Journal of Physics
Conference Series
The 11th Biennial Conference on Classical and Quantum Relativistic Dynamics of Particles and Fields
1239

ISSN: 1742-6596

OPEN ACCESS

The open access *Journal of Physics: Conference Series (JPCS)* provides a fast, versatile and cost-effective proceedings publication service.

Latest published conferences

Vol 2688 Go

Conference archive

2024 Go

View forthcoming volumes accepted for publication.

If you would like more detailed information regarding *Journal of Physics: Conference Series* please visit conferenceseries.iop.org, and if you are interested in publishing a proceedings with IOP Conference Series please visit our page for conference organizers.

Conference organizers can use our online form and we will get in touch with a quote and further details.

Most read

Latest articles

JOURNAL LINKS

Journal home
Journal Scope
Information for organizers
Information for authors
Contact us
Reprint services from Curran Associates

JOURNAL INFORMATION

2004-present
Journal of Physics: Conference Series
doi: 10.1088/issn.1742-6596
Online ISSN: 1742-6596
Print ISSN: 1742-6588

IOP

Table of contents

Volume 2688

2024

← Previous issue Next issue →

7th International Conference on Mechanical Engineering Research 2023 (ICMER 2023) 12-13 september 2023 Kuantan, Malaysia

Accepted papers received: 05 January 2024

Open all abstracts

Preface

Frontier Manufacturing

Frontier Automotive Technology

Enhancement of Efficiency and Mitigation of Pollutan Emissions in a Compression Ignition Engine by the Utilization of Rice Bran Oil as Green Fuel

M. Norhafana, C.K. Ihsan, M.M. Noor, A.A. Hairuddin, K. Kadirgama, D. Ramasamy and A.M. Hussein

View article   PDF

JOURNAL LINKS

Journal home

Journal Scope

Information for organizers

Information for authors

Contact us

Reprint services from Curran Associates

IOP

Journal of Physics: Conference Series

The Simulation of Biogas Combustion in Top Open Burner

To cite this article: A. Selvam *et al* 2024 *J. Phys.: Conf. Ser.* **2688** 012023

THE SIMULATION OF BIOGAS COMBUSTION IN TOP OPEN BURNER

A.Selvam[1], M.M.Noor[1*], M.Norhafana[1], C.K. Ihsan[2], A.Khalid[3],
R.A.Mahmood[4,5], S.Harikrishnan[6], S.Nayak[7]

[1]Faculty of Mechanical and Automotive Engineering Technology, Universiti Malaysia Pahang Al-Sultan Abdullah (UMPSA), 26600 Pekan, Pahang, Malaysia.
[2]Jabatan Kejuruteraan Mekanikal, Politeknik Muadzam Shah, 26700 Pahang, Malaysia
[3]Faculty of Engineering, Koya University, University Park, Danielle,
Mitterrand Boulevard, Koya KOY45, Kurdistan, Iraq.
[4]School of Mechanical and Electrical Engineering, University of Southern Queensland, Queensland, Australia
[5]Collage of Mechanical Engineering, University of Zakho, Kurdistan, Iraq
[6]Department of Mechanical Engineering, Kings Engineering College, Chennai, India
[7]School of Mechanical Engineering, Kalinga Institute of Industrial Technology (KIIT University), Bhubaneswar, Odisha, India

*Corresponding author: muhamad@umpsa.edu.my

ABSTRACT

The top open furnace is commonly used for the heating processes. The efficiency of the top open furnace is low due to the amount of heat wasted through the top open. This study was using ANSYS Fluent, a two-dimensional computational fluid dynamic (CFD) model that was used to build the top open furnace. Exhaust gas recirculation (EGR) was installed in the boiler in order to collect the exhaust gas and reuse it to dilute the oxygen supply. To check the combustion of low calorific gas (LCV) gas, which is biogas composed of 60% methane and 40% carbon dioxide by mass fraction, the computational study started with a standard combustion with EGR. Medium-sized mesh is used for the smoothing grid. This mesh uses inflation to enable the size of the cells and the stack element. The findings of the numerical sensitivity test show that the boundary conditions along the combustion chamber wall can affect the flame temperatures. The MILD regime was reached using biogas fuels when the right parameters were used.

Keywords: **c**omputational fluid dynamic, ANSYS, moderate or intense low oxygen dilution, hydrogen, biogas

INTRODUCTION

Today, fossil fuels are widely used to meet energy needs. By 2042, the world's energy demand is expected to be over 18 billion tons of oil equivalent, with fossil fuel combustion accounting for 80% of it. To meet increasing energy demands, combustion is expected to be the most important source of energy [1-3]. These fuels have two significant flaws. The first is that fossil fuels are finite by nature and will likely run out soon. The second is that carbon-rich fuels release carbon dioxide during combustion, which has negative effects on the environment. The utilisation of clean and renewable energy sources, such as green energy, hydrogen energy, biofuel, or biogas, is therefore a research priority for scientists. Fuels made from biomass also play a significant role as energy carriers. Especially in rural regions, biogas or biohydrogen, a type of clean and renewable energy, can effectively replace conventional energy sources (fossil fuels, oil, etc.), which also have environmental drawbacks and deplete more quickly [4-7].

A national and industrial scale of biogas implementation has been accomplished, making it a promising renewable energy source [8]. In order to meet the Sustainable Development Goals (SDGs), this work offers a preliminary evaluation of the function and contribution of biogas as a sustainable source of energy. It is stated that 12 out of the 17 SDGs have been demonstrated to directly affect and be involved with biogas. The capacity of biogas to boost renewable energy, lessen climate change, enhance waste management, and create jobs are its main contributions. For meeting a portion of the energy requirement, biogas offers a very alluring solution. The proper operation of biogas systems can benefit consumers and communities in numerous ways, protecting resources and the environment [1].

Biogas produced from garbage, waste, and energy products will be significant in this area in the future. A flexible renewable energy source, biogas can also be used to fuel automobiles. It can be utilised to generate electricity and heat in place of fossil fuels. Biogas with a high methane content (biomethane) can take the place of natural gas as a raw material for the synthesis of chemicals and other compounds. Compared to other methods of producing bioenergy, biogas has a number of advantages. The method, which employs locally accessible resources to significantly lower greenhouse gas emissions compared to fossil fuels, is ranked as one of the most effective energies and environmentally benign technologies for producing bioenergy [9-11].

In 2007, European biogas energy production increased by more than 20% annually to 6 million tonnes of oil equivalents (Mtoe). Due to the rapid expansion of agricultural biogas plants on farms, Germany has surpassed all other countries in the world in terms of its production of biogas. On German farms, there were about 4,000 agricultural biogas production units operating by the end of 2008. Energy crops make up million tonnes of biomass that might be anaerobically digested annually within the agricultural sector of the European Union (EU) [12]. The most crucial co-substrates in the EU are energy crops, which have the most potential. The useable biogas potential of organic wastes and energy crops in Germany is depicted in Figure 1 [13]. If energy crops are grown on 2 million hectares (11% of agricultural area), they might produce more than 50% of the biogas that could be produced. More than 80% of the potential feedstocks originate in agriculture, including harvesting residues and animal dung [14, 15].

In this study, numerical modelling for biogas combustion in a furnace model was carried out using computational fluid dynamics (CFD). A two-dimensional CFD model and ANSYS Fluent software were used to construct the open-top furnace. There is a spike in interest in increasing energy efficiency as a result of the need to address environmental pollution (emissions) and energy sustainability (fuel depletion). Excellent thermal efficiency combustion technologies and biogas (renewable) fuels are long-term options.

METHODOLOGY

CFD is a method of numerically solving a fluid flow-related physical event using computational power after modelling it mathematically. The most popular technology for developing remedies for liquid-related or non-solid liquids is now computational fluid dynamics (CFD). In CFD analysis software, studies of water flow are conducted using physical characteristics including velocity, pressure, temperature, density, and viscosity [16, 17]. One method for designing and running the simulation experiment virtually without having to physically construct the model is CFD. Building a model and then repeating the procedure until the desired outcome is achieved is quite expensive. This technique can be carried out utilising commercial software and CFD modelling, which is significantly less expensive than making physical 2 models. Numerous engineering challenges, including those involving gas turbines, industrial furnaces, boilers, internal combustion engines, flameless combustor technology, and other engineering applications, have successfully been simulated using CFD [18, 19].

To minimise errors, boundary conditions must be precisely stated. The choice of boundary conditions has a significant impact on the outcome of CFD simulations. An air and fuel supply pipe were used, and a velocity inlet boundary condition was used. The exhaust outlet on top of the burner was defined by an outlet vent boundary condition. There was a no-slip wall barrier. The boundary condition for velocity at the combustion chamber wall was implemented using a typical wall function. The wall's temperature was set to 300 K, and the exhaust outlet boundary condition employed an exhaust fan with zero-gauge pressure. To verify that the furnace wall boundary conditions were equivalent to the experimental ones, they were placed at a constant temperature (300 K) [20-22].

Estimating the primary combustion qualities of biogas constituents based on their chemical composition is useful for understanding a variety of phenomena that occur during combustion processes and conducting comparative exchangeability analyses. This is accomplished through the use of numerical simulation and computation tools. Below is a balanced equation (1) for methane combustion:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O \tag{1}$$

Biogas is a concoction of several gases. The volume parts xvi that are numerically equal to the molar parts xi are used to express the composition of biogas. Calculating the mixture M's molecular weight as below (Eq. 2).

$$M = \frac{m}{n} = \frac{\sum n_i \times M_i}{n} = \sum n_i \times \ M_i \ (\frac{kg}{mol}) \tag{2}$$

where m is the mixture's weight in kilogrammes; n is the quantity of each component; xi is the component's molar fraction; and Mi is the component's molar weight.

Calculation for the mixture's r universal gas constant is as below (Eq. 3).

$$r = \frac{R_m}{M} = \frac{8{,}314}{M} \tag{3}$$

where: Rm– molar gas constant; M – molar weight of the mixture. The mass part of individual gas components σi is calculated using equation (4) from xi value below.

$$\sigma_i = \frac{m_i}{m} = \frac{n_i \times M_i}{n \times M} = x_i \frac{M_i}{M} \tag{4}$$

where: m_i – weight of the component (kg); m – weight of the mixture (kg)

Heating Power of Biogas

The biogas heating power, Q_n, based on 1 kg of the mixture is calculated:

$$Q_n = \sum \sigma_i \times Q_{ni} \tag{5}$$

The heating power of biogas Q_n, based on 1 m^3 of mixture at basic conditions is calculated:

$$Q_n = Q_n \left(\frac{J}{KG}\right) \times \rho_{BG} \qquad (kg/m^3)(J/m^3) \tag{6}$$

where: σ_i – mass part of particular component; Q_{ni} – heating power of the component.

Density of Biogas

The density of biogas ρ_{BG} is calculated by the equation (7) of state for an ideal gas as below.

$$\rho_{BG} = \frac{1}{v} = \frac{p}{r \times T} \tag{7}$$

where: v – specific volume of the mixture, T – thermodynamic temperature.
In terms of relative density, the density of biogas is determined by dividing the gas density (BG) by the density of the surrounding air (a) under the following basic conditions (Eq. 8) below.

$$d = \frac{\rho_{BG}}{\rho_a} \tag{8}$$

Simulation for Geometry Design

The Design Modeller programme in ANSYS Workbench was used to draw the furnace. The combustion chamber seen in Figure 1 was initially created using a CFD simulation of an enclosed combustion chamber similar to that in [23, 24].

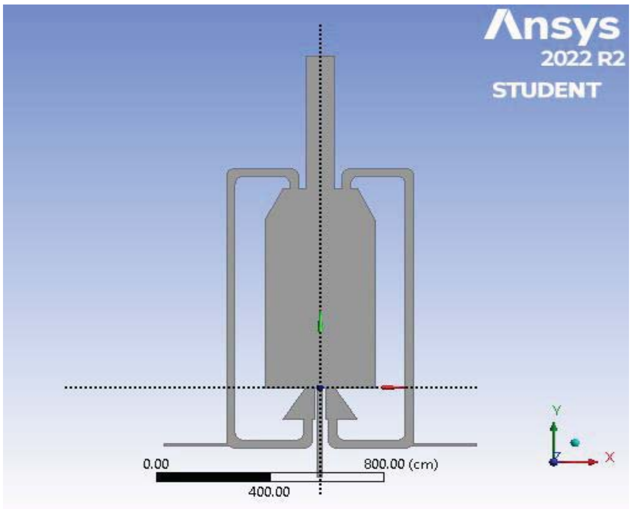

Figure 1: Basic enclosed combustion furnace chamber with top open.

Preliminary Model

To check the combustion of low calorific gas (LCV) gas, which is biogas composed of 60% methane and 40% carbon dioxide by mass fraction, the computational study started with a standard combustion with EGR. Model meshing is the most crucial step in the CFD process. The mesh is crucial, because it's known that the snare size affects how delicately the simulation results come out. The result of meshing is a grid of cells or primitives on which all of the fluid inflow equations need to be solved. The "cost of the simulations" is the sum of the processing time and data stores, and the size of the grid will have a considerable impact on both. The speed of the confluence and the delicateness of the outcome will both be greatly impacted by the grid. While narrow grids will provide a low speed of confluence with high delicacy, coarse grids (many cells) will produce a high speed of confluence but most likely low delicacy. Large numbers of cells, often several hundred thousand grid cells, are required to solve industrial CFD problems. Figure 2 depicts the simulation's meshing in use [23].

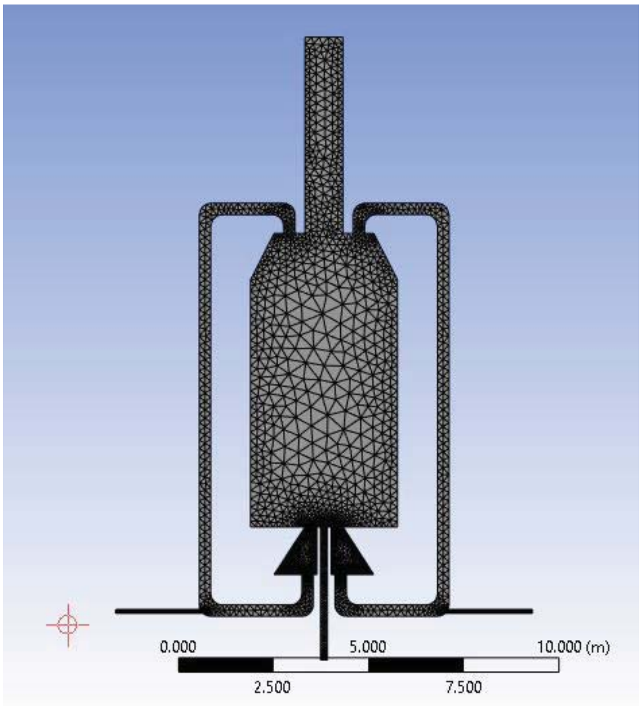

Figure 2: Furnace model meshing condition.

Table 1: Meshing details.

Sizing	Mesh Grid
Smoothing	Medium
Skewness Max	0.99132
Skewness Min	2.1142e-005
Nodes	4142
Elements	7031

Inflation

In order to allow the stack element and the cells to size in a distinctive manner that is frequently only allowed at their boundaries, inflation must be utilised in this mesh. Close to no-slip barriers, the normal gradient can be trapped to create an expanding layer. Only by using thin elements and few, large elements can this be accomplished. 5 layers, a 20% growth rate, and a maximum thickness of 0.002 m.

Table 2: Inflation setting parameters.

Item	Setting
Use Automatic inflation	Program controlled
Inflation Option	Total Thickness
Inflation Algorithm	Pre
View Advanced Option	Yes
Collision Avoidance	Layer Compression
Growth Rate Type	Geometric
Use Post Smoothing	Yes
Number of Layers	5
Growth Rate	1.2
Maximum Thickness	0.002m
Gap Factory	0.5
Maximum Height Over Base	1
Maximum Angle	140.0
Fillet Ratio	1
Smoothing Iterations	5

RESULTS AND DISCUSSIONS

The MILD combustion technique can reduce pollutants while improving thermal efficiency. Although MILD combustion has had a lot of success, it still requires further in-depth investigation due to the necessity for open-ended furnaces. Using an open-ended furnace with an enclosure wall, the exhaust gas was collected and used in this study's Exhaust Gas Recirculation (EGR). To dilute the oxygen before it reacts with the fuel and raises the temperature of the reactant, the EGR pumps some of the exhaust gas back into the combustion chamber. This system is an open-ended furnace because some of the exhaust gas can flow out and be used as external EGR. Numerical modelling for MILD combustion using CFD was done in a furnace.

The MILD furnace was drawn using the design modeller tool in ANSYS Workbench. A CFD simulation of a simple enclosed combustion chamber, like the one shown in Figure 1 above, served as the initial step in the construction of the combustion chamber. To test the burning of LCV gas (biogas), which is composed of 60% methane and 40% carbon dioxide, 65% methane and 35% carbon dioxide, and 70% methane and 30% carbon dioxide by mass fraction, the computational work began with regular combustion with EGR. Through a fuel delivery pipe with a 17 cm wide, the fuel reaches the combustion chamber at a speed of 0.003 m/s. Through a gas supply pipe downstream of the chamber, air was infused at 0.09 m/s. EGR functions by returning some exhaust gas to the combustion chamber.

The basic goal of EGR is to directly heat the mixture by heating the hot flue gas, which will dilute the oxygen in the combustion chamber. Numerical modelling was used to analyze the performance of a recently constructed combustion chamber. The CFD setups and setup are the same for the other furnace designs. As illustrated in Table 3 [25], the furnace configuration in use includes clearly defined inlets for the delivery of fuel as well as for boundary conditions.

Table 3: Typical data of furnace.

Item	Data
Fuel	60%CH_4+40%CO_2 by mass fraction
Oxidiser	Atmospheric air. Heated to 300K.
Fuel Inlet	17cm
Air Inlet	10cm
Chamber size	Diameter-386cm, Height- 650cm
EGR	2 EGR with 30cm each inlet
Mesh Method	Structural Mesh
Elements/nodes	0.05 element size with linear method

Chamber Temperature Profile

The flame temperatures are one of the principal discoveries and the primary sign that the MILD combustion regime was attained. The results of the temperature distribution simulation are shown in Figures 3, 4, and 5, respectively, using 60% CH4, 40% CO2, 65% CH4, and 70% CH4, 30% CO2. The narrow temperature range demonstrates that MILD combustion was accomplished for the synthetic air simulation with oxygen mass fractions ranging from 3% to 21%.

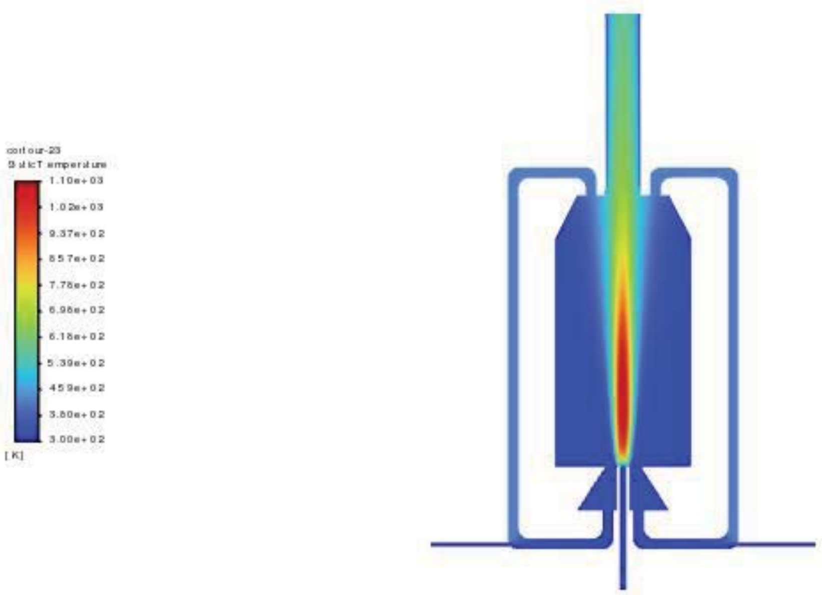

Figure 3: Temperature contour for CH_4 60% and CO_2 40%.

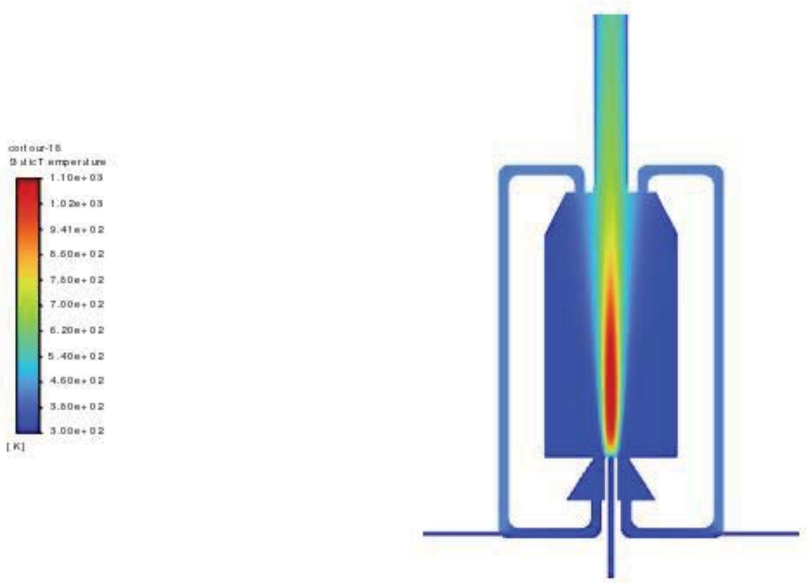

Figure 4: Temperature contour for CH_4 65% and CO_2 35%.

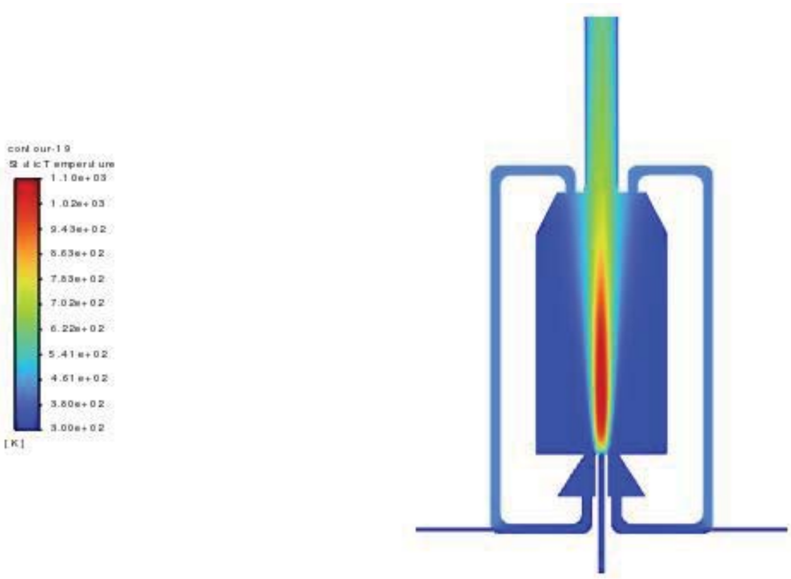

Figure 5: Temperature contour for CH_4 70 % and CO_2 30%.

The calculation was convergent, and the outcome satisfied the requirements for MILD and non-premixed combustion. For biogas fuel, 1,173 to 1,223 K is the critical temperature range to reach the stable MILD combustion regime [20, 26-28]. Figure 3's temperature contour of 60% methane and 40% carbon dioxide reaches a maximum temperature of 1096.293K, which is mild combustion because it is within the biogas fuel's threshold range. The temperature contour shown in Figures 4 and 5 for methane 65% and carbon dioxide 35% and methane 70% and carbon dioxide 30% respectively attained their maximum temperatures of 1100.678K and 1104.196K. The simplified flame temperature and MILD condition for the relevant temperature contours are shown in the table below.

Table 4: Flame temperature and MILD condition.

Temperature Contour	Figure 3	Figure 4	Figure 5
Flame temperature	1096.293K	1100.678K	1104.196K
Mild condition	Yes	Yes	Yes

Chamber Velocity Profile

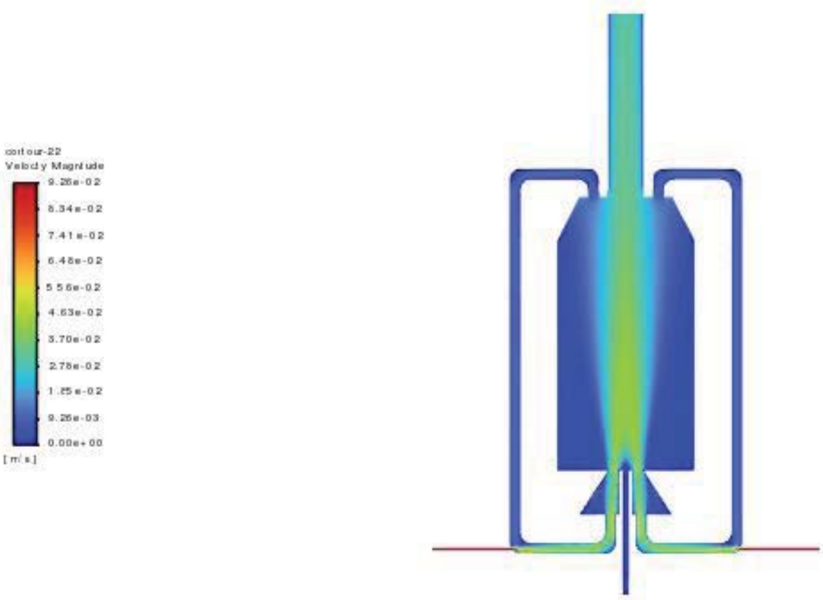

Figure 6: Velocity magnitude contour for CH_4 60 % and CO_2 40%.

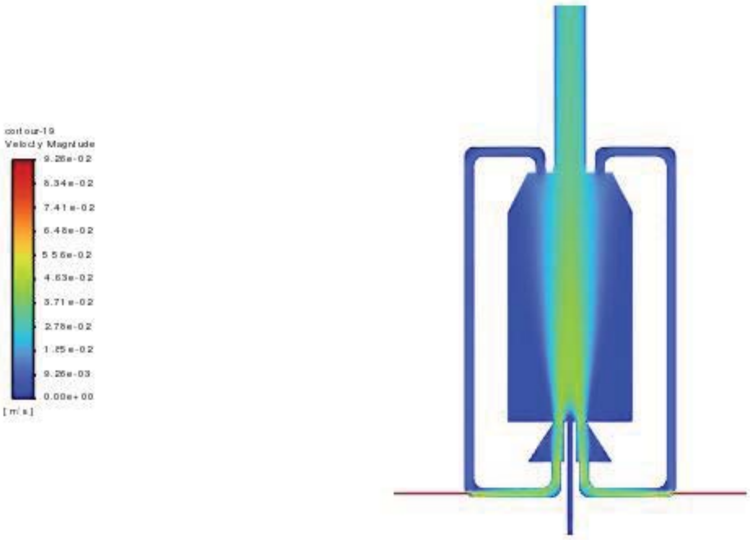

Figure 7: Velocity magnitude contour for CH_4 65 % and CO_2 35 %.

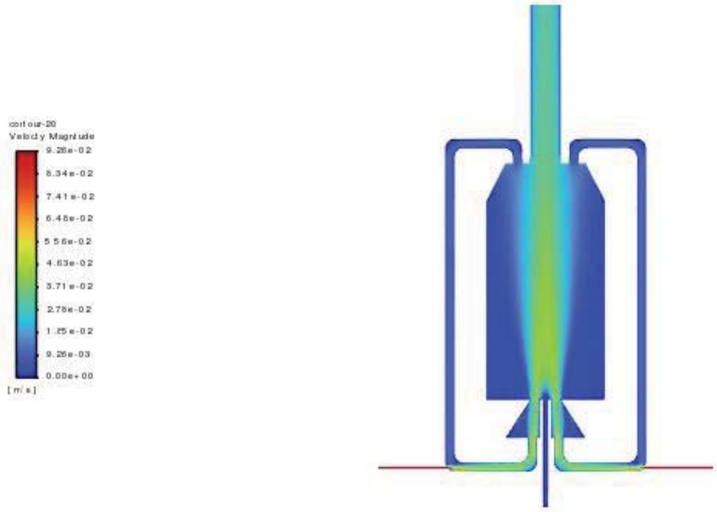

Figure 8: Velocity magnitude contour for CH_4 70 % and CO_2 30%.

For each air input, the air stream velocity was maintained at 0.09 m/s. The simulations were run for the situation of atmospheric air with a mass fraction of 10% oxygen. Figures 6, 7, and 8 demonstrate the magnitude of velocity. The air entering the engine is moving at the fastest speed, 0.09 metres per second, into the EGR pipe and the combustion chamber. The outcome demonstrates that the chamber temperature is considerably influenced by the exhaust opening while the air inlet velocity has little effect on it. For an air entrance velocity of 0.09 m/s, all maximum and average chamber temperatures as well as air mixing temperatures are practically similar [27].

In the temperature contour cases of Figures 4 and 5, when the biogas composition is 65% methane and 35% carbon dioxide, followed by 70% methane and 30% carbon dioxide, there is a very slight increase in temperature. Since different biogas compositions have been used, a slight increase in velocity can be detected. The greatest speed recorded in Figure 6 is 0.092621 metres per second. The maximum velocity for Figures 7 and 8 is 0.092630 m/s and 0.092638 m/s, respectively.

CONCLUSIONS

Biogas numerical modelling has been used to analyse the performance of the combustion in an open-ended boiler. A portion of the open-ended furnace's exhaust gas will be used as EGR, and one end of the furnace has enclosed walls that will help retain and use the heat from the flame. The CFD technique was utilised to conduct the parametric analyses needed to design and optimise the combustion chamber. The sections that follow offer an overview of the findings and ideas for more research. Numerical modelling continues to make significant contributions to combustion research, which has focused on MILD combustion for furnaces for many years. Prior studies on MILD combustion have largely focused on closed furnaces with internal or external oxygen dilutions and oxidant preheating. The underlying principles of MILD combustion are not fully known because there has been so little experimental and simulation study in this field. In this study, CFD was used to design and optimise the development of the furnace's geometry and air-fuel equivalency ratio. The numerical modelling was done using the tool ANSYS Fluent R2. The basis was a straightforward enclosed wall with an open top combustion chamber and two EGR pipes.

In-depth studies of three-dimensional CFD for MILD combustion in a variety of burners and combustion chambers have been conducted by numerous researchers. Using the for-profit programme ANSYS Fluent (R2), the furnace design and air-fuel supply ratio for this experiment were created and optimised. The findings of the numerical sensitivity test show that the boundary conditions along the combustion chamber wall have a significant impact on the flame temperatures. The MILD regime was reached using biogas fuels when the right parameters were used. According to numerical modelling for the experimental setup and the same furnace shape. When the appropriate oxidant preheating temperature and oxygen dilution are utilised, the open-end furnace can attain the MILD combustion regime. For the 10% oxygen mass fraction, the traditional industrial burner cannot produce a uniform temperature inside the chamber.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

ACKNOWLEDGMENTS

The laboratory support by Faculty of Mechanical and Automotive Engineering Technology and the financial support by Research Management Office (RMC) Universiti Malaysia Pahang Al-Sultan Abdullah (UMPSA) through research grant RDU223302 is gratefully acknowledged.

REFERENCES

1. Alabaş, B., et al., *Effect of oxygen enrichment of Biogas-Hydrogen mixtures in a premixed combustor on the combustion instability and emissions.* Fuel, 2023. **340**: p. 127498.
2. Kozarac, D., et al., *Analysis of benefits of using internal exhaust gas recirculation in biogas-fueled HCCI engines.* Energy Conversion and Management, 2014. **87**: p. 1186-1194.
3. Noor, M.M., A.P. Wandel, and T. Yusaf, *MILD combustion: The future for lean and clean combustion technology.* International Review of Mechanical Engineering, 2014. **8**(1): p. 251-257.
4. Haldar, D., et al., *Purification of biogas for methane enrichment using biomass-based adsorbents: A review.* Biomass and Bioenergy, 2023. **173**: p. 106804.
5. Ameen, M., et al., *Prospects of Bioenergy Development in Future*, in *Reference Module in Earth Systems and Environmental Sciences*. 2023, Elsevier.
6. Achinas, S., V. Achinas, and G.J.W. Euverink, *A Technological Overview of Biogas Production from Biowaste.* Engineering, 2017. **3**(3): p. 299-307.
7. Machineni, L., et al., *Biohydrogen production from lignocellulosic feedstock: Abiotic and biotic methods.* Renewable and Sustainable Energy Reviews, 2023. **182**: p. 113344.
8. Gupta, P., C. Kurien, and M. Mittal, *Biogas (a promising bioenergy source): A critical review on the potential of biogas as a sustainable energy source for gaseous fuelled spark ignition engines.* International Journal of Hydrogen Energy, 2023. **48**(21): p. 7747-7769.
9. Balat, M. and H. Balat, *Biogas as a Renewable Energy Source—A Review.* Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 2009. **31**(14): p. 1280-1293.
10. Elif Gulsen Akbay, H., *Anaerobic mono and co-digestion of agro-industrial waste and municipal sewage sludge: Biogas production potential, kinetic modelling, and digestate characteristics.* Fuel, 2024. **355**: p. 129468.
11. Vilas Bôas, T.F., et al., *Energy potential from the generation of biogas from anaerobic digestion of olive oil extraction wastes in Brazil.* Cleaner Waste Systems, 2023. **4**: p. 100083.

12. Ben-Iwo, J., V. Manovic, and P. Longhurst, *Biomass resources and biofuels potential for the production of transportation fuels in Nigeria.* Renewable and Sustainable Energy Reviews, 2016. **63**: p. 172-192.
13. Hosseini, S.E. and M.A. Wahid, *Development of biogas combustion in combined heat and power generation.* Renewable & Sustainable Energy Reviews, 2014. **40**: p. 868-875.
14. Jeguirim, M. and B. Khiari, *Chapter 11 - Solid biofuels production and combustion at domestic scales*, in *Advances in Biofuels Production, Optimization and Applications*, M. Jeguirim and A.A. Zorpas, Editors. 2024, Elsevier. p. 207-239.
15. Jenkins, B.M., *Global Agriculture: Industrial Feedstocks for Energy and Materials*, in *Encyclopedia of Agriculture and Food Systems*, N.K. Van Alfen, Editor. 2014, Academic Press: Oxford. p. 461-498.
16. Li, H., *A new model predicting the propagation speed of pressure pulse in multiphase fluid.* International Journal of Multiphase Flow, 2023. **164**: p. 104464.
17. Noor, M.M., A.P. Wandel, and T. Yusaf, *Detail guide for CFD on the simulation of biogas combustion in bluff-body mild burner.* 2nd International Conference of Mechanical Engineering Research (ICMER) 2013, 2013: p. 1-25.
18. Hosseini, S.E., G. Bagheri, and M.A. Wahid, *Numerical investigation of biogas flameless combustion.* Energy Conversion and Management, 2014. **81**: p. 41-50.
19. Munera, B.A.H., A.A.A. Arrieta, and F.J.C. Sierra, *Numerical models for the phenomenological study of flameless combustion.* Ingenieria E Investigacion, 2009. **29**(2): p. 70-76.
20. Noor, M.M., *Experimental and Numerical Study of MILD Combustion in an Open-End Furnace with Exhaust Gas Recirculation using Methane and Biogas*, in *School of Mechanical and Electrical Engineering*. 2015, PhD Thesis, University of Southern Queensland: Australia.
21. Tu, Y.J., et al., *Effects of furnace chamber shape on the MILD combustion of natural gas.* Applied Thermal Engineering, 2015. **76**: p. 64-75.
22. Noor, M.M., A.P. Wandel, and T. Yusaf, *A review of MILD combustion and open furnace design consideration.* International Journal of Automotive & Mechanical Engineering, 2012. **6**: p. 27.
23. Noor, M.M., A.P. Wandel, and T. Yusaf, *Analysis of recirculation zone and ignition position of non-premixed bluff-body for biogas mild combustion.* International Journal of Automotive and Mechanical Engineering, 2013. **8**(1): p. 1176-1186.
24. Noor, M., A.P. Wandel, and T. Yusaf, *Numerical investigation of influence of air and fuel dilution for open furnace MILD combustion burner.* Proceedings of the 2012 Qld Southern Regional Engineering Conference (SREC 2012), 2012.
25. Noor, M.M., Wandel, A. P., Yusaf, T. , *Design and development of mild combustion burner.* Journal of Mechanical Engineering and Sciences, 2013. **5** (1): p. 15.
26. Noor, M.M., A.P. Wandel, and T. Yusaf, *Simulation of Biogas Combustion in MILD Burner.* Journal of Mechanical Engineering and Sciences, 2014. **6**: p. 9.

27. Obaideen, K., et al., *Biogas role in achievement of the sustainable development goals: Evaluation, Challenges, and Guidelines.* Journal of the Taiwan Institute of Chemical Engineers, 2022. **131**: p. 104207.
28. Noor, M.M., A.P. Wandel, and T. Yusaf, *Air fuel ratio study for mixture of biogas and hydrogen on mild combustion.* International Journal of Automotive and Mechanical Engineering, 2014. **10**(1): p. 2144-2154.