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Six-Stroke Cylinder Engine : An Emerging Technology

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ABSTRACT

The requirement for the advancement of internal combustion (IC) engines and enhance methods for the combustion cycle is increasing day by day. The four-stroke combustion engine is extensively used due to better fuel economy and less exhaust smoke. However, the major drawback includes a considerable amount of extra heat energy generation that directly adds up to waste energy. In order to overcome the limitation, the idea of computing two extra strokes in the four-stroke engine to utilize the waste energy has been introduced. The six-stroke engine has significantly improved the fuel working ratio per cycle. Incorporating alternative fuels like hydrogen and HHO into six-stroke technology increases efficiency and minimizes exhaust emissions. A six-stroke engine could be the solution for making hybrid automobile technology more convenient. The review article aims to thoroughly understand the underlying principles behind the improved efficiency of a six-stroke cylinder engine. The researches on the six-stroke cylinder engine are summarized in the literature review. The design configuration of alternative fuels is discussed towards the end of the paper.

Key words : Six-stroke engine, IC engine, Hydrogen, HHO, Exhaust emission

1. INTRODUCTION

Enhancing the efficiency of the engine has turned out to be one of the most challenging problems in today's world. The modern-day developments in engine improvement are an effort to achieve ever purifier engines which are ruled via extra and more stringent emission policies and aim at reducing intake and emissions. The expansion ratio is thoroughly connected to the efficiency of a reciprocating IC engine. So surge in the expansion ratio permits an increase in fuel consumption efficiency. Researchers have invested several years to figure out how to enhance the thermal efficiency of IC engines. An overwhelming percentage of IC engines operate on four-stroke IC engines because of their high power-to-weight ratio. The generation of considerable amounts of extra thermal energy during the exhaust stroke of the cycle is the major drawback of a modern four-stroke engine. The dissipation of extra heat occurs through cylinder walls. Hence, it is considered as lost energy. The six-stroke engine is a revolutionary blend of the two-stroke and four-stroke engines. It comprises the upper part of the two-stroke engines and the bottom rather than the central portion of the four-stroke engine[1-3,38]. Even though these engines were first constructed in the 1880s, they are still planned to be improved and used in the coming years [4]. The internal combustion engine's operation cycle can be divided into four distinct processes: Intake, Compression, Expansion, and Exhaust. Along with the four processes, Six stroke cylinder engine comprises two additional strokes. The additional power and exhaust stroke use water instead of fuel to entrap the waste heat from the four-stroke engine. This results in no further requirement of the coolant system. The six-cylinder engine completely separates itself from the two-stroke and four-stroke engine due to its thermodynamic cycle and a redesigned cylinder head with two extra chambers[5,6].

2. LITERATURE REVIEW

Much research work has been conducted on six-stroke engines, and various six-stroke engine designs have been proposed. Kéromnès et al.[7] article offer the improvement and the confirmation of a unique layout of a 5 stroke IC engine. He stated that the employment of an advanced level of techniques could help to reduce brake-specific fuel consumption but will also have a significant impact on cost. The size of the engine was large and reducing the size might increase the possibility of heat loss. Conklin et al.[8] found that in the exhaust of an IC engine, the thermal energy which escapes from the engine has the potential to serve as the fuel energy. He demonstrated that the addition of two extra strokes helps to utilize the waste energy from the fourth stroke which is used in the next stroke pursued by water injection causing the generation of high pressure. This result in an improvement in the working ratio of the six-stroke engine. An increase in efficiency and decrease in overall power output in six-stroke was noted through the experiments. A remarkable decline in the specific fuel consumption is also recorded. Kothari[13] investigation also showed a decrement in the fuel intake and improvement in the brake thermal efficiency in a six-stroke internal combustion engine as compared to the four-stroke two-cylinder diesel engine. Griffin[9] investigated on single effect, sliding valve, and six-stroke engine in an experiment. Towards the end of the exhaust stroke, additional air was injected into the cylinder to achieve the additional expansion stroke. The cycle was completed at 180° crank angle. The majority of six-stroke engines use Griffin's principle as their operating principle. Schimanek[10] proposed that the volumetric efficiency has to be increased for enhancing the power output. He attempted to add two more strokes at the end of the exhaust stroke. Liedtke[11] recognized the significance of using surplus exhaust heat in the cylinder. He suggested injecting steam into the cylinder to utilize the waste heat generated on the cylinder walls and piston surface during combustion. He intended to get the second expansion stroke as well. Dyer[5] concluded that the reason behind the increment of efficiency is the utilization of lost thermal energy. He noticed an enhancement in the exhaust system as well as a simplification in the cooling system. Furthermore, he also observed that water injection into the hot exhaust gases enhanced cylinder pressure. Singh[12] designed the six-stroke engine's in which the water was injected with the help of sensors and a computer. Sensors were attached to the spark-ignition engine and the signals received by the sensors were processed in a computer. He used a high-pressure water pump to compress the water and a high-pressure direct injector to inject water into the cylinder. The sprayed water gradually changes to steam without initially depleting the heated air-fuel mixtures due to which additional expansion stroke is generated. Crower[6] stated that Nitrogen oxide emissions were reduced due to the engine's cooler functioning. With the injection of water, he demonstrated the evaporation of water and the production of the extra power stroke. The necessity of the cooling unit was predicated to lower as well. Szybist et al.[14] worked on enhancing the efficiency of the six-stroke engine. He proposed a design in which the cylinder did not release all of the exhaust gases and was partially filled with exhaust gases. The water evaporated by injecting it into the hot gases that had been burned. A minor increase in cylinder pressure is observed during the rapid vaporization of water. But, there was no change in cylinder temperature. Water droplets were evaporated instantly after being injected onto a heated surface. The effect is known as the Liedenfrost effect [15]. Kiran [16] stated that the addition of second power stroke help in improving efficiency with low pollution and this will change the engine business all over the world. Water is sprayed into the hot combustion chamber through the injector pump when the temperature hits roughly 200°C. Water is transformed into superheated steam rapidly, allowing an expansion of 1600 times as compared to its original volume and pressing the piston towards BDC for another stroke. Fu et al.[17,18,19] investigated waste heat recovery and turbocharging with steam. He also studied thermal energy recovery using steam-assisted turbocharging. He concluded that when the speed of the engine is less than 2000 rpm, steam-assisted turbocharging has a greater exhaust gas energy recovery efficiency than exhaust turbocharging, although it is lower than steam turbocharging. Gasimi et al. [20]demonstrated the various adjustments required for the conversion of a four-stroke into a six-stroke engine. Chades et al.[35] suggested to inject a liquid containing reducing agent that can react with Nox molecules during additional strokes to purify the gas produced by combustion. Karmalkar et al. [21] has also conducted studies on the use of six-stroke engines in hybrid cars and examined power-saving and fuel efficiency. Kelem et al. [22] proposed a model six-stroke engine with a free-stroke mechanism. The purpose of free strokes was to clean and reduce the temperature of the cylinder by utilizing air. The design focused on enhancing volumetric and thermal efficiency. Arabaci et al. [23] analyzed and observed an increase in efficiency with appropriate water injection quantity and timing. The cooling effect of water played a major role in the rise in the volumetric efficiency of the engine. Arabaci [4] also analyzed performance through mathematical modeling and clearly stated the superiority of a six-stroke engine over a four-stroke engine. He further investigated design parameters by developing a thermodynamic model and examining the kinetic and dynamic properties of a six-stroke engine [24]. Chen et al. [25] proposed a new concept of a six-stroke engine operating on a Rankine cycle. The introduction of the Rankine cycle in the cylinder has proved to increase the efficiency and indicated power of the cycle. Nimsiriwangso et al. [26] modeled and simulated a six-stroke engine with liquid injection technology. He modified parameters like the valve timing, combustion duration, and speed engine to achieve the optimum condition for maximum efficiency and minimum exhaust emission. They noticed a significant boost in engine output as well as a decrease in brake-specific fuel consumption. Nox (Nitrogen oxides) emissions were reduced, while HC (Hydrocarbon) emissions were increased as compared to a four-stroke engine. Manglik et al. [27] and Thatoi et al. [28] have also carried out theoretical researches on the conversion of a four-stroke engine into a six-stroke engine.

3. WORKING PRINCIPLE

The working of a six-stroke engine is explained with the help of the Bajulaz Six-Stroke Engine. The basic components include the Intake valve, Heating chamber valve, Combustion chamber valve, Exhaust valve, Cylinder, Combustion chamber, Air heating chamber, Wall of the combustion chamber, Fuel injector, Heater/Spark plug. In the first stroke (Suction stroke), the piston is initially present at the top dead centre (TDC) and moves towards the bottom dead centre (BDC) due to which pressure difference is generated which further allows the flow of the air into the cylinder. The piston starts moving towards the TDC from the BDC during the second stroke (Compression stroke). The primary objective is to compress the supply air. During this stroke, the inlet valve shuts and the heating chamber valve opens up. The movement of the piston towards the TDC pushes the air into the heating chamber. In the third stroke (Expansion stoke), the fuel injected through the fuel injector. Then spark plug generates an ignition which initiates the combustion of the mixture. This combustion exerts pressure on the top surface of the piston, which forces the piston to move downwards. During this process, all other valves are closed. In the fourth stroke (Re-compression stroke), the piston again starts moving from the BDC towards the TDC and the combustion chamber valve opens for allowing air to enter the combustion chamber. The extra thermal energy is transmitted to the air entrapped in the air chamber through the wall of the combustion chamber. The energy absorption process leads to a significant increase in temperature and pressure of the entrapped air. In the fifth stroke (Steam-powered stroke), the heating chamber valve opens. It allows the highly pressurized air to enter the cylinder and force the piston to again moves towards the BDC. In the sixth stroke (Exhaust stroke), the air inlet valve remains closed. The air is now pumped out through the exhaust [29,36].

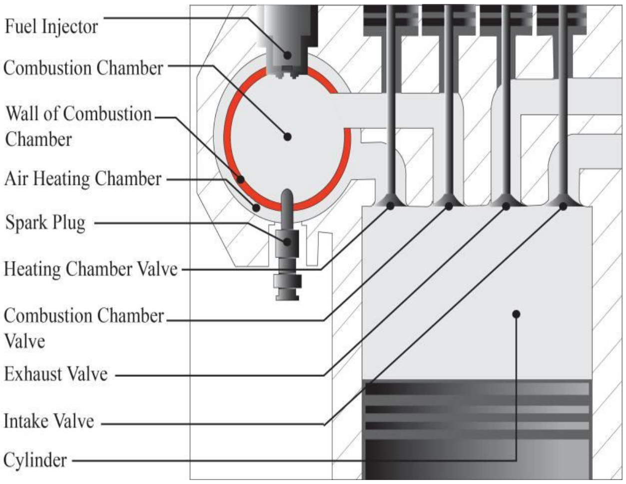

Fig. 1: Components of 6-Stroke Engine

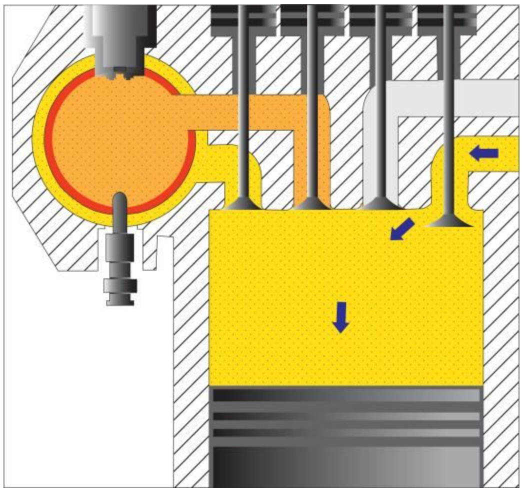

Fig. 2: Suction Stroke

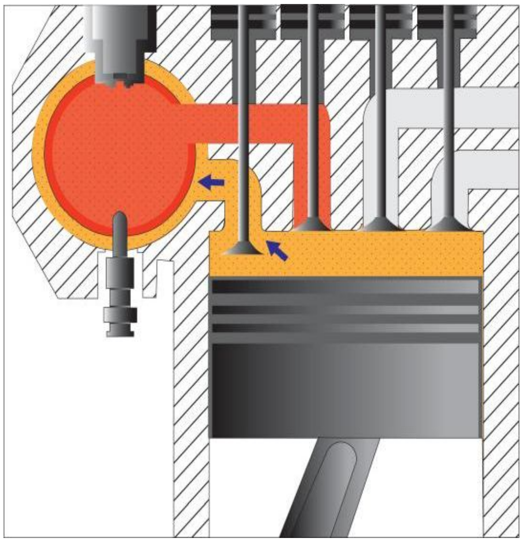

Fig. 3: Compression Stroke

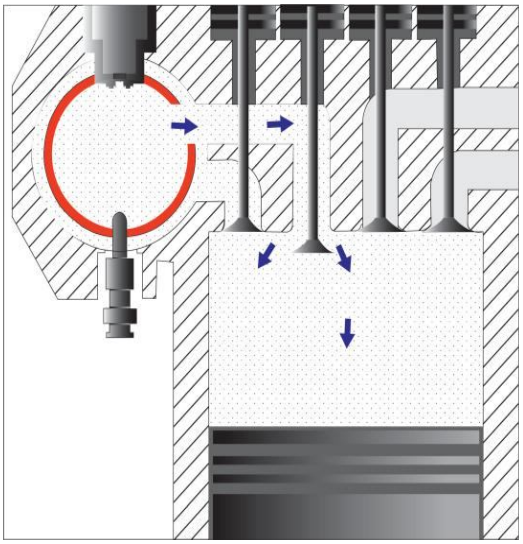

Fig. 4: Expansion Stroke

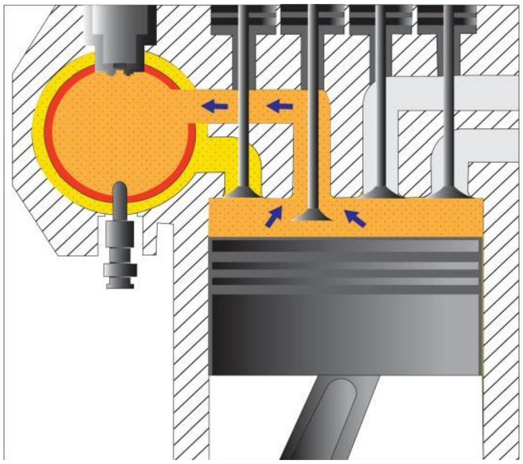

Fig. 5: Re-Compression Stroke

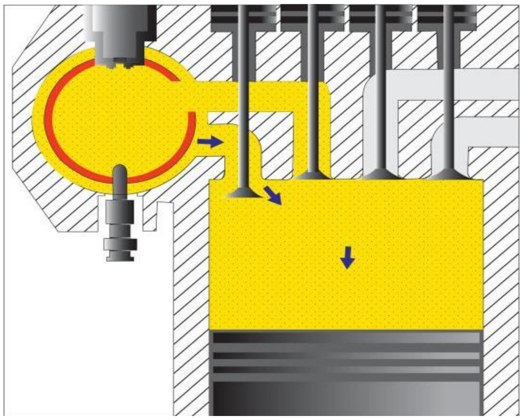

Fig. 5: Steam power Stroke

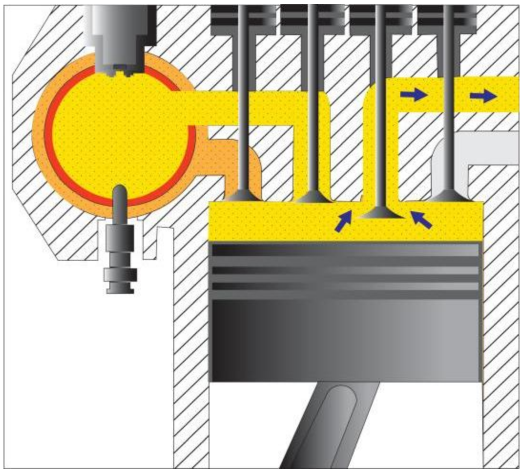

Fig. 7: Exhaust Stroke

4. ADVANTAGES OF SIX-STROKE ENGINE

After the valves are shut in a six-stroke engine, the volume change during the compression cycle is relatively higher than in a four-stroke engine. The power stroke is significantly higher in the six-stroke engine compared to the four-stroke engine. In six strokes, comparatively more energy is obtained from the expansion stroke. The efficiency and torque developed is significantly higher. A remarkable reduction in CO and NOx emissions are observed. Its capacity to operate on vegetable-based fuels and low-polluting gases under ideal conditions provides it with features that will allow it to meet the most stringent criteria. Its lightweight, typical petrol engine design, and low combustion chamber compression ratio do not rule out the usage of diesel fuel. The extra thermal energy is absorbed by the air/water for providing additional strokes. This leads to a reduction in engine temperature, and hence heavy external cooling systems and radiators are no longer mandatory [21,28,30].

5. PROPOSAL FOR ALTERNATIVE FUELS

Hydrocarbon fuels are the most common supply of energy. These fuels are utilized in a variety of purposes, including the production of electricity, transportation etc. Hazardous contaminating emissions, higher levels of greenhouse gas, and devastating disasters such as large-scale oil spills are disadvantages of utilizing hydrocarbon fuels. Moreover, inflated costs and political instability as a result of foreign sources are additional drawbacks. The six-stroke engines initial four-strokes use standard fossil fuels like gasoline and diesel. The next two strokes, on the other hand, are powered by air or water. As the cylinder temperature is still high from the last expansion stroke, the air or water absorbs the heat and expansion takes place. As a result, the piston is pushed downward for the additional expansion stroke. Utilizing a fuel with a greater calorific value than air or water with a lower flash point can increase the efficiency of the engine. As a result, the fuel consumption for the same quantity of power is reduced. Hydrogen and Brown’s gas (HHO) is proposed to be the most suitable gas to substitute air and water.

5.1 Hydrogen Fueling Configuration

Hydrogen's clean-burning properties provide a compelling reason to investigate its use as a potential alternative fuel. It is considered superior to fossil fuels in terms of conserving oxygen in the air supply as it does not require oxygen from the atmosphere to burn. Moreover, nothing comes out of the exhaust pipe when hydrogen burns completely. The primary benefit of hydrogen combustion in present era is the reduction in emission greenhouse gases. Since it requires a lot of energy to extract hydrogen from water, it is referred to be an energy carrier rather than an energy source. The kindling energy of hydrogen is quite low. The energy required to ignite hydrogen is roughly 10% than that necessary to ignite gasoline. Hydrogen has none of the issues that liquid fuels do, such as vapour lock, cold wall quenching, insufficient vaporization, improper mixing etc. The problems associated with hydrogen are pre-ignition and backfire. To convert a conventional I.C engine to a hydrogen-powered engine, the appropriate engine, carburetor, and spark plug adjustments must be accomplished. However, hydrogen storage is also a challenge.

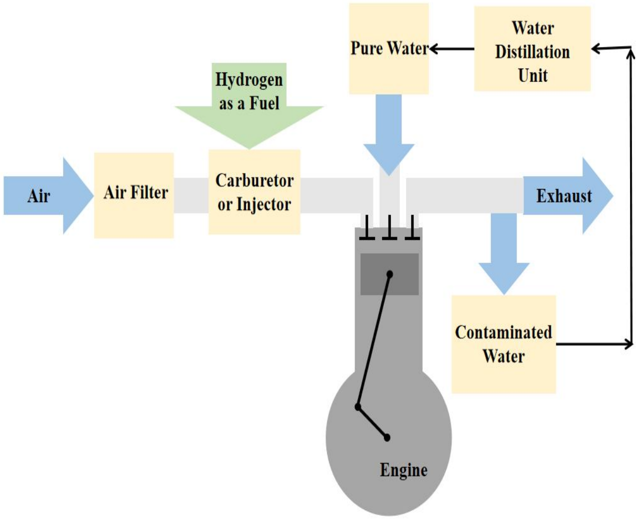

Fig. 6: Hydrogen Fueling Configuration

The graphical representation above depicts the plan for incorporating hydrogen fueling into a six-stroke engine. The air is supplied through an air filter. The injector delivers hydrogen to the cylinder on the first stroke. In the second stroke, hydrogen is compressed and burned, forcing the piston downwards for the power stroke. Water is produced during the exhaust stroke and is sent through the Distillation Unit, where it is condensed and distilled. After that, the distilled water is recirculated for use in the fifth and sixth strokes. However, due to losses and impurities, the number of cycles that the water may be reused is restricted as it might result in the deterioration of engine parts. Water vapor and NOx are the primary emissions from a hydrogen-fueled engine. Other substances including HC, CO, CO_2, SOx (Sulphur oxides), and smoke are either undetectable or negligible as compared to the quantity detected in a diesel engine. When hydrogen is mixed with air in a SI or CI engine, it has a considerable effect on the engine's efficiency and brake power [31,32,37].

5.2 Brown’s Gas Fueling Configuration

Brown Gas (HHO) is a mixture of hydrogen and oxygen (O_2) by a volumetric ratio of 2:1. The quantity of energy emitted is unaffected by the combustion mode. Its nature is implosive. The gases collapse back into the water when burned in their purest form. HHO production begins when the engine is turned on and ends when it is turned off. As it is produced instantaneously and does not require storage, and thereby minimizes the threat of explosion. Brown gas burns in the combustion engine and has the potential of releasing oxygen into the atmosphere depending upon the arrangement. As a result, using Brown's gas as a fuel can enhance the oxygen levels of our environment by adding oxygen to the air. Replacing a pressure reducer and throttle valve instead of a carburetor are some necessary changes that need to be done.

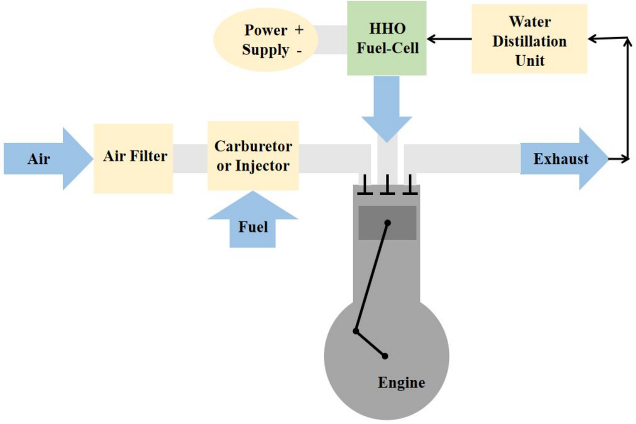

Fig. 7: HHO Fueling Configuration

The graphical representation above depicts the plan for incorporating Brown's Gas fueling into a six-stroke engine. In the carburetor, purified air is combined with fuel. The combustion chamber receives this mixture. In this case, HHO (Oxyhydrogen) can be added to the air-fuel mixture. It has been discovered that at full load, Brown's gas enriched operation consumes 6% less gasoline than a normal engine running without Brown's Gas. In this design, Brown's Gas is also supplied in the fifth stroke. This HHO is injected during the fifth stroke, and as it burns, it produces oxygen and water. This water can be distilled and re-utilized in the same way as in hydrogen-fueled engines. Oxygen is created in the HHO engine, which cuts emissions by up to 40%. Brown's Gas is unquestionably easier to implement and more effective than Hydrogen. Hence, it can be concluded that by employing HHO in gasoline engines, fuel conversion ratio is improved and fuel consumption rate and exhaust emissions lowers. Moreover, the construction of HHO fuel cell is simple, inexpensive and can be easily combined with various engines. As a result, it has a prosperous future in next-generation alternative fueling technologies [33,34,37].

4. APPLICATION IN HYBRID AUTOMOBILE

Introducing six-stroke engines in hybrid automobiles aims to improve the mileage and minimize emissions of a gas-powered vehicle while also addressing the drawbacks of an electric vehicle. The gasoline-electric hybrid automobile is fueled by both fuel and electricity. A fuel tank is located beneath the hood of a gas-powered vehicle and delivers gasoline to the engine. The engine then drives the wheels through a transmission. A hybrid's engine is compact and employs innovative technologies to minimize pollution and boost efficiency. The fuel tank serves as an energy storage unit for the gasoline engine. The hybrid automobile's electric motor is complex. Its sophisticated electronics enable it to function as both a motor and a generator. However, by serving as a generator, it slows down the automobile and restores energy to the batteries. It is notated that when a 6 stroke engine is used instead of a 4 stroke engine, the fuel consumption is reduced drastically. This leads to an increment in the mileage of automobiles and thus making it more convenient. However, The initial manufacturing cost is also high because of changes in the gear arrangement for connecting the electric motor and the gasoline engine [21].

5. CONCLUSION

The six-stroke engine is a revolutionary concept with a huge potential of improving performance in future automobiles. The improved efficiency is due to the recovery of energy from the engine's combustion gases. It offers a significant increase in efficiency and power output along with a reduction in specific fuel consumption. Six stroke engine has proved to be eco-friendly technology as well. The exhaust emissions like CO and NOx are much lower as compared to four-stroke engines. The implementation of six-stroke engine technology combined with alternative fuels configuration is very much essential for sustainable development. Even the application of six-stroke engines in hybrid automobiles has been observed to be effective. Some of the challenges in the path of practical adaptation of six-stroke engines are high initial cost and larger size. The focus on minimizing its cost, size and making the technology more reliable and convenient leads to the scope of further research in the field of novel six-stroke technology.

REFERENCES

1. A.A. Azmi, Thermodynamic analysis for a six stroke engine for heat recovery, Ph.D. Thesis, UMP (2012).
2. Y. Icingur, E. Arabaci, The idealized air-fuel cycle and the performance analyses of a six stroke spark-ignited engine, Journal Of Polytechnic-Politeknik Dergisi 16 (1) (2013) 37–44.
3. Saidur R, Muzammil W, Hassan M, Paria S. Technologies to recover exhaust heat from internal combustion engines. Renew Sustain Energy Rev 2012;16:5649–59
4. Arabaci, E. (2020). Performance analysis of a novel six-stroke otto cycle engine. Thermal Science, (00), 144-144.
5. Dyer L. Internal combustion engine; 1920, USPTO, 1339176, Greenwich. p. 1– 4.
6. Crower B. Method and apparatus for operating an ınternal combustion engine; 2007, USPTO, 2007/022977, Jamul. p. 1–13
7. Kéromnès, A., Delaporte, B., Schmitz, G., & Le Moyne, L. (2014). Development and validation of a 5 stroke engine for range extenders application. Energy Conversion and Management, 82, 259-267.
8. Conklin, J. C., & Szybist, J. P. (2010). A highly efficient six-stroke internal combustion engine cycle with water injection for in-cylinder exhaust heat recovery. Energy, 35(4), 1658-1664.
9. Griffin, S. (1889). Method of operating gas engines.
10. Schimanek E. Combustion engine. 1913; USPTO, 1068173, Budapest. p. 1–4.
11. Liedtke H. Internal combustion and steam engine. 1917; USPTO, 1217788, Philadelphia. p. 1–11.
12. Singh, S. (2001). U.S. Patent No. 6,311,651. Washington, DC: U.S. Patent and Trademark Office.
13. Kothari, T. U. (2014). Design and Analysis of Six Stroke Internal Combustion Engine.
14. Szybist, J. P., & Conklin, J. C. (2012). U.S. Patent No. 8,291,872. Washington, DC: U.S. Patent and Trademark Office.
15. Liedenfrost JG. On the fifixation of water in diverse fifire. Heat Mass Transfer 1966;9:1153–66.
16. Kiran, P. (2013). A Feasibility study on waste heat recovery in six stroke IC engine. International Journal on Mechanical Engineering and Robotics, 1(1), 113-117.
17. Fu J, Liu J, Yang Y, Ren C, Zhu G. A new approach for exhaust energy recovery of internal combustion engine: steam turbocharging. Appl Therm Eng 2013;52:150–9.
18. Fu J, Liu J, Wang Y, Deng B, Yang Y, Feng R, et al. A comparative study on various turbocharging approaches based on IC engine exhaust gas energy recovery. Appl Energy 2014;113:248–57.
19. Fu J, Liu J, Deng B, Feng R, Yang J, Zhau F, et al. An approach for exhaust gas energy recovery of internal combustion engine: steam-assisted turbocharging. Energy Convers Manage 2014;85:234–44.
20. Gasim, M. M., Chui, L. G., & Bin Anwar, K. A. (2012, May). Six Stroke Engine Arrangement. In The International Conference on Applied Mechanics and Mechanical Engineering (Vol. 15, No. 15th International Conference on Applied Mechanics and Mechanical Engineering., pp. 1-6). Military Technical College.
21. Karmalkar, C., & Raut, V. (2014). Analyzing the implementation of six stroke engine in a Hybrid Car. International Journal of Mechanical Engineering and Applications, 2(1), 1-4.
22. Kelem, H.,and Kelem, E.,. U.S. Patent No. 7,726,268. Washington, DC: U.S. Patent and Trademark Office, 2010
23. Arabaci, E., İçingür, Y., Solmaz, H., Uyumaz, A., & Yilmaz, E. (2015). Experimental investigation of the effects of direct water injection parameters on engine performance in a six-stroke engine. Energy conversion and management, 98, 89-97.
24. ARABACI, E., & KILIÇ, B. (2018). Novel Over-Expanded Six-Stroke Engine Mechanism. Bitlis Eren Üniversitesi Fen Bilimleri Dergisi, 7(2), 320-338.
25. Chen, H., Guo, Q., Yang, L., Liu, S., Xie, X., Chen, Z., & Liu, Z. (2015). A new six stroke single cylinder diesel engine referring Rankine cycle. Energy, 87, 336-342.

26. Nimsiriwangso, A., Barnes, P., Doustdar, O., Wyszynski, M. L., Mohyeldin, G. M. M., & Kowalski, M. (2019). 6-stroke engine: thermodynamic modelling and design for testing. Journal of KONES, 26.
27. Manglik, V. K. (2014). Development of high efficiency engine by combing IC engine and EC engine. Int J Mech Civil Eng, 72-5
28. Thatoi, D. N., & Gaur, S. (2021). Design and thermal analysis of six stroke engine. Materials Today: Proceedings.
29. Bajulaz, R. (1985). U.S. Patent No. 4,513,568. Washington, DC: U.S. Patent and Trademark Office.
30. B. Ramya, Study and analysis of six stroke engine, Int. Journal of Engineering Research and Applications ISSN (2014) 2248–9622.
31. Prasath, B. R., Leelakrishnan, E., Lokesh, N., Suriyan, H., Prakash, E. G., & Ahmed, K. O. M. (2012). Hydrogen operated internal combustion engines–a new generation fuel. International Journal of Emerging Technology and Advanced Engineering, 2(4), 52-57.
32. Das, L. M., Gulati, R., & Gupta, P. K. (2000). A comparative evaluation of the performance characteristics of a spark ignition engine using hydrogen and compressed natural gas as alternative fuels. International journal of hydrogen energy, 25(8), 783-793.
33. Al-Rousan, A. A. (2010). Reduction of fuel consumption in gasoline engines by introducing HHO gas into intake manifold. International journal of hydrogen energy, 35(23), 12930-12935.
34. Bhardwaj, S., Verma, A. S., & Sharma, S. K. (2014). Effect of Brown gas on the performance of a four stroke gasoline engine. International Journal of Emerging Technology and Advanced Engineering, 4(1), 300-308.
35. K. Chandes, N. Dronniou, Six-stroke internal combustion engine, method of operation of such an engine and vehicle equipped with such an engine, uS Patent App. 12/808,218 (Oct. 28 2010).
36. S. Shukla, M.S. Alimi, Analysis and review of six stroke internal combustion engine, IOSR Journal of Mechanical and Civil Engineering 12 (6) (2015) 2278–1684.
37. Mohandas, G., & Desai-Patil, V. (2015). Review of Six Stroke Engine and Proposal for Alternative Fuels. SSRG International Journal of Mechanical Engineering (SSRG-IJME), 2(10), 19-24.
38. Peeraiah, M., Reddy, M. C., & Venugopal, A. (2015). Enhancement Of Engine Performance And Reduction Of Emissions By Changing Piston Geometry. International Journal Of Emerging Trends In Engineering Research, 3(6), 499–510.