**A COMBUSTION CHARACTERISTICS STUDY FOR MIX BIOFUEL EXTRACTED FROM WASTE PALM AND WASTE COTTON SEED COOKING OIL BY CONSIDERING EFFECT OF COMPRESSION RATIO**

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 **ABSTRACT**

Due to the excessive use of petroleum-based fuels in industry and automobiles, the world is currently facing serious problems such as the global energy crisis, environmental pollution and global warming. As a result, there is growing global awareness of how to prevent the fuel crisis by developing alternative fuel sources for engine applications. Numerous research programs are currently underway to replace diesel with a suitable alternative fuel such as biodiesel. Non-edible sources such as Mahua Oil, Karanja Oil, Neem Oil, Jatropha Oil, Simarouba Oil, etc. are designed to produce biodiesel. Fatty acids such as stearic acid, palmitic acid, oleic acid, linoleic acid, and linolenic acid are commonly found in nonedible oils. Vegetable oils mixed with diesel fuel in various proportions have been experimentally tested by many researchers in different countries. In developing countries like India, these inedible vegetable oils are easy to grow, but it is not economically feasible to convert them to methyl esters through various chemical processes. The purpose of this article is to perform a combustion analysis of biodiesel obtained from waste palm oil and used cottonseed oil, where the two biodiesels are mixed in equal parts, i.e. a total of 10% biodiesel blended with 90% compressed diesel. Gears 17 and 18 at an engine speed of 1,500 rpm.

**Keywords:** Biofuel, Combustion, Waste Palm Cooking Oil, Waste Cotton Seed, Compression ratio.

1. **INTRODUCTION**

Substantial expand in the demand of petroleum gas raised the worries about the surroundings and its supply. This led to the search of choice fuels for its utilization in Internal Combustion (IC) engines. Research in the subject of sustainable choice fuels nonetheless faces challenges due to the fact of complexities such as greater value of production, feasibility of utilization in current engines etc. Global vehicular transportation is typically established on liquid fuels like fuel and diesel, exceptionally produced from crude oil. Bio-generated fuels such as alcohols and biodiesels have emerged as main gamers for IC engine applications. Biodiesel is favoured as sustainable diesel engine gasoline with universal decrease greenhouse gasoline (GHG) emission in contrast to mineral diesel. Lower fragrant content, inherent oxygen content, decrease sulfur awareness and particulate remember (PM) emission etc. are some of the benefits of biodiesel over mineral diesel. Biodiesel is derived from transesterification of triglycerides current in straight vegetable oil (SVO), waste cooking oil (WCO) and animal fat etc. which often comprised fatty acid alkyl esters. Tomesh Kumar Sahu et al [1] focused on effect of compression on combustion characteristics of biodiesel extracted from waste cooking oil under no load to full load condition for compression ratio of 18 and 20 and at 1500 RPM constant engine speed. Swarup Kumar Nayak et al [2] investigated the performance and emission characteristics of mahua biodiesel and using additives for 5, 10 and 15 % blending with diesel. Naveen Kumar et al [3] conducted experiment on agricultural engine to study spray, performance and emission characteristics of biodiesel blended with diesel and blending in proposition of 10%, 20%, 30%, 40% and 50% by volume. Ahmed I. El-Seesy et al [4] studied the effect of adding multiwalled carbon nanotubes to waste cooking oil biodiesel on the performance and emission characteristics of biodiesel and diesel blended with no load condition and at 1000 RPM speed. K.A. Abed et al [5] concentrated on effect of biodiesel on performance of diesel engine having capacity of 5.775 kW and running at 1500 RPM. In the present work emission, performance characteristics are observed. Selvakumar Raja et. al [6] studied the influence of compression ratio on emission characteristics of waste cooking oil extracted biodiesel operated engine, and in the present study 16.5, 17.5 and 18 these three compression ratios are considered. Ales Hribernik et al [7] evaluated performance and emission studies of indirect injected biodiesel operated engine. The injected fuel quantity was measured, and the injection pressure and injector needle lift time history were acquired. Parvaneh Zareh et al [8] carried out comparative analysis of performance and emission characteristics of castor, coconut and waste cooking based biodiesel operated engine and biodiesel is extracted as per ASTM norms. Atul Dhar et. al.[9] studied the Performance, emissions and combustion characteristics for biodiesel extracted from Karanja oil in transportation engine with 20 %biodiesel and rest of the diesel..Dhinesh Balasubramanian et al [10] focused on numerical and experimental analysis of biodiesel and biodiesel blended with diesel in B60, B40, and B20 and using exhaust gas recirculation (EGR) for B20 minimum NOx emission for 10 % EGR rate can be obtained for twin cylinder engine. M. S. Gad et al [11] investigated the effects of blending waste cooking oil (WCO) biodiesel with gasoline and kerosene on diesel engine performance, combustion characteristics and emissions compared to fossil diesel. Murat Kadir Yesilyurt [12] focused on effect of injection pressure on performance and emission outcome waste cooking oil extracted biodiesel blended with diesel and injection pressure varies between 170-220 bars and such six pressures is taking in account. M.A. Kalam et al [13] the experimental study carried out to evaluate emission and performance characteristics of a multi-cylinder diesel engine operating on waste cooking oil such as 5% palm oil with 95% ordinary diesel fuel (P5) and 5% coconut oil with 95% ordinary diesel fuel. G.R. Kannan et al [14] worked on production of biodiesel from waste cooking oil using response surface method and using such biodiesel engine is operated at 100 % load and at 1500 RPM. WCO-ME exhibited lower heat release rate, shorter ignition delay of 10.90CA and slightly longer combustion duration of 54.40 CA when compared to diesel at same load condition. Esmail Khalife et al [15] investigated experimentally the effect of presence of low water level in waste cooking oil biodiesel on full load by varying engine speed I which 5 % biodiesel and 2,3 and 4 % water is mixed with diesel. Senthilkumar Masimalai et al [16] studied the effect of oxygen enrichment in performance waste cooking oil operated engine for different oxygen concentrations such as 21% (WCO+21%O2), 23% (WCO+23%O2), 24% (WCO+24%O2) and 25% (WCO+25%O2) by volume. The lowest smoke (50%) was found with WCO+25%O2 at the maximum power output. Hydrocarbon and carbon monoxide emissions were considerably reduced with all concentrations of oxygen in the intake air. Yahya Ulusoy et al [17] targeted on waste cooking oil methyl ester as gasoline in diesel engine and studied thermal, combustion and emission traits of point out gasoline thinking about two speeds of 1800 and 2800 RPM with 10, 20, 30 and forty percent blending. Nik Nur Fatin Amiera Nik Aziz et al[18] acquired effects emission consequences from 10 and 30 % blended waste cooking oil biodiesel with diesel and It was once determined that the for 30 % biodiesel emits decrease emission in contrast to diesel however at the equal time generates a decrease temperature profile. X. J. Man et al [19] centered on the impact of waste cooking oil biodiesel on the particulate mass, wide variety concentration, nanostructure, and oxidative reactivity below one of a kind engine speeds and engine loads. Sang Hyuck Park et al [20] carried out factors and residences of the biodiesel have been characterized through gasoline chromatography− mass spectrometry (GC−MS), Fourier radically change infrared spectroscopy (FT-IR). Souvik Barman et al [21] developed pilot plant to produce the waste cooking biodiesel and estimated the manufacturing value of identical to set up the business viability of biodiesel. Mohammed Abdul Raqeeb et al [22] suggested the bodily and chemical residences of waste cooking oil, Esterification, Transesterification and manufacturing of Biodiesel from waste cooking oil by using a number of techniques and catalysts. Ales Hribernik et al [23] studied have an effect on of waste cooking oil blended with diesel and its impact on combustion overall performance in case of gasoline injection tactics of an oblique injected diesel engine. Jeewan VachanTirkey et al [24] performed experiments the use of biodiesel extracted from waste oil and combined with diesel oil at 10, 20, 30, zero and 50% through volume. . K. Muralidharan et al [25] conducted tests on a single cylinder -stroke variable CR multi-fuel engine fueled with waste cooking oil methyl ester and its 20%, 0%, 60% and 80% blends with diesel engines. T. D. Tsoutsos et al. [26] investigated the conversion of used cooking oils (UCO) to biodiesel for fuel and the biodiesel chain. Shiv Kumar Sharma at el [27] conducted tests on six biodiesel-diesel blends to evaluate the performance characteristics and the main conclusion is that due to high viscosity and density and low calorific value of biodiesel. Abdullah Al-Ghafisst al [28] focused on the effect of injection pressure on thermal efficiency and emission characteristics using a mixture of 10, 20 and 30% waste cooking oil in diesel oil with a compression ratio of 17.5. Haseeb Yaqoob et al [29] carried out a detailed review of waste cooking oil biodiesel, where various parameters of compression ignition engine emissions, heat and combustion efficiency were considered to take into account technical, economic and environmental impacts. Hoi Nguyen Xa and others [30] conducted experiments to collect biodiesel from waste cooking oil using a catalyst and start an engine with biodiesel mixed with commercial diesel. Prajapati P.A et al [31, 32,33] labored on performance, emission and combustion traits for biodiesel extracted from waste cooking cotton seed oil and waste palm cooking oil at 1500 and 1700 RPM for compression ratio 17 and 18. The studies from [34] [35] Nikul K Patel et al. [36] SK Singh et al. summarize biofuel extracted from non-edible seeds and cotton waste. Biofuel are integrated with various applications in an hybrid applications such as heat exchanger [37-40] Patel Anand et al. and solar air & water heater [41-53] Anand Patel et al. to increase energy efficacy and renewability.

1. **EXPERIMENTAL SETUP**

A schematic representation of the test setup, together with the necessary measuring devices, is shown in Table 1. In order to determine the braking power of the motor when driven by an external load group in electrically variable operation, an AC generator with a maximum output of 4.5 kW was directly connected. This test was conducted to investigate the combustion of a diesel engine fueled with a 10% by volume blend of conventional diesel fuel W(C+P)BD on a single cylinder compression ignition engine under five load conditions (no load, 25th % , 50%, 75% and 100% The engine has the ability to measure fuel consumption and engine speed. The engine received air through an air box fitted with a port to measure air consumption. A pressure differential meter was used to measure the pressure difference between them. In the current factory, the engine speed and compression ratio are kept at 1500 rpm, i.e. 17 and 18 respectively.



###### **Figure 1:** Experimental Set up

1. **RESULTS AND DISCUSSION**

**Figure 2:** Net heat release Vs Crank angle for 1500 RPM and for CR 17

**Figure 3:** Net heat release Vs Crank angle for 1500 RPM and for CR 18

Fig 2 and Fig 3 indicate net heat release with variation in crank angle at 1500 RPM and for compression ratio s are 17 and 18 for 10 % blending of mixed biodiesel extracted from waste cooking cotton oil seed and waste cooking palm oil and to obtain better results here effective crank angle should be between 3400-3800 and 3550-3600 for compression ratio of 17 and 18 respectively. In case of 10% the peak values and overall heat release lower than diesel in case of both compression ratios.

**Figure 4:** Cylinder Pressure Vs Crank angle for 1500 RPM and for CR 17

**Figure 5:** Cylinder Pressure Vs Crank angle for 1500 RPM and for CR 18

Fig 4 and Fig 5 show cylinder pressure with variation in crank angle for diesel and blending of a biodiesel obtained from waste cooking cotton seed oil and palm oil and mixing of both equal proportion of 10% with 90 % diesel in case of compression ratios 17 and 18. It is clearly observed from Fig 3 and Fig 4 that with rises in compression ratio the peak is shifted towards left and at compression ratio 18 cylinder pressures almost overlap over diesel cylinder pressure profile.

**Figure 6:** Mean Gas Temperature (MGT) Vs Load for 1500 RPM and for CR 17

**Figure 7:** Mean Gas Temperature (MGT) Vs Load for 1500 RPM and for CR 18

Fig 6 and Fig 7 show mean gas temperature (MGT) variation for diesel blended biodiesel of mixture of both biodiesel with speed 1500 rpm CR 17 and CR 18. From Fig 5 and Fig 6 it is clear that similar trends are found in case of both compression ratio but for CR 18 over entire load variation MGT in case of diesel and Bio diesel blending are almost same.

**Figure 8:** Rate of Pressure Rise Vs Load for 1500 RPM and for CR 17

**Figure 9:** Rate of Pressure Rise Vs Load for 1500 RPM and for CR 18

Fig. 8 and Fig 9 show Rate of Pressure Rise (RPR) with load incase WCO(C+P)BD with diesel in 10%, for 1500 rpm at CR 17 and 18. Compare to compression ratio 17 with increment in compression ratio 18 the values of RPR increases over entire load range.

1. **CONCLUSION**

The major outcome of present work is that the compression ratio is highly influencing parameter in case of combustion studies for bio diesel operated engine.

1. **REFERENCES**
2. Tomesh Kumar Sahu, Sumit Sarkar, Pravesh Chandra Shukla,Combustion investigation of waste cooking oil (WCO) with varying compression ratio in a single cylinder CI engine, Fuel, Volume 283, 2021
3. Swarup Kumar Nayak, Bhabani Prasanna Pattanaik, Experimental Investigation on Performance and Emission Characteristics of a Diesel Engine Fuelled with Mahua BiodieselUsing Additive, Energy Procedia Volume 54, 2014
4. Naveen Kumar, Ankit Sonthalia , Mukul Tomar and Rashi Koul, An experimental investigation on spray, performance and emission of hydrotreated waste cooking oil blends in an agricultural engine, International J of Engine Research, 2020
5. Ahmed I. El-Seesy, Influence of adding multiwalled carbon nanotubes to waste cooking oil biodiesel on the performance and emission characteristics of a diesel engine: an experimental investigation, International Journal of Green Energy, 2019
6. K.A. Abed , A.K. El Morsi, M.M. Sayed, A.A. El Shaib, M.S. Gad, Egyptian Journal of Petroleum, 2018
7. Selvakumar Raja, Jaikumar Mayakrishnan, Sasikumar Nandagopal, Sangeethkumar Elumalai, and Ramanathan Velmurugan, Comparative Study on Smoke Emission Control Strategies of a Variable Compression Ratio Engine Fueled with Waste Cooking Oil, SAE International by University of Minnesota, 2018
8. Ales Hribernik and Breda Kegl, Performance and Exhaust Emissions of an Indirect-Injection (IDI) Diesel Engine When Using Waste Cooking Oil as Fuel, *Energy & Fuels, Volume 23, 2009*
9. Parvaneh Zareha Ali Asghar Zare,, Barat Ghobadian, Comparative assessment of performance and emission characteristics of castor, coconut and waste cooking based biodiesel as fuel in a diesel engine, Energy, 2017
10. Atul Dhar, Avinash Kumar Agarwal, Performance, emissions and combustion characteristics of Karanja biodiesel in a transportation engine, Fuel, Volume 119, 2014
11. Dhinesh Balasubramanian , Anh Tuan Hoang , Inbanaathan Papla Venugopal ,Arunprasad Shanmugam , Jianbing Gao, Tanakorn Wongwuttanasatian, Fuel, 2019
12. M. S. Gad and Mohamed A. Ismail, Effect of waste cooking oil biodiesel blending with gasoline and kerosene on diesel engine performance, emissions and combustion characteristics, Process Safety and Environmental Protection, 2020
13. Murat Kadir YESILYURT, The effects of the fuel injection pressure on the performance and emission characteristics of a diesel engine fuelled with waste cooking oil biodiesel-diesel blends, Renewable Energy, 2018
14. M.A. Kalam, H.H. Masjuki, M.H. Jayed, A.M. Liaquat, Emission and performance characteristics of an indirect ignition diesel engine fuelled with waste cooking oil, Energy, Volume 36, 2011
15. G.R. Kannan , K.R. Balasubramanian , S.P. Sivapirakasam R. Anand, Studies on biodiesel production and its effect on DI diesel engine performance, emission and combustion characteristics, International Journal of Ambient Energy, Volume 32, 2011
16. Esmail Khalife, Hanif Kazeroni, Mostafa Mirsalim, Taha Roodbar Shojaei2,, Pouya Mohammadi, Amran Mohd Salleh, Bahman Najafi, Meisam Tabatabaei,, Experimental investigation of low-level water in waste-oil produced biodiesel-1 diesel fuel blend, Energy, 2016
17. Senthilkumar Masimalai, Venkatesan Kuppusamy, Assessment of Performance, Emission and Combustion Behaviour of a WCO Based Diesel Engine Using Oxygen Enrichment Technique, SAE International, 2015
18. Yahya Ulusoy, Rıdvan Arslan, Yu¨ cel Tekin, Ali Su¨rmen, Alper Bolat, Remzi S ahin, Investigation of performance and emission characteristics of waste cooking oil as biodiesel in a diesel engine, Petroleum Science, Volume 15, 2018
19. Nik Nur Fatin Amiera Nik Aziz, Mazlan Said, Muhammad Syahiran Abdul Malik, Combustion Study of Waste Cooking Oil Biodiesel in an Oil Burner, Jurnal Teknologi, volume 82, 2020
20. X. J. Man, C. S. Cheung, Z. Ning, and K. F. Yung, Effect of Waste Cooking Oil Biodiesel on the Properties of Particulate from a DI Diesel Engine, Aerosol Science and Technology, Volume 49, 2015
21. Sang Hyuck Park, Neelam Khan, Seungjin Lee, Kathryn Zimmermann, Biodiesel Production from Locally Sourced Restaurant Waste Cooking Oil and Grease: Synthesis, Characterization, and Performance Evaluation, ACS Omega volume 4 2019
22. Souvik Barman, Tushar Jash, Study on Optimization of Process Parameters for Biodiesel Production from Waste Cooking Oil and its Cost of Production, International Journal of Engineering Research & Technology, Volume 4, 2015
23. Mohammed Abdul Raqeeb and Bhargavi R, Biodiesel production from waste cooking oil, Journal of Chemical and Pharmaceutical Research, Volume 7, 2015
24. Ales Hribernik and Breda Kegl, Performance and Exhaust Emissions of an Indirect-Injection (IDI) Diesel Engine When Using Waste Cooking Oil as Fuel Energy & Fuels Volume 23, 2009
25. Jeewan VachanTirkey, Amar Kumar Singh, S. K. Shukla, Performance and Emission Characteristics of CI Engine Operated with Waste Cooking oil Methyl-Ester and Diesel Blends, International Journal of Engineering and Advanced Technology, Volume 5 ,2015
26. K. Muralidharan, D. Vasudevan, Performance, emission and combustion characteristics of a variable compression ratio engine using methyl esters of waste cooking oil and diesel blends,Applied Energy 88 (2011) 3959–3968
27. T.D.Tsoutsos, S.Tournaki, O.Paraíba, S.D.Kaminaris, The Used Cooking Oil-to-biodiesel chain in Europe assessment of best practices and environmental performance, Renewable and Sustainable Energy Reviews 54 (2016) 74–83
28. Shiv Kumar Sharma, D.D. Shukla, Kamal Kishore Khatri And Nitesh Singh Rajput, Performance Evaluation of Diesel Engine Using Biodiesel Fuel Derived from Waste Cooking Refined Soyabean Oil**,** IJMPERD, Vol. 7, Oct 2017
29. Abdullah Al-Ghafis and M. Shameer Basha, Experimental Trails on Diesel Engine Performance and Emission Characteristics of Waste Cooking Oil Combinations at Varying Injection Pressures, American Journal of Applied Sciences, Volume 18, 2021
30. Haseeb Yaqoob, Yew Heng Teoh , Farooq Sher, Muhammad Umer Farooq , Muhammad Ahmad Jamil , Zareena Kausar5, Noor Us Sabah, Muhammad Faizan Shah, Hafiz Zia Ur Rehman and Atiq Ur Rehman, Potential of Waste Cooking Oil Biodiesel as Renewable Fuel in Combustion Engines: A Review, Energies Volume 14, 2021
31. Hoi Nguyen Xa, Thanh Nguyen Viet, Khanh Nguyen Duc and Vinh Nguyen Duy, Utilization of Waste Cooking Oil via Recycling as Biofuel for Diesel Engines, Volume 5, Recycling 2020.
32. Prakashkumar A. Prajapati, Dr.Namjoshi Sadanand, Thermal Performance Analysis for Single Cylinder Diesel Engine using Biodiesel from Waste cooking Cottonseed oil and Diesel, International Journal of Mechanical Engineering- Kalhari journal , Volume 6, 2021
33. Prakashkumar A. Prajapati, Dr.Namjoshi Sadanand, Thermal and Emission Evaluation of Single Cylinder Diesel Engine Using Waste Palm Cooking Oil Extracted Biodiesel, International Journal of Mechanical Engineering- Kalhari journal , Volume 7, 2022
34. Prakashkumar A. Prajapati, Dr.Namjoshi Sadanand, Comparative Evaluation of Thermal and Emission characteristics of Extracted Biodiesel from waste cooking cotton seed oil and waste palm cooking oil blended with Diesel, Stochastic Modelling & Application, Volume 6, 2022.
35. Nikul K. Patel, Anand K. Patel, Ragesh G. Kapadia, Shailesh N. Shah, Comparative Study of Production and Performance of Bio-fuel Obtained from Different Non-edible Plant Oils, International Journal of Energy Engineering, Vol. 5 No. 3, 2015, pp. 41-47. doi: 10.5923/j.ijee.20150503.01.
36. Nikul K Patel , Padamanabhi S Nagar , Shailesh N Shah , Anand K Patel , Identification of Non-edible Seeds as Potential Feedstock for the Production and Application of Bio-diesel, Energy and Power, Vol. 3 No. 4, 2013, pp. 67-78. doi: 10.5923/j.ep.20130304.05.
37. SK Singh, SA Namjoshi, A Patel, Micro and Macro Thermal Degradation Behavior of Cotton Waste, REVISTA GEINTEC-GESTAO INOVACAO E TECNOLOGIAS, Volume 11, issue 3, Pages- 1817-1829.
38. Patel, AK, & Zhao, W. "Heat Transfer Analysis of Graphite Foam Embedded Vapor Chamber for Cooling of Power Electronics in Electric Vehicles." Proceedings of the ASME 2017 Heat Transfer Summer Conference. Volume 1: Aerospace Heat Transfer; Computational Heat Transfer; Education; Environmental Heat Transfer; Fire and Combustion Systems; Gas Turbine Heat Transfer; Heat Transfer in Electronic Equipment; Heat Transfer in Energy Systems. Bellevue, Washington, USA. July 9–12, 2017. V001T09A003. ASME. https://doi.org/10.1115/HT2017-4731.
39. Anand Patel, "Thermal Performance Investigation of Twisted Tube Heat Exchanger", International Journal of Science and Research (IJSR), Volume 12 Issue 6, June 2023, pp. 350-353, https://www.ijsr.net/getabstract.php?paperid=SR23524161312, DOI: 10.21275/SR23524161312.
40. Patel, Anand "Performance Analysis of Helical Tube Heat Exchanger", TIJER - International Research Journal (www.tijer.org), ISSN:2349-9249, Vol.10, Issue 7, page no.946-950, July-2023, Available: http://www.tijer.org/papers/TIJER2307213.pdf.
41. Patel, Anand. “EFFECT OF PITCH ON THERMAL PERFORMANCE SERPENTINE HEAT EXCHANGER.” INTERNATIONAL JOURNAL OF RESEARCH IN AERONAUTICAL AND MECHANICAL ENGINEERING (IJRAME), vol. 11, no. 8, Aug. 2023, pp. 01–11. <https://doi.org/10.5281/zenodo.8225457>.
42. Patel, A. (2023k). Enhancing Heat Transfer Efficiency in Solar Thermal Systems Using Advanced Heat Exchangers. Multidisciplinary International Journal of Research and Development (MIJRD), 02(06), 31–51. https://www.mijrd.com/papers/v2/i6/MIJRDV2I60003.pdf.
43. Patel, A. (2023f). Thermal Performance of Combine Solar Air Water Heater with Parabolic Absorber Plate. International Journal of All Research Education and Scientific Methods (IJARESM), 11(7), 2385–2391. http://www.ijaresm.com/uploaded\_files/document\_file/Anand\_Patel3pFZ.pdf
44. Patel, Anand. “Effect of W Rib Absorber Plate on Thermal Performance Solar Air Heater.” International Journal of Research in Engineering and Science (IJRES), vol. 11, no. 7, July 2023, pp. 407–412. Available: https://www.ijres.org/papers/Volume-11/Issue-7/1107407412.pdf
45. Patel, Anand. "Performance Evaluation of Square Emboss Absorber Solar Water Heaters." International Journal For Multidisciplinary Research (IJFMR), Volume 5, Issue 4, July-August 2023. https://doi.org/10.36948/ijfmr.2023.v05i04.4917
46. Anand Patel. “Thermal Performance Analysis of Wire Mesh Solar Air Heater”. Eduzone: International Peer Reviewed/Refereed Multidisciplinary Journal, vol. 12, no. 2, Aug. 2023, pp. 91-96, https://www.eduzonejournal.com/index.php/eiprmj/article/view/389.
47. Patel, A (2023). "Thermal performance analysis conical solar water heater". World Journal of Advanced Engineering Technology and Sciences (WJAETS), 9(2), 276–283. https://doi.org/10.30574/wjaets.2023.9.2.02286.
48. Anand Patel. ""Comparative Thermal Performance Investigation of Box Typed Solar Air heater with V Trough Solar Air Heater"". International Journal of Engineering Science Invention (IJESI), Vol. 12(6), 2023, PP 45-51. Journal DOI- 10.35629/6734".
49. Patel, Anand, et al. “Comparative Thermal Performance Evaluation of U Tube and Straight Tube Solar Water Heater.” International Journal of Research in Engineering and Science (IJRES), vol. 11, no. 6, June 2023, pp. 346–352. www.ijres.org/index.html.
50. Patel, Anand.“Comparative Thermal Performance Investigation of the Straight Tube and Square Tube Solar Water Heater.” World Journal of Advanced Research and Reviews, vol. 19, issue no. 01, July 2023, pp. 727–735. https://doi.org/10.30574/wjarr.2023.19.1.1388.
51. Patel, A (2023). "Comparative analysis of solar heaters and heat exchangers in residential water heating". International Journal of Science and Research Archive (IJSRA),09(02), 830–843. <https://doi.org/10.30574/ijsra.2023.9.2.0689>
52. Patel, Anand. “Comparative Thermal Performance Evaluation of V-shaped Rib and WShape Rib Solar Air Heater.” International Journal of Research Publication and Reviews, vol. 14, issue no. 7, July 2023, pp. 1033–1039.
53. Patel, Anand. “Experimental Evaluation of Twisted Tube Solar Water Heater.” International Journal of Engineering Research & Technology (IJERT), vol. 12, issue no. 7, IJERTV12IS070041, July 2023, pp. 30–34, <https://www.ijert.org/research/experimental-evaluation-of-twisted-tube-solar-water-heater-IJERTV12IS070041.pdf>.
54. Anand Patel. "Effect of Inclination on the Performance of Solar Water Heater." International Journal for Scientific Research and Development 11.3 (2023): 413-416.