Engineering Universe for scientific Research and management
ISSN (Online): 2319-3069
Vol. XIV Issue VI
June 2022

Numerical Analysis of Pulse Detonation Engine Field with Hydrogen-Air as a Fuel

Praveen Kumar Shrivastav[1], Mr Jitendra Jayant[2], Dr. Dhananjay yadav[3] and Sachin Baraskar[4]
Mechanical Department, SSSUTMS, Sehore, M.P./466001, India[1]
Mechanical Department, SSSUTMS, Sehore, M.P./466001, India[2]
Mechanical Department, SSSUTMS, Sehore, M.P./466001, India[3]
Mechanical Department, SSSUTMS, Sehore, M.P./466001, India[4]
praveensriv95@gmail.com[1], jitendra@yahoo.co.in[2]
dhananjay.yadav1@gmail.com[3],sachinbaraskar4@gmail.com[4]

Abstract

The numerical simulation is based on the detailed combustion reaction which consisting of 12- species and 27 reactions. A Grid adaptation technic has been used in order to resolve the detonation front of the structured grid. Very good comparisons are obtained for the NO and NOx emissions due to various chemical reactions in the mixing case. In this research, in viscid, k-e and k-w-SST turbulence model has been performed and a better result are obtained with in viscid turbulence model than the other two turbulence models in its class.From this research it is clear that NOx formation in pulse detonation engine can be minimized either by operating with lean or rich mixtures or by using small tubes for combustion. The results indicate that the simple chemical reaction is adequate to describe the H2-air kinetics in the pulse detonation engine combustor. Finally, these numerically simulated results were validated with the previously published literature and NASA-CEA (National Aeronautics and Space Administration -Chemical Equilibrium with Applications).

Keywords: *Numerical simulation, supersonic combustion, hydrogen fuel, PDE, NOx*

1. Introduction

Now a days entire World is moving towards the NOx emission free or pollution free environments. However, the hydrogen fuels is one of the most demanding low emission fuel and also known for green hydrogen. Using of the hydrogen fuels can reduce the carbon emission by almost 20%. Hydrogen fuels can be produced from conventional methods as fuel cells. As we know emissions from hydrocarbon fuels lead to increase the stowage of ozone and methane and finally increasing the global warming. The availability of the hydrogen is more in the universe, most of the researchers saying that it is easily available in more than 90% of all atoms. However, the hydrogen is a by-product of water and can be easily extracted and can be stored. This can be used to produce a large amount of energy with low emission rate. The fire process is an important process for many advanced systems. A the fire process can be seen as destructive or explosive. Deflagration is primarily controlled by mass and thermal diffusion and has a fire rate one meter or more per second. Usually, the deflagration process is slow pressure drop can also be modeled as a continuous burning process.

Engines based on flagration reduction processes can be built to operate in a stable environment and it is easy to improve the design with modular analysis of each sub-system. Most Conventional engines, such as turbofans, turbojets, ramjets, and rocket engines, use a strong fire-retardant process .In contrast to the reduction of flag ration, the firing process takes place very quickly and produce a powerful blazing wave, or explosive wave, spreading around two thousand meters per second to unheated reactants. The explosive wave cancan be described as a strong shock wave.

1.1 Environmental Benefits and Advantages of Hydrogen Fuel

As mentioned above, unlike other energy sources, hydrogen is not free in nature and therefore needs to be produced. The production method determines how much natural benefit hydrogen fuel can bring. By focusing on the purity of hydrogen production strategies, in raw hydrogen, there are many natural benefits to this energy source: Extracts: Hydrogen is the most abundant element in the universe, making it infinite. Material: Hydrogen can be used in production or transported when needed elsewhere. Best Storage Factors: Unlike batteries, which can hold a large amount of electricity for a long time, hydrogen can be stored for a long time until needed. It uses More Renewable Energy: Hydrogen can be produced using more energy than renewable energy sources such as wind farms, which means that this energy is not wasted and instead is 'converted' into non-renewable hydrogen.

More Energy-Efficient Than Fossil Fuels: Hydrogen contains about three times as much energy as fossil fuels, making it more energy efficient.

Immediate Availability: Because raw hydrogen can be produced anywhere in water and electricity to produce more heat and electricity, it is readily available for processing.

Fuel Cells: Hydrogen fuel cells offer many additional benefits, including improved energy efficiency, portability and faster refueling times for environmentally friendly vehicles.

1.2 The Future of Green Hydrogen

Despite the challenges associated with raw hydrogen, it looks like it will be an integral part of climate change neutrality. Incorporated into all plans issued by the European Commission's 'Net Zero' by 2050, hydrogen can store accumulated energy from renewable energy, de carbonize sectors including long-distance transport and heavy industry, and replace combustible fuels such as zero-carbon. fuel and chemical feedstock production.

Europe is leading the way in green hydrogen, not only with natural benefits such as reducing greenhouse gas emissions, but also in creating a hydrogen economy as part of the EU economic recovery after COVID, under the continental European Green Deal. to be the first in the world to achieve climate neutrality by 2050. To achieve this, we will need to completely eliminate the use of fossil fuels and reduce gas emissions by 80-95% by 2050.

1.2.1 Heat Storage

The United States is also investigating green hydrogen, as the US Department of Energy is investing millions in hydrogen fuel research, while Australia, Chile, Germany, Japan and Saudi Arabia are also investing in crude hydrogen.

It is believed that raw hydrogen power will be one of the components in a comprehensive mix of climate change mitigation solutions, including energy efficiency, renewable energy and direct electricity generation. This is especially true for areas such as aviation, shipping, long-distance truck transport and the production of concrete and metal, all with high fuel requirements or high temperatures, making it difficult to stop. Experts believe that the use of raw hydrogen will increase over the next decade, but existing infrastructure limits will soon be reached. Upgrading infrastructure to the required capacity quickly enough can be a challenge without the necessary policy changes to support market growth. Yes, if managed properly, growing a hydrogen economy can generate income and support thousands of jobs in the years to come. The global future of green hydrogen depends on investment levels from manufacturers, petrol stations and infrastructure developers.

2. Literature review

[1] Zel'dovic and Fickett and Jacobs (2021) The proposed use of controls pulsating pumping is almost always hot. By , this method was considered the most advanced airline systems. In recent years, pulse burn detonation (PDC) has also been regarded as a stand-alone gas-fired power plant and a public aircraft .Research work on this concept is carried out mainly in the USA, mainly by General Electric ,U.S. Air Force , University of Cincinnati and University of Texas at Arlington . Russia and more recently China and Germany . The actual fulfillment of the PDC cycle is illustrated by the system. Oil and air are supplied to the spray tube in and ignited in step in such a way that the explosion spreads through the tube again. leads to a sharp increase in pressure and temperature . As the explosive wave exits the tube , the flammable products are eliminated and purified , allowing for a resumption of the cycle .

Other challenges stem from the integration of PDC into a gas turbine, with regard to the transmission of power to the turbine and the interaction of the pressure waves with the turbine. An overview of theoretical foundations and application concepts can be found at the release of nitrogen oxides (abbreviated as NOx) into heat detonation has not received much attention so far. However, it can be expected that strong temperatures and pressures reached after a previous detonation explosion could lead to significant NOx formation.

[2] Rouser K. P et al. (2020) It has been argued that short stays prevent significant NOx formation, but this topic has not been properly investigated. Therefore, at present the work provides for the construction of a basic NOx probe during the expansion of the tube blast wave as well as an assessment of potential mitigation measures. A comprehensive review of the literature showed that only a handful of studies have attempted to evaluate NOx PDC formation. Yungster et al. performs a check and numerical study of hydrogen-fueled NOx emissions and hydrocarbon- fueled PDC . The temporary state of the explosive temperature and the high pressure and temperature peaks make it a challenge to test the exhaust gases. In this study, the exhaust was investigated for some time in the operation of multiple cycles and analyzed offline. As the blower tube is cleaned in each cycle, the exhaust gas is cleaned of air and the degree of purification depends on the amount of firing. The test data obtained in this way in are reproduced. For comparison, the emission limit is based on European guidelines 2010/75 / EU for natural gas engines are also shown. However, it should be emphasized that the directive refers to the normal NOx emission of 15% oxygen, whereas test data do not perform normally.

[3] Frolov, S. M., et al. andKuo et al.(2019) followed and combined with a shock wave. The shock wave compresses and heats the reactants at a temperature where the reaction occurs at a sufficiently high rate so that the deterioration of the fire hazard spreads rapidly as a shock wave. From the point of view of the force, the vibration wave gives it the ability to initiate a reaction, while the energy released by the reaction keeps the shock moving. Their assumption that no reaction occurs in a shock wave was based on the fact that the wavelength of the shock wave is arranged in a series of several free cellular pathways, while the range of the reaction area is orderly.

[4] Nicholls et al. (2018) A great effort was made by him at the University of Michigan in the United States. They performed a series of single-cycle and multi- cycle explosion tests with hydrogen / oxygen, hydrogen / air, acetylene / oxygen, and acetylene / oxygen mixtures in a stainless steel blasting pipe mounted on a pendulum- mounted pendulum. The tube is 182.9 cm long (6 feet) and the inner diameter is 2.54 cm (1 inch). Petrol and oxidizer were injected regularly from the end of the tube head and fitted with a spark plug located 25.4 inches (10 inches) downstream. A maximum frequency of 35 Hz was detected in their experiments. The most promising results were demonstrated by a mixture of hydrogen / air, in which specific fuel-based

[5] Helman et al. and colleagues (2017) re-examined the concept of PDE at the US Naval Postgraduate School. They performed a series of experiments with ethylene / air mixture, indicating the first effective PDE for ventilation. The system was operated at frequencies up to 25 Hz, the maximum allowable solenoid valve used to control gas flow. An important new concept used in their evaluation is the use of a predetonator to overcome the need for power to launch a bomb. The explosion was first started in a predetonator, a small tube containing a mixture of ethylene / oxygen, and then transferred to the first blast tube. The predetonator capacity is only 2% of that of the first blast tube. Based on the test results, they suggested that a frequency of 150 Hz and a specific frequency of 1000-1400 s could be obtained from the active PDE.

3. Dimensional Analyses

3.1 Governing Equations

The analysis is based on two-dimensional savings estimates of weight, intensity, and strength and takes into account the relative chemical kinetics. Disturbing results are not considered in the present study due to their small role in determining the overall dynamic flow and dynamic performance of PDEs. If the chemical reaction rate is expressed by a single progression variant, the controlling mathematical result can be recorded in the following vector:

3.1.1 Calculation of Propulsive

The rapid performance of PDE must be calculated accurately. There are a number of methods for measuring pressure, such as combining pressure forces on a thrust wall, using a ballistic pendulum, load cell, wet thrust stand, and a spring-damper system, as discussed in the above chapter. In numerical simulations, pressure or thrust can be obtained by combining the compressive force on the thrust wall or by the pressure balance across the system. The latter applies to PDEs including both inlet and nozzle outlets. Considering the control-volume that contains the fluid inside the entire engine, the energy efficiency of the engine

3.1.2 ZND Detonation Wave Propagation

The results for the model configuration with tube diameter of 4 cm, height of phase change material in the tube being 17 cm, and the wall temperature 10oK above the mean melting temperature of the PCM, have been studied for the purpose of this project. The effect of varying ‘C’ on the melting of PCM, between 105 and 1010, was investigated to obtain comparable results to the experimental results, as can be seen in the figure below,

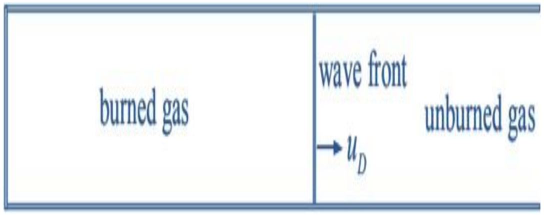

Figure3.1: propagation of ZND detonation

4. Numerical Simulation

The computational PDE model adopted in this study includes a number of commonly used simplification. Tube is initially assumed to contain the same mixture of combustible gases before the firing. The valves are open to operate instantly. The detection of detonation is carried out in a high-tech way gas driver power, as described below. Finally, the detonation process is measured by a planer detonation wave. Recent comparisons with test data show that analytics and calculation are based on it these measurements can model in a way that works properly of single-pulse PDE. However, cell formation detonation front creates local region of high pressure and temperature, which can affect NOx production.

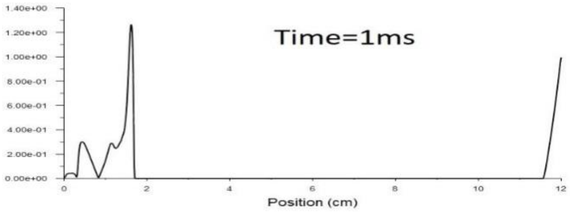

Figure 4.1: Variation of Mach Number

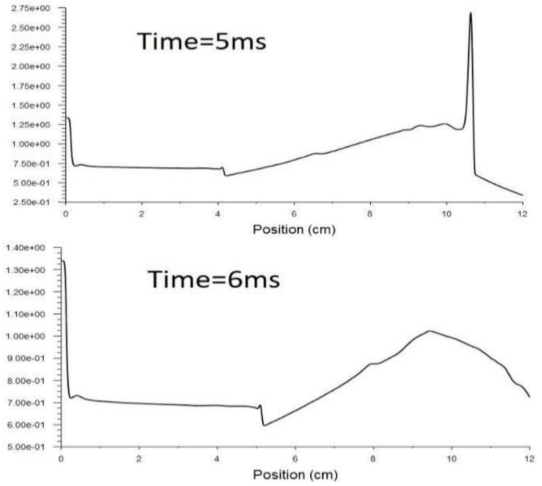

Figure 4.2: Variation of densityw.r.t Time

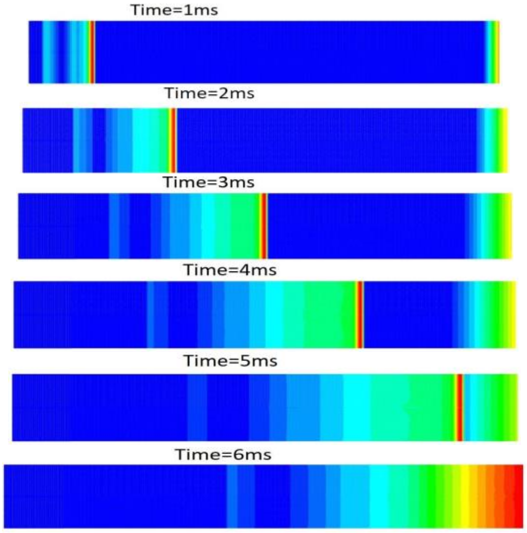

Figure 4.3: Mach Contours representation

5. Conclusions

- Although almost all PDE cycle work is focused on the stability and efficiency of the engine cycle.
- Understanding the output components of the PDE will be critical before replacing any current towing engine.
- Due to the completely different ignition of the detonation waves compared to conventional combustion equipment, it is not clear that the PDE will have NOx emissions that are much smaller or much higher than current operating systems.
- This paper represents the first look at how NOx is formed in these engines, as well as the amount of gas emissions that should be expected from a base engine under different operating conditions along with the pulse detonation cycle for the first stage or for one cycle.

Future Work

The present PDE studies indicate that the PDE tube can significantly increase the propulsive efficiency and thrust performance of single-tube PDEs. The effect of the length and diameter of the tube matters a lot and must be investigated in the future. Other shape and geometrical parameters such as the CD Nozzle, convergent and divergent nozzle must be added and investigated in the future to aid the PDE nozzle design.

References

[1] Zel'dovich and Fickett and Jacobes ―Reaction Propulsion by Intermittent Detonative Combustion,‖ Ministry of Supply, Volkenrode Translation, .

[2] Ruser K P et al, H.R., and Morrison, R.B., ―Intermittent Detonation as a Thrust-Producing Mechanism,‖ Jet Propulsion, Vol. 27, No. 5

[3] Frolov,S.M.,et al and Kuo et al J.A., ―A Preliminary Study of the Application of Steady State Detonative Combustion of a Reaction Engine,‖ Jet Propulsion, Vol. 28

[4] Nicholls et al ,Performance Characteristics of an Intermittent-Detonation Device,‖ U.S. Naval Ordnance Test Station, China Lake, CA, NAVWEPS Report 7655

[5] Helman et al and Colleagus S., ―Detonation Pulse Engine,‖ AIAA Paper

[6] Deng, J.X. and Ma et al ―An Introduction to Pulse Detonation Engines,‖ AIAA

[7] Mohanraj et al , ―Pulse Detonation Engine Theory and Concepts,‖ Developments in High-Speed-Vehicle Propulsion Systems, Edited by Murthy, S.N.B. and Curran, E.T., Vol. 165, Progress in Astronautics and Aeronautics, AIAA, Reston, VA, .

[8] Ebrahimi et al , ―Recent Developments in the Research on Pulse Detonation Engines,‖ AIAA

[9] E.C. Maciel and C. S. T. Marque ―System Performance and Thermodynamic Cycle Analysis of Airbreathing Pulse Detonation Engines,‖ Journal of Propulsion and Power, Vol. 19, No. 4

[10] Ankit Chaurasia, Kumari Ambey Verma, On the Use of Detonative Combustion in Power Engineering, Journal of Technical Physics, Vol. 10, No. 17,

[11] Jistuang Gong Theory and Experiment, Dover, Chap. 2, pp. 35–38. 11

[12] Zhiwu Wang Lisi Wei―The Energy of Detonation,‖ U.S. Naval Ordnance Lab., NAVORD Rept. 4366, White Oak, MD; available as NTIS AD113271—Old Series

[13] Bellini, R. und F. K. Lu: Exergy Analysis of a Pulse Detonation Power Device. J. Propul. Power, 26(4):875–877,

[14] Goldmeer, J., V. Tangirala und A. Dean: System-Level Performance Estimation of a Pulse Detonation Based Hybrid Engine. J. Eng. Gas Turbines Power, 130(1):011201) .

[15] Rasheed, A., A. H. Furman und A. J. Dean: Pressure Measurements and Attenuation in a Hybrid Multitube Pulse Detonation Turbine System. J. Propul. Power, 25(1):148–161,

[16] Rasheed, A., A. H. Furman und A. J. Dean: Experimental Investigation of the Performance of a Multitube Pulse Detonation Turbine System. J. Propul. Power, 27(3):586–596, 2011.

[17] Rouser, K. P., P. I. King, F. R. Schauer, R. Sondergaard und J. L. Hoke: Unsteady Performance of a Turbine Driven by a Pulse Detonation Engine. AIAA paper 2010-1116, .

[18] Caldwell, N., R. Brunnet und E. Gutmark: Experimental Analysis of a Hybrid Pulse Detonation Combustor/Gas Turbine Engine. AIAA paper 2008-121,

[19] Caldwell, N., A. Glaser und E. Gutmark: Performance Measurements of a Pulse Detonation Engine Array Integrated with a Turbine. AIAA paper 2006- 4307,.

[20] Panicker, P. K., J. M. Li, F. K. Lu und D. R. Wilson: Application of Pulsed Detonation Engine for Electric Power Generation. AIAA paper 2007-1246,.

[21] Frolov, S. M., et al., Formation of nitrogen oxides in detonation waves, Russian Journal of Physical Chemistry B 5.4 (2011): 661-663.

[22] Deng, J. X., L. X. Zheng, C. J. Yan, L.Y. Jiang, C. Xiong und N. Li: Experimental Investigation of a Pulse Detonation Combustor- Turbine Hybrid System. AIAA paper 2009-506,