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CFD Model and inspection of burner for biogas design by genetic Algorithm

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Abstract

Fuel, like water, is essential for survival in today's civilization. Sea and land-based fossil fuels provide fuel for automobiles, cooking, and power generation. In a few centuries, these fossil fuels will be depleted. As a result, finding non-conventional fuel sources to replace these fossil fuels is crucial. Biogas, which is produced from biological waste, can be used as a fuel substitute. Many studies are being carried out to increase biogas production efficiency so that it can be used as an alternative fuel. Traditional fossil fuels are substantially more expensive than biogas.

The purpose of this research is to develop a biogas-fueled domestic kitchen burner. A burner must be appropriately designed to get the most out of it. The ideal design aims for the best dimensions, the most holes on the burner, the best air-fuel mixture, and, most significantly, the best fuel flow rate. Biogas combustion on a burner is modeled using Computational Fluid Dynamics, and the burner design is optimized using a Genetic Algorithm. Other expert-led investigations and data from various sources backed up the numerical simulation results. As a result of the creation of such burners, biogas is used more efficiently and waste is reduced. This technology is relatively inexpensive, which will benefit low-income people in both urban and rural settings.

Keywords: CFD, Biogas Burner, Genetic Algorithm, Combustion Modeling

1. INTRODUCTION

In order for biogas burners to function properly, some design features must be addressed. So that more combustion can be created with less fuel, the ideal design should have an optimal hole diameter on the burner top, an optimal number of holes, and an optimal mass flow rate. The final experimental parameter is the maximum flame temperature obtained following biogas combustion. Methane accounts for 60–70% of biogas. The maximum flame temperature for methane (60-70 percent) is 12000C, according to statistics certified by many national and international bodies.

2. COMBUSTION

Biogas combustion in a burner produces carbon dioxide and water by reacting with oxygen in the air. [2].

$$CH_4 + 2O_2 \rightarrow CO_2 + H_2O$$

One volume of methane takes two volumes of oxygen to make one volume of carbon dioxide and two volumes of steam. Because biogas contains 60% methane and air only contains 21% oxygen:

$\frac{1}{0.6} = 1.667$ volumes of biogas require $\frac{2}{0.21} = 9.52$ volumes of air. i.e. one volume of biogas requires $\frac{9.52}{1.67} = 5.71$ volumes of

air. i.e. $\frac{1}{1+5.71} = 0.1489 \approx 0.15 = 15\%$ biogas in air. This is called as stoichiometric air requirement.

Biogas will only burn in a small range of biogas-to-air ratios, from 9 to 17 percent biogas. If the flame is "too rich," or contains too much fuel, it will burn inefficiently and produce toxic carbon monoxide and soot (carbon particles).

The burner is designed to provide 1.55kW of heat. When developing a burner, a design factor is considered, and the required heat energy for design is 2.7kW, which is used in simulation to compute mass flow rate at input.

3. BASIC MODEL FOR ANALYSIS

A 3D depiction of the combustion area is required for the combustion simulation. This is where biogas is combined with air and burned above the burner top. The model is shown in Figure 1.

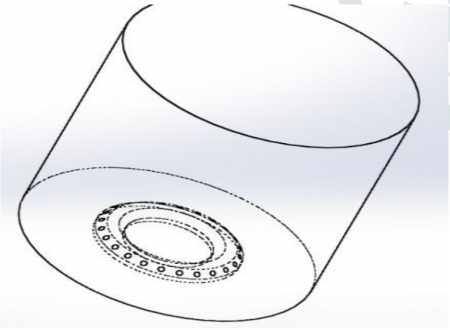

Fig. 1 Basic 3D Model

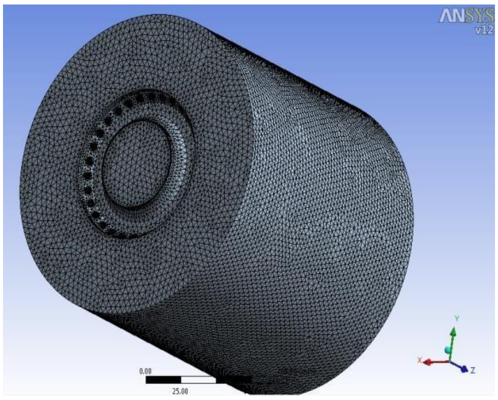

Fig. 2 Mesh Model

The volume region where combustion takes place is depicted in the diagram above. This 3D model was produced in Solidworks and then imported for examination into Ansys Fluent Design Module.

4. EXPERIMENTAL ANALYSIS AND CFD SIMULATION

The Ansys Fluent software suite is used to simulate combustion. Designing, meshing, pre-processing, and post-processing are the four key steps in combustion modeling. Create a 3D model in Solidworks and import it into Fluent's Design Module to finish the design. Mesh will provide a grid of cells or elements from which the desired fluid flow equations can be solved. The most important step in the CFD process is model meshing. The meshing quality is determined by the meshing technique.

The process of assigning CFD models and equations to the design is known as preprocessing, and the process of getting results is known as post processing.

4.1 Governing Equations

In parallel with physical tests in the lab, numerical simulations can be used to aid in the interpretation of physical results and even to determine a key phenomenological component of the experiments that is not apparent from the laboratory data. A commercial finite volume CFD code was used to make this numerical prediction.

A computer analysis begins with the derivation of the governing equations for the phenomenon under investigation. As a result, this section contains the whole set of accurate governing equations for gaseous reacting fluxes.

$$\frac{\partial \rho}{\partial t}+\frac{\partial(\rho u_i u_j)}{\partial x_i} = B_i-\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\mu\left[\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}-\delta_{ij}\frac{2}{3}\left(\frac{\partial u_k}{\partial x_k}\right)\right] + S_i^u \qquad (1)$$

The above-mentioned Navier–Stokes equations are what we're talking about. The local pressure, the fluid's dynamic viscosity, the momentum sources per unit volume, and the fluid's body forces are all included in this equation. The rate of change of momentum per unit volume over time is represented by the first term on the left side of this equation, whereas momentum transport owing to convective motion is represented by the second term. The components on the right side of the equation are fluid motion-induced viscous shear forces. Enthalpy[3] is used to express the energy equation, which is the fifth equation:

$$\frac{\partial(ph)}{\partial t}+\frac{\partial(\rho u_i h)}{\partial x_i} = \left(\frac{\partial}{\partial x_j}\right)\left(\Gamma_{\mathrm{h}}\frac{\partial \mathrm{h}}{\partial x_j}\right)+\frac{\partial p}{\partial t}+\frac{\partial u_i p}{\partial x_j}+\Psi + S^h \qquad (2)$$

And where is the enthalpy source generated on a volumetric source basis, is the turbulent viscosity to Prandtl number ratio, is the dissipation function, and is the enthalpy source generated on a volumetric source basis.

4.2 Combustion Modeling

The efficient simulation of both the mixing and reactions of key chemical species at the same time is required for accurate simulation of turbulent combustion processes. For each of the chemical species of interest, a partial differential conservation equation of the form[3] can be developed as a starting point:

$$\frac{\partial}{\partial t}(\rho Y_i) + \frac{\partial}{\partial x_i}(\rho u_i Y_i) + \frac{\partial}{\partial x_i}\left(\frac{\mu_e \partial Y_i}{\sigma_m \partial x_i}\right) + R_i S_i \qquad (3)$$

The transport equations used for simulation in summery are as follows:

Mass (continuity equation)

$$\frac{\partial \rho}{\partial t} + \nabla.\rho U = 0 \qquad (4)$$

Momentum

$$\frac{\partial \rho U}{\partial t} + (\nabla.\rho UU) = -\nabla p + \nabla.\tau + \rho g \quad (5)$$

Enthalpy

$$\frac{\partial \rho h}{\partial t} + \nabla.\rho = \nabla.\lambda_e \nabla T - \nabla.q_{rad} + \nabla.\Sigma_l \rho h_l(T) D_e \nabla m_1 \quad (6)$$

Temperature

$$\rho C_p \frac{DT}{Dt} = \nabla.\lambda_e \nabla T - \nabla.\Sigma_l \rho h_l(T) D_e \nabla m_1 - \rho \Sigma_l \frac{Dm_1}{Dt} h_l(T) \qquad (7)$$

Species Mass Function

$$\frac{\partial \rho m_1}{\partial t} + \nabla.\rho U m_1 = \nabla.D_e \rho \nabla m_1 - R_l \quad (8)$$

4.3 Combustion Simulation

For combustion modeling, Ansys Fluent Partially Pre Mixed Combustion Model is used. Flames that have been partially premixed with nonuniform fuel-oxidizer mixes are known as partially premixed combustion systems[19] (equivalence ratios). Such flames include premixed jets discharging into a quiet environment, lean premixed combustors with diffusion pilot flames and/or cooling air jets, and poorly premixed inlets. To account for radiation in combustion, the P-1 Radiation model is utilized. The mass flow rate is used as the boundary condition for fuel inlets, and the outlet is set to the top of the 3D model. Air is introduced with atmospheric pressure and temperatures in wall boundary conditions. A PDF table for methane with a purity of 60% is generated in the simulation's pre-processing portion.

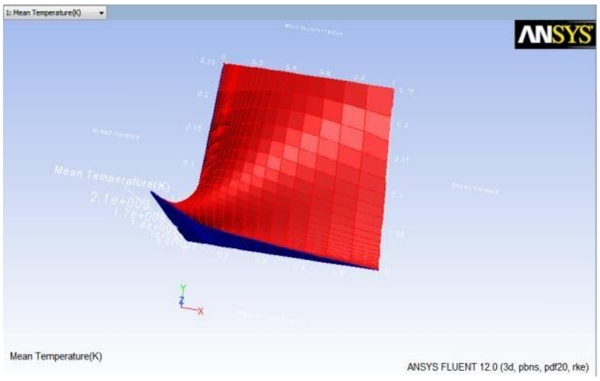

Fig. 3 PDF Table

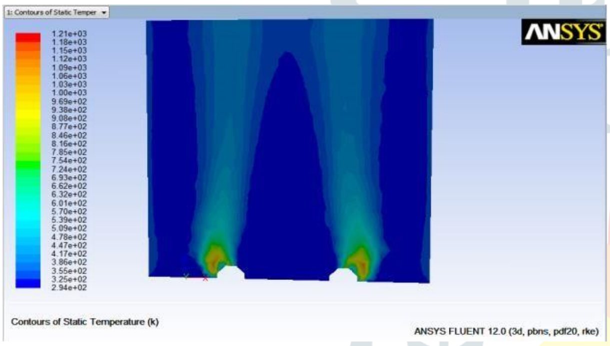

Fig 4 Contours of Static Temperature

The link between Mean Temperature and Mixture Fraction is depicted in the PDF (Probability Distribution Function) Table. In the first simulation, the simulation outlines of static flame temperatures were constructed. The mass flow rate required for inlet boundary conditions is calculated using a Matlab function and a relationship between methane's high heating value.

The boundary conditions for mass 3D models are changed, affecting the sizes and quantity of burner holes. The data shown in the table below is compiled from the results of numerous simulations:

Table 1 Simulation Results after varying parameters:

Sr.	**MFR (kg/s)**	**Hole Dia (mm)**	**No. of Holes**	**Flame Temp (℃)**
1	8.00E-06	5	18	1205
2	8.00E-06	5	18	1277
3	8.00E-06	4	24	1297
4	8.00E-06	3	30	953
Sr.	**MFR (kg/s)**	**Hole Dia (mm)**	**No. of Holes**	**Flame Temp (℃)**
5	1.00E-05	3	30	929
6	1.50E-05	3	30	937
7	1.00E-05	5	18	1337
8	2.00E-05	3	30	957
9	7.00E-06	4	30	1175
10	8.00E-06	4	30	1217
11	9.00E-06	4	30	1269
12	1.00E-05	4	30	1298
13	8.00E-06	4	24	1211
14	9.72E-06	4	30	1146
15	8.00E-06	5	30	1212
16	9.00E-06	5	30	1268
17	10.00E-6	5	30	1298

In the preceding table, d = 3 mm results in a flame temperature of less than 1200, which is unacceptable. As a result, the optimal values for d are 5 and 4 mm.

The above result is sent to MiniTab program for equation formation using the curve fitting approach.

4.4 Curve Fitting

It is a technique which fit curves and surfaces to data using regression, interpolation, and smoothing.

In Minitab software results inserted in tabular form with x1= mass flow rate of fuel in kg/s x2= Hole diameter in mm x3 = number of holes y = flame temperature in °C

The equation formed is:

From genetic algorithm optimum values of design parameters obtained as follows:

x1=8.007 i.e. mass flow rate of fuel (10^{-6}) x2 = 4.005 i.e. hole diameter x3 = 29.998 i.e. number of holes on burner.

The aforementioned equation (5.1) is utilized as the goal function for a genetic algorithm to discover the best burner parameters using Matlab Optimtool.

4.5 Genetic Algorithm

The genetic algorithm is a method based on natural selection, the driving force behind biological evolution, for solving both confined and unconstrained optimization problems. To obtain the objective function in the Optimtool setup, the Matlab M file 'burnfun.m' was constructed.

From genetic algorithm optimum values of design parameters obtained as follows:

x1=8.007 i.e. mass flow rate of fuel (10^{-6})

x2 = 4.005 i.e. hole diameter

x3 = 29.998 i.e. number of holes on burner.

The objective function value is 1210, which is permitted for optimal combustion. The Roulette Wheel approach is utilized for GA selection. Other settings remained at their defaults. The lower and upper bounds are the minimum and maximum values of three variables.

5. Final Model

With a hole diameter of 4mm, 30 holes on the burner top, and a mass flow rate of 810-6 kg/s in the inlet boundary condition, the final simulation model is based on the following characteristics.

As a result, the simulation results are as follows:

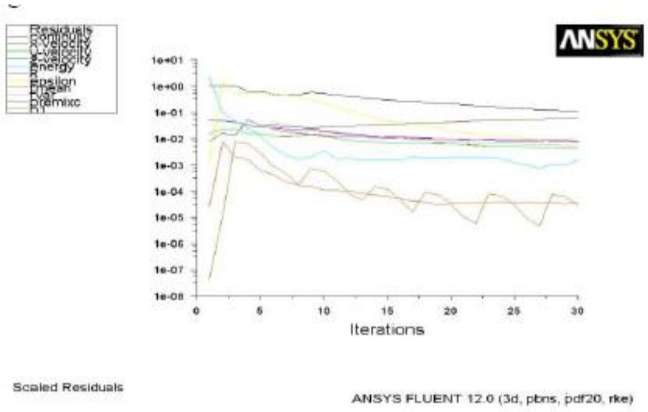

Fig 5 Scaled Residuals

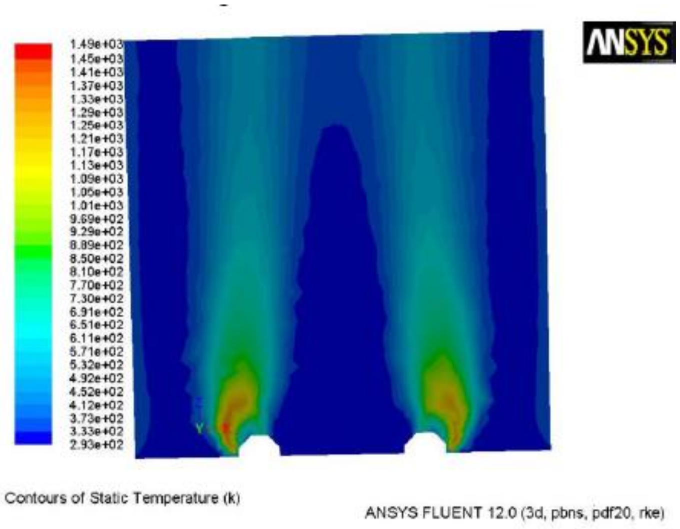

Fig. 6 Contours of Static Temperature (k)

Figure 6 depicts the contours of static temperature of created flames. The maximum flame temperature determined by modeling is 1490K, or 1217°C. The flame temperature for methane with a purity of 60% is 1200°C[21].

6. CONCLUSION

Biogas produced from kitchen trash can be used as a domestic cooking fuel, especially as the cost of fossil fuels rises. Anaerobic fermentation of kitchen waste produces biogas that contains 60–70 percent methane (CH4). This study's burner design provides an efficient model of a burner that can be used to cook with biogas as a fuel. The burner provides efficient performance with a hole diameter of 4mm, a fuel air mixture mass flow rate of 810-6 kg/se c, and a total of 30 holes on the burner port, according to simulation. When compared to data from several institutions, these burner specifications result in a flame temperature of 1217 [17][21][24]. Biogas containing 60% methane has a flame temperature of around 12000C. It denotes that the CFD simulation results, as verified by the optimization tool, are correct. The controlled mass flow rate is a crucial parameter. Because higher mass flow rate leads to excessive biogas leakage and less is insufficient to achieve combustion, the value of mass flow rate provided by the genetic algorithm is the optimum value of mass flow rate. Furthermore, the hole diameter used is optimal, as values greater than 4mm waste fuel and values less than 4mm do not offer an appropriate flame temperature. This burner's design is kept simple to save money. As a result, a low-cost efficient burner with the aforementioned design characteristics can be used to cook with biogas. Because this burner is designed for low-income people, particularly those living in remote rural areas, who are unable to afford rising fuel prices. Biogas will help to address the problem of garbage disposal because it is produced from kitchen waste.

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