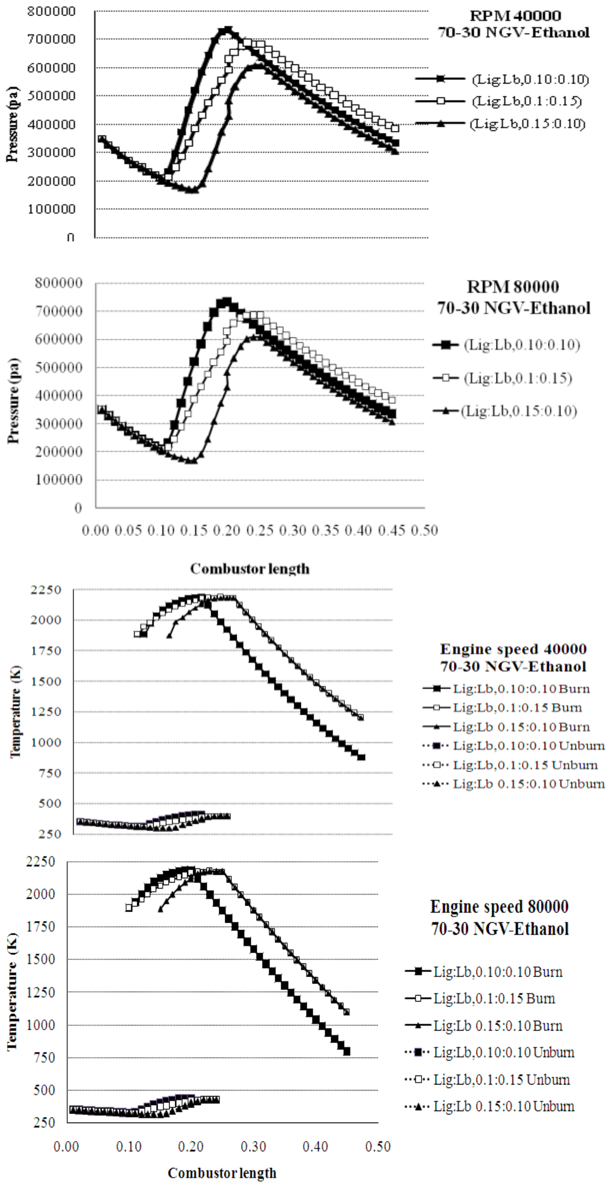



**Fig 7** Pressure-Temperature-engine speed

### 4.6 Effect of Engine speed on pressure-temperature profiles

This simulation test was run at equivalence ratio 0.8 and pressure 3.5. The silo combustor specifications ($L_{ig}$:$L_b$) to be used in the simulation as following 0.10:0.10, 0.10:0.15 and 0.15:0.15 respectively. In case, these pressures and temperatures are almost the same values as showed in Fig. 7. These results indicate that as the engine speed does not affect to design predictions of pressures and temperatures

## 5. Conclusion

The present work achieves its goal by being a simple, fast and silo combustor model. Based on the Olikara-Borman method [3,4], a subroutine for equilibrium combustion [3,4] product was developed and obtained. The results obtained can be used as a first-degree approximation and is useful in numerous engineering applications including general design predictions and easily adapt to any combustion chamber shape for a micro gas turbine. Due to its simplicity and computational efficiency, the model can also be used as a preliminary test on a wide range of alternate fuels.

## 6. Acknowledgement

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## 7. References

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