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Original Article

Numerical Analysis and Feasibility Study of Compressed Biosyngas Cylinders for Automobile Application

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Abstract *- Sustainable development of the energy system requires renewable fuels for power generation and transportation. The biosyngas is a biomass-derived renewable fuel that has to be stored somewherefor utilization in the automobile. In this study, a biosyngas cylinder with a capacity of 20 litres was designed for Stainless Steel (SS) and Composite Material (CM), i.e., E-Glass Epoxy UD, at a gas pressure of 50 bar and atmospheric temperature of 25 °C. For the design of the gas cylinder, the inner diameter was assumed to be 200 mm. The design results revealed the height of both cylinders to be 716 mm, cylinder wall thickness6.1 mm (SS) and 6.7 mm (CM), and the mass of the empty gas cylinders as 21.49 kg for SS 5.33 kg for CM. Then, ANSYS Static Structural analysis of the gas cylinder was carried out for varying pressures and temperatures for both the materials. Then, the energy content and total weight of the cylinder were analyzed. Further, different layouts were also prepared for the arrangement of gas cylinders in the boot space. The gas cylinder made of CM has corrosion resistance property and has a total mass less than SS cylinder and hence more suitable.*

Keywords - *Biosyngas, Composite Material (E-Glass Epoxy UD), Energy content, Gas cylinder design, and Numerical Analysis*

I. INTRODUCTION

Worldwide global warming is increasing day by day due to a surge in pollution caused by automotive vehicles, industrial plants, and most importantly, due to changes in humans' lifestyles and energy consumption. For sustainable development of the energy system, renewable fuels like biosyngas, bio-hydrogen, biogas, biodiesel are required to be used for energy generation and automobiles. The biosyngas is a renewal gas prepared by the gasification process, by burning the biomass (agricultural, animals, crops, and industrial residues) in the presence of less Oxygen and using the gas coming out from the biomass for the online engines and also for thermal applications.

When anyone talks about biosyngas in the Automobile Sector, the gas has to be stored somewhere. Currently, cylinders are only designed and available for LPG and CNG, so the cylinder has to be designed for its utilization in the automobile. As biosyngas is renewal in nature, it is eco-friendly to nature when compared to existing fossil fuels-based engines that are Petrol and Diesel.

Gasoline engines have already shown their capabilities in automobiles for public transport and heavy-duty commercial vehicles. So, by an increase in pollution, the government also started imposing stringent environmental rules. The company has to lower the exhaust emissions from the internal combustion engines and CO_2 addition into the environment. Therefore, there is a need to shift from fossil fuels to biased renewal fuels like biosyngas, hydrogen, bio-diesels, etc.

The renewal fuels like 'Biosyngas' will play an important role in the future, as fossil fuels are reducing daily. By seeing this, numbers of 'Biosyngas Plants' will be set up in the future. For sustainable energy development, the use of renewable fuels has to be started if anyone wants to save his/her tomorrow, as they are (renewal fuels) not as polluting when directly comparing it to the fossil fuels that are petrol and diesel.

II. BIOSYNGAS CYLINDER FOR AUTOMOBILE APPLICATIONS

A. Biosyngas

Biosyngas or wood gas is a typical mixture of Hydrogen, Carbon Monoxide, Methane, Carbon Dioxide, and Nitrogen. It is produced by partial burring of the biomass in less oxygen, and it is acidic. Its name came from the intermediates of SNG, i.e., Synthetic Natural Gas. The main application of biosyngas is for heat generation and as a fuel for internal combustion engines(Patil et al., Prasad et al., Ray et al.)([1], [2], [3]).

Reference[4] did the study on the renewable syngas process from the biomass. The overall aim of the study was to research and develop a trajectory for biomass-fired entrained flow gasification system for cost-effective, highly efficient, and reliable production of Biosyngas from multiple biomass streams. Reference[5] reported that syngas could be created by gasifying plants biomass or from waste products pyrolysis. The syngas can also be produced from any hydrocarbon feedstock (Panwar et al.) [6].

B. Gaseous fuel operated vehicles

Reference[7] studied Liquefied Petroleum Gas in the vehicles to familiarise legislators with existing practice as LPG is clean and has a low cost of ownership than petrol and diesel. Reference[8] experimented on CNG as a clean fuel in Korea for automobiles applications. This work concluded that, due to changes in the environmental norms and increased pollution, some alternative sources of fuels are required for the existing spark-ignition engines. Reference[9]carried out the ‘Overview of Hydrogen as a Vehicles Fuel’, as hydrogen fuel is moved from mainstream to commercialization purpose, as it is safe for humans and, most importantly, eco-friendly. Their second work aims to inform the people that a carbon-free environment can also be achieved by producing the vehicle with carbon-free renewal energy sources.

C. Designing and numerical analysis of the gas cylinder

The theoretical design of the gas cylinder requires the calculation of thickness, height, and mass of the gas cylinder (Bhandari) [10]. Reference[11] carried out the study on LPG gas cylinder which needs high compressive and tensile and strength for the cylinder. Their objective was to lower the weight of the LPG gas cylinder by using different materials, as steel have some safety glitches. So, they have taken some different Aluminium Alloy materials. Corrosion allowance, paint protection, transportation allowance was also given to the LPG gas cylinder in terms of thickness, so it can have a prolonged lifecycle and can also tolerate some wear and tear. Reference[12]done the software analysis of gas cylinder, where the gas is kept above atmospheric pressure. After that, doing many kinds of literature investigation, they concluded that, gas cylinder fails due to corrosion and the transport of gas cylinder is also challenging([13], [14], [15], [16]). Reference[17]carried out the study on domestic LPG cylinders. They designed the gas cylinder in Solidworks Software and carried out the different results in ANSYS Software. The cylinder must have high strength as it stores the fluid at high pressure [18]. Reference[19]deliberated the behavior of gas-filled in the gas cylinder having different heads like hemispherical and semi-ellipsoidal. Later on, they discovered its response subjected to vertical and horizontal standard impact by using solid spherical steel of weight 4kg at varying rates using ANSYS software.

The literature study found that investigators and researchers have worked on the different aspects of the biosyngas, such as production, cleaning, and characterization. The biosyngas production and direct power generation have also been reported. But for storage of biosyngas in gas cylinders and utilization in automobiles, the design of a gas cylinder for materials like Stainless Steel and Composite Material is still lacking. At present, the gas cylinders are being designed and available for LPG and compressed natural gas(CNG). Therefore, proper design of the gas cylinder is needed for biosyngas [20], [21] [22].

In this study, the design of a gas cylinder with a 20 liter capacity as 50 bar for storage of biosyngas is being carried. The Static Structural analysis of the gas cylinders for varying pressures conditions and temperatures is carried. Further, the energy content and total weight analysis are carried. Finally, different cylinder layouts are prepared to place the biosyngas cylinders in the automobile boot space of the selected vehicle, i.e., Maruti Suzuki Swift.

III. MATERIALS AND METHODS

The study is being carried out in different steps. Initially, the gas cylinder was designed for biosyngas, and numerical analysis was carried out, followed by calculating energy content and total weight analysis. Then different orientations for the biosyngas gas cylinder were prepared for the available boot space of the vehicle.

A. Designing of the gas cylinder

The cylinder for biosyngas was designed for 20 litres of capacity at 50 bar gas pressure. The design calculations were done by using design formulas for thin cylinders (Bhandari) [10]. The thickness of the cylinder was calculated by using Eq. (1).

$$t = \frac{P_i D_i}{2\sigma} \quad \ldots\ldots (1)$$

where t = Cylinder wall thickness (mm), P_i = Internal pressure (bar), D_i = Internal diameter of the gas cylinder, was assumed according to the available boot space in the vehicle (mm), σ = Permissible tensile stress of cylinder material (N/mm^2).

The height of the gas cylinder was calculated by using Eq. (2).

$$H = \frac{(V - 1.33\pi R_i^3)}{\pi R_i^2} + 2R_i + 2t \quad \ldots\ldots (2)$$

where,H = total height/length of the cylinder (mm), V = Volume of the empty cylinder (mm^3), R_i = Inner radius of the cylinder (mm) and t = thickness of the cylinder wall (mm).

Mass of the empty cylinder was calculated by using Eq. (3).

$$m_{cyl} = \left[\frac{4}{3}\pi\left(R_o^3 - R_i^3\right) + 2\pi R_i \times t \times l\right] \times \rho \ldots (3)$$

where,R_i= inner radius of the cylinder (mm), R_o = Outer radius of the cylinder (mm), l = length/height of the cylindrical section, i.e., except hemispherical (mm), and ρ = density of the material for cylinder.

For the design of the gas cylinder, the factor of safety was taken as 2.5. For long-term use of the cylinder, transportation allowance (0.1mm)is also given to the gas cylinder in terms of thickness(Tom et al., 2014) [11]. The design calculations were done for thickness, height, and mass of the empty biosyngas cylinder. The diameter (D_i) of the cylinder was assumed 200 mm, according to its fitment in the available space in the automobile boot. The cylinder was designed using theoretical co-relations for the gas pressures 50 bar for Stainless Steel and Composite material (E-Glass Epoxy UD).

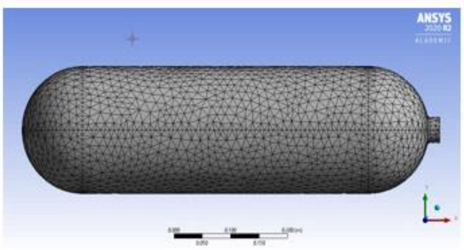
B. Development of CAD model for the gas cylinder

The Computer-Aided Design (CAD) model of the gas cylinder was prepared using SolidworksSoftware as per the specifications shown in Table 1. The prepared CAD model of the gas cylinder is shown in Fig. 1(a).

Table 1Specifications of gas cylinder

Input Parameters	**Stainless Steel**	**Composite Material**(E-Glass Epoxy UD)
Capacity	20 litre	20 litre
Inner diameter	200 mm	200 mm
Outer diameter	206 mm	206 mm
Thickness	6.1 mm	6.7 mm
Height	716 mm	718 mm
Mass of empty cylinder	21.48 kg	6.034 kg

(a) CAD model



(b) Meshing

Fig. 1 CAD model and meshing of the gas cylinder

C. Numerical analysis using ANSYS software

The Static Structural analysis for the gas cylinder was carried out in ANSYS Software [23]. The CAD model was imported in .igs format to the design modular. Then, materials properties were assigned from the project schematic window, and select the Stainless Steel and Composite Material (E-Glass Epoxy UD) from the list of the different materials. Further, the steps followed are **-**

1) ***Selection of Material***: Engineering data was selected from the geometry option in the outline window. After that, select the material Stainless Steel and Composite (E-Glass Epoxy UD) one by one and perform the different conditions on them. Meshing is an integral part of the engineering simulation process where complex geometries are divided into simple elements. The CAD model was discretized with the mesh size of 0.008 m, the number of nodes 31569, and the number of elements 15905.
2) ***StaticStructural***: In Static Structural apply pressure of 50 bar inside the gas cylinder and 1 bar pressure on the gas cylinder (atmospheric pressure). After that, fix the gas cylinder from its nozzle part and apply the thermal condition of 25°C.
3) ***Solution***: Total deformation, directional deformation, max principal strain, thermal strain, and max principal stress were obtained in the form of results, and lastly, save the project.

With the factor of safety 2.5, as selected for the cylinder design, the working yield strength of the material Stainless Steel was 8.28×10^{7} Pa and 8.6×10^{7} Pa for Composite Material (E-Glass Epoxy UD). For the validation of the ANSYS model, the result of maximum principal stress for Stainless Steel8.55×10^{7} Paand for Composite Material (E-Glass Epoxy UD) 9.98 $\times10^{7}$Pa at 50 bar of pressure and 25°C were compared with the working strength of material for the respective cylinder. The percentage difference between maximum principle stress and working yield strength for Stainless Steel was found -3.16 %and for composite Material (E-Glass Epoxy UD) 7.04 %. The error is induced stress, and working stress is less than 10%, and the cylinder is also provided with 2.5-factor safety. Hence, the model is validated for further analysis. Then, numerical analysis was carried out for the varying pressure of 1-200 bar at a constant temperature of 25°C and the varying temperature of 25-1500°C at a constant pressure of 50 bar.

D. Energy content and total weight analysis of the gas cylinder

Energy Content in biosyngas was calculated for finding out the total energy available in the gas at different pressures of the gas, and the Total Weight of the gas cylinder was calculated for finding out the total or the gross weight of the cylinder at different pressures conditions. The mass of the biosyngas in the gas cylinder was calculated by using Eq. (4).

$$m_{gas} = \frac{PVM}{RuT} \quad (4)$$

where, m_{gas}= Mass of gas (kg), P = Pressure of gas (bar), V = Volume of gas (litres), M = Molar mass of gas is 124.5kDa [24], Ru = Universal gas constant (8.31 $J\cdot K^{-1}\cdot mol^{-1}$), T = Absolute temperature of gas (°C)

Based on the mass and the calorific value $(C.V._{BSG})$Of the gas, the Energy Content in the cylinder was calculated by using Eq. (5).

$$E_{BSG} = m_{gas} \times (C.V._{BSG}) \quad (5)$$

where m_{gas}= Mass of the biosyngas in the cylinder and $C.V._{BSG}$= Calorific Value of Biosyngas. Then, based on the mass and the calorific value $(C.V._{Petrol})$ Of the petrol, the Energy Content in the petrol tank was calculated by using Eq. (6).

$$E_{Petrol} = m_{Petrol} \times (C.V._{Petrol}) \quad \ldots\ldots\ldots\ldots\ldots\ldots(6)$$

where, m_{Petrol}= Mass of the Petrol in the tank of selected vehicle and $C.V._{Petrol}$= Calorific Value of Petrol 44 MJ/kg [25].

The total mass of the cylinder, including the mass of the cylinder and the gas, was calculated by using Eq. (7).

$$Total\ mass\ of\ cylinder = m_{empty\ cyl} + m_{gas}. \quad (7)$$

where, $m_{empty\ cylinder}$ = Mass of the empty gas cylinder (kg) and m_{gas} = Mass of the gas-filled in the cylinder (kg). The energy content and total mass were analyzed per cylinder of biosyngas, whereas the fuel quantity for petrol was taken as 37 liters for a passenger car Maruti Swift.

E. Gas cylinder layout

The different arrangements for the biosyngas cylinders were carried out for the available boot space in the selected vehicles, i.e., Maruti Suzuki Swift, which has 268 litres. Approximate length, width, and height are around 1200 mm, 550 mm, and 550 mm, respectively. The study was carried out for different arrangements of cylinders in terms of layouts and the number of cylinders.

IV. RESULTS AND DISCUSSION

A. The thickness of the cylinder at varying pressure

The design calculations were done using Eq. (1) for Stainless Steel and Composite Material (E-Glass Epoxy UD) to find out the thicknessatvarying pressure of 1-100 bar at an interval of 10. The thickness of the gas cylinder with respect to varying pressure is shown in Fig. 2. It is observed from Fig. 2 that the thickness of the gas cylinder wall increased linearly concerning increasing gas pressure. So, with an increase in thickness, the mass of the gas cylinder also increases.

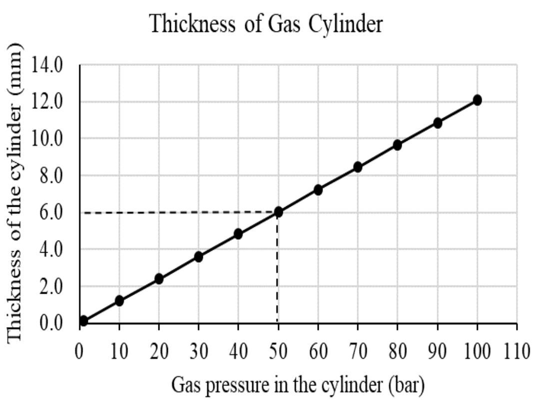


Fig. 2Thickness of the gas cylinder with respect to varying pressure

For the initial design of the gas cylinder gas filed with biosyngas at 50 bar of pressure, the exact thickness of the cylinder comes to be 6.03 mm for Stainless Steel and 5.81 for the Composite Material (E-Glass Epoxy UD). The approximate thickness of both the materials is near each other, so the thickness taken was 6 mm for a capacity of 20 liters.

B. Analysis of gas cylinder for total deformations

The total deformation at 50 bar pressure and 25℃ temperature is shown in Fig. 3, for the gas cylinder made of Stainless Steel and composite material (E-Glass Epoxy UD). It was observed that one end of the gas cylinder (from its nozzle) was fixed (boundary conditions), and the other end was free to move. By comparing both the materials, we can see that total deformation values are more in Composite Material (E-Glass Epoxy UD) then in stainless steel by observing the fringes pattern/color. The deformations at the center of the cylinder were more than its head area. Vector direction was also calculated for both the materials. So for the conclusion, a gas cylinder made of Stainless Steel has a lesser value of total deformation (0.00010158 m) compared to a cylinder made of E-glass Epoxy UD (0.00087198 m).

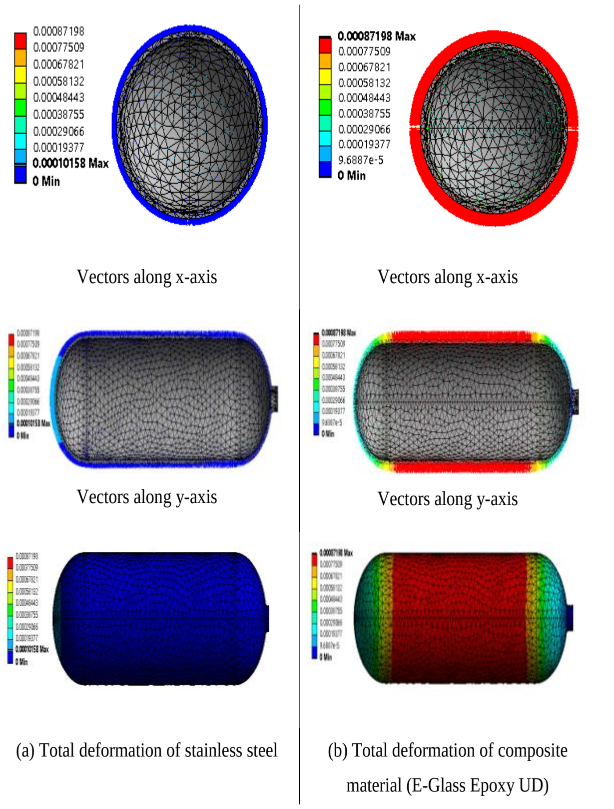
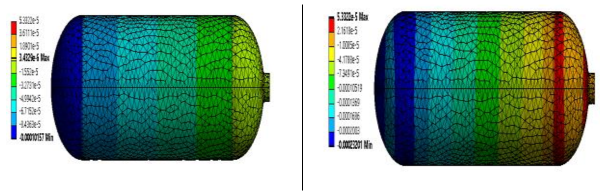


Fig.3Comparison in total deformation in gas cylinders made of stainless steel and composite material (E-Glass Epoxy UD) at pressure 50 bar and temperature 25 ℃

C. Analysis of gas cylinder for directional deformation

The analysis for directional deformation was carried out for both the materials at 50 bar of pressure and 25℃ temperature. The cylinder was fixed from its nozzle part, and the bottom part was allowed to move. It was found that directional deformation in Composite Material (E-Glass Epoxy UD) was more (5.33×10^{-5} m) than directional deformation in the stainless steel material (3.43×10^{-6} m), by seeing its color fringes pattern, which is shown in Fig. 4.



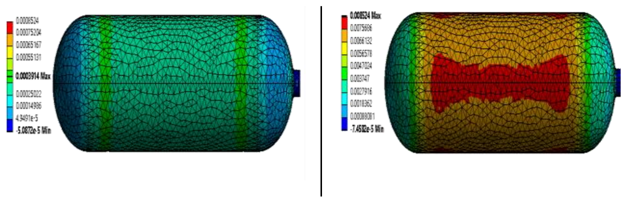
(a) Directional deformation of stainless steel (b) Directional deformation of composite material (E-Glass Epoxy UD)

Fig. 4Directional deformation in gas cylinders made up of stainless steel and composite material (E-Glass Epoxy UD) at pressure 50 bar and temperature 25 °C

Although the deformation is less in stainless steel, Composite Material (E-Glass Epoxy UD) is more secure than stainless steel due to its material properties advantages.

D. Analysis of gas cylinder for maximum principal elastic strain

The maximum principal elastic strain in stainless steel and composite material (E-Glass Epoxy UD) is shown in Fig. 5. Where the pressure was fixed at 50 bar, and the temperature was at 25°C. Here also, the strain values are less in stainless steel (0.0003914 m/m) than in composite material (E-Glass Epoxy UD) (0.008524 m/m). The red color at the center shows the maximum amount of strain-induced in composite (E-Glass Epoxy UD), whereas steel is almost linear. The strain was more constricted at the center part of the gas cylinder in Composite Material (E-Glass Epoxy UD), then moving towered its top and bottom parts.

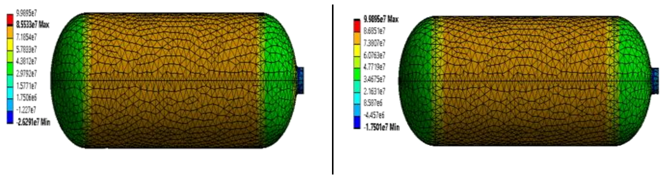


(a) Max principle strain of stainless steel (b) Max principle strain of composite material (E-Glass Epoxy UD)

Fig. 5 Max principle strain in stainless steel and composite material (E-Glass Epoxy UD)at pressure 50 bar and temperature 25 °C

E. Analysis of gas cylinder for maximum principal stress

The maximum principal stress on the gas cylinder is shown in Fig. 6, where the pressure and temperature were fixed at 50 bar and 25°C, respectively. Whereas comparing both of them, the indeed stresses were approximately near to each other by visualizing the results of both, and also the color or fringe pattern is almost identical to each other. The stress values are also in the optimum/desired range. For the conclusion, the stresses level in stainless steel is numerical less (8.55×10^7 Pa), but composite material (E-Glass Epoxy UD) has (9.98×10^7Pa). Despite having more numerical values, it is more suitable for the design of gas cylinders due to its less weight advantage and strength advantages over stainless steel.



(a) Max principal stress of stainless steel (b) Max principal stress of composite material (E-Glass Epoxy UD)

Fig. 6Max principle stress in-cylinder made of stainless steel and composite material (E-Glass Epoxy UD) at pressure 50 bar and temperature 25 °C

Table 2 Comparative analysis results of gas cylinders at 50 bar pressure and at 25°C temperature

Results Parameter	**Stainless Steel**	**Composite Material**(E-Glass Epoxy UD)
Total Deformation	0.00010158 m	0.00087198 m
Directional Deformation	3.43×10^{-6} m	5.33×10^{-5} m
Maximum Principal Elastic Strain Max	0.0003914 m/m	0.008524 m/m
Maximum Principal Stress Max	8.55×10^7 Pa	9.98×10^7Pa

F. Comparison of maximum principal elastic strain at the varying temperature of the gas cylinder

By comparing both the materials simultaneously (Stainless Steel and Composite (E-Glass Epoxy UD)) at 50 bar of pressure and at the temperature of 25°C to 1500°C, it was found that as soon as temperature increase in the cylinder, the maximum principal elastic stain for both the materials increases linearly, which is shown in Fig. 7 for Max principal elastic strain (max). In the case of SS, the induced strain w.r.t. temperature in the case of stainless steel was increased linearly, whereas in the case of E-Glass Epoxy UD, the strain was initially constant up to 200 °C, and later on increased linearly. Also, the value of strain in Composite Material (E-Glass Epoxy UD) was less than in Stainless Steel material at higher temperatures.

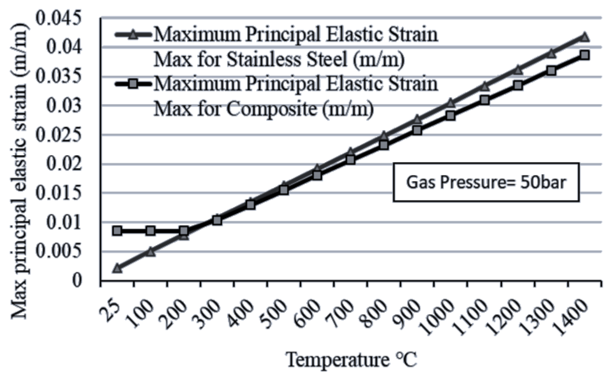


Fig. 7. Max principal elastic strain for stainless steel and composite material (E-Glass Epoxy UD) (max) at varying temperature

Itis observed from Table 2 that all the values in deformations, max principal elastic strain, thermal and in max principal stress, values are likely less in stainless steel when compared to Composite Material (E-Glass Epoxy UD) (E-glass Epoxy UD), but Composite Material (E-Glass Epoxy UD) has its different advantages over stainless steel, like it has low weight, less prone to rusting, has comparable strength to stainless steel. The thickness of the gas cylinder is also directly proportional to pressure inside the cylinder to compensate for the cylinder design. If the pressure increases inside the gas cylinder, the thickness will also increase to compensate for the cylinder design. By observing different results, we can compare different aspects of the cylinder, at what pressure, at what temperature, how the gas cylinder will behave in varying or different temperature and pressure conditions.

G. Analysis of energy content and the total weight of the cylinder

Analysis was carried out for the calculation of energy content and for finding the total weight of the gas cylinder, made of stainless steel and composite (E-Glass Epoxy UD). For biosyngas cylinder of 20 litres capacity at 50 bar pressure, the mass of gas was 5.01 kg per cylinder. The comparative calorific values for biosyngas and petrol are shown in Fig. 8-a. The calorific value of biosyngas was 4.92MJ/kg, which is very low and may affect the driving range of the vehicle when directly comparing it to the calorific value of petrol, i.e., 44 MJ/kg [25]. It is observed from Fig. 8-b that the energy content of biosyngas per cylinders was 24.68 MJ and the energy content in petrol for 37 litres, i.e., the mass of fuel of capacity for Maruti Suzuki Swift 2021was 1172.16 MJas shown in Fig. 8-b. The stored quantity of biosyngas can be increased by increasing the cylinder pressure or by increasing the number of cylinders.

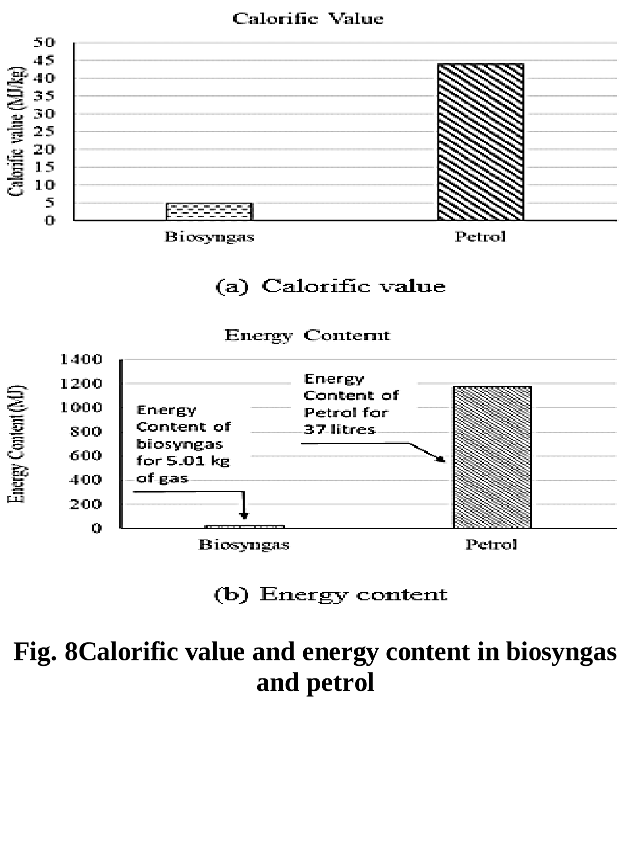


Fig. 8Calorific value and energy content in biosyngas and petrol

After calculating the energy content of the biosyngas, the total weight of the gas cylinder was also calculated for both the materials SS and composite (E-Glass Epoxy UD), as shown in Fig. 9. So by comparing different values of both the materials, it was found that the weight of the composite material (E-Glass Epoxy UD) cylinder was almost half the weight of stainless steel at 50 bar of internal pressure. As a result, Composite Material (E-Glass Epoxy UD) is easy to handle in its day-to-day usage, and also it is rust-resistant.

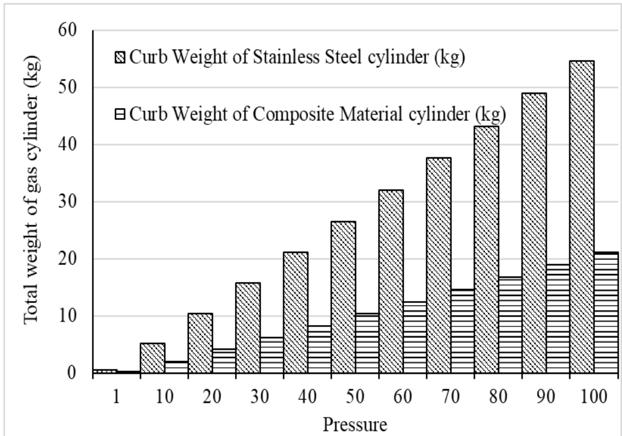


Fig. 9 Total weight of cylinder for stainless steel and E-Glass Epoxy UD

By using the next-gen materials like Composite (E-Glass Epoxy UD) will be playing an important role in the future, as it has added advantages over existing cylinder material, i.e., Stainless Steel. The Composite (E-Glass Epoxy UD) has advantages like corrosion resistance, light in weight, and can withstand the desired temperature and pressure same as Stainless Steel material.

H. Cylinder arrangement and layout

The different cylinder arrangements and layouts were prepared for keeping the biosyngas cylinder in the boot space of Maruti Suzuki Swift 2021 [26], as is shown in Fig. 10. In Swift, up to four biosyngas cylinders can be installed in double(Fig. 10(a)), two near to each other and one on them (Fig. 10(b)), and lastly, two over two (Fig. 10(c)). According to the need of the customers, the cylinder arrangements can be selected, requiring more space or more fuel gas for driving. The more number of cylinders result in more mass of biosyngas, and the more distance traveled. When the number of biosyngas cylinders increases, there is also an increase in the overall weight of the vehicle. Despite the installation of four cylinders, some space is there for keeping the luggage in the boot space.

For two-cylinder arrangements, the total weight becomes 53 kg for SS and 20.68 kg forCM (E-Glass Epoxy UD). For three-cylinder arrangements, the total weight becomes 79.5 kg for SS and 31.02 kg for CM (E-Glass Epoxy UD). Finally, for the four-cylinder arrangements, the total weight becomes 106 kg for SS and 41.36 kg for CM (E-Glass Epoxy UD).

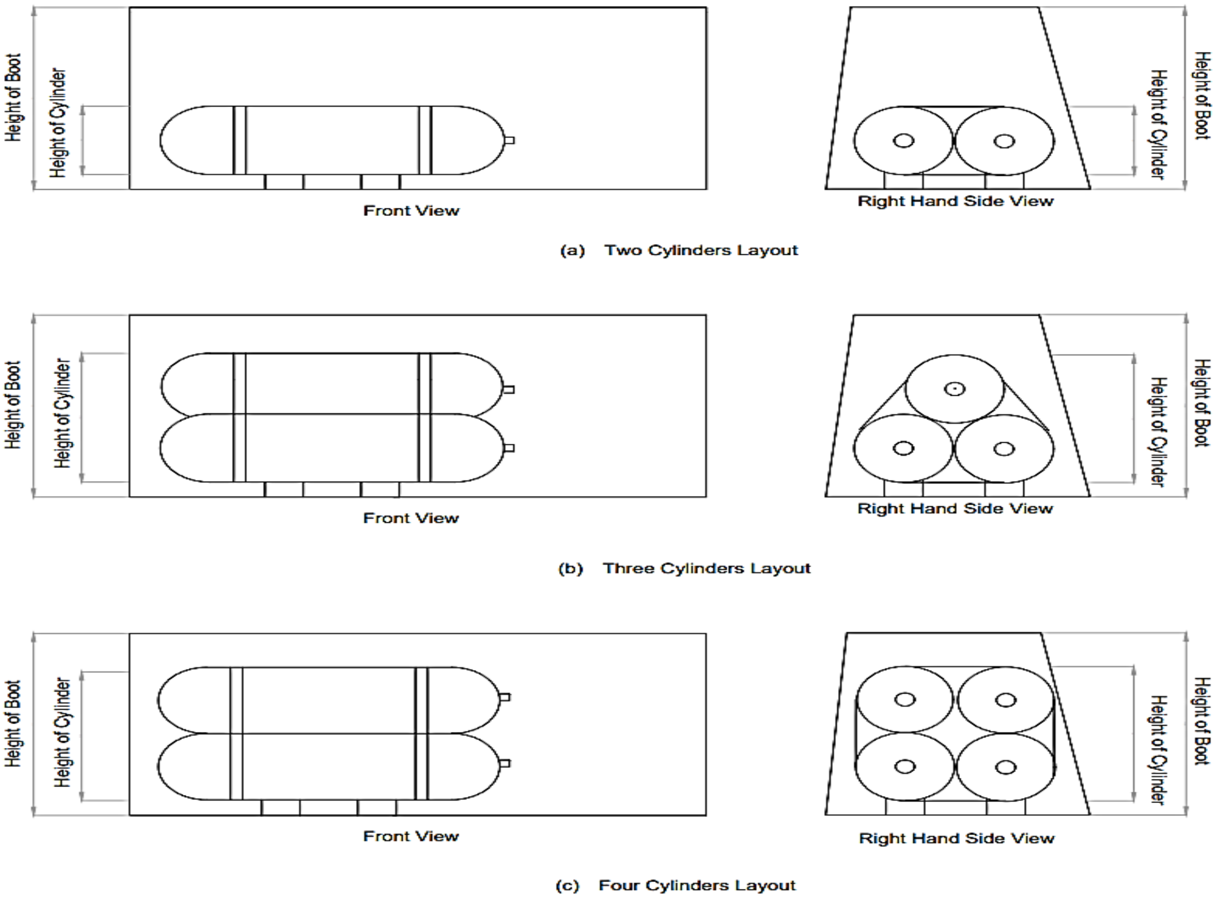


Fig. 10. Gas cylinders arrangement in the boot space of Maruti Suzuki Swift

V. CONCLUSIONS

The design and CAD analysis was carried out for the gas cylinder made of Stainless Steel (SS) and Composite Material (CM), i.e., E-Glass Epoxy UD, for the storage of compressed biosyngas at 50 bar pressure and 25 °C atmospheric temperature.

1) The biosyngas cylinder, designed with a capacity of 20 litres, inner diameter 200 mm, a factor of safety 2.5, and gas pressure 50 bar, has designed specifications height 716 mm and thickness 6.1 mm for SS material, whereas height 718 mm and thickness 6.7 mm for CM. The CAD model analysis results were obtained and found that total deformation of 0.00010158 m for Stainless Steel and 0.00087198 m for Composite Material (E-Glass Epoxy UD), directional deformation of 3.43×10^{-6} m for Stainless Steel and 5.33×10^{-5} m for Composite Material (E-Glass Epoxy UD), the maximum principal elastic strain of 0.0003914 m/m for Stainless Steel and 0.008524 m/m for Composite Material (E-Glass Epoxy UD) and maximum principal stress of 8.55×10^{7} Pa for Stainless Steel and 9.9895 $\times 10^{7}$Pa for Composite Material (E-Glass Epoxy UD)appeared. The gas cylinder made of CM is at par with SS in terms of strength. The temperature variation was more dominant on elastic strain in the SS cylinder in the higher temperature range, as compared to the cylinder made of CM.
2) The total weight and energy content of the biosyngas cylinder was calculated at 50 bar of pressure and a temperature of 25°C. The calorific value of biosyngas 4.92 MJ/kg is quite low as compared to the calorific value of petrol 44 MJ/kg. The energy content of one biosyngas cylinder was 24.68 MJ/cylinder for 5.01 kg of biosyngas at 50 bar of pressure. On the contrary, the energy content of the petrol tank of the selected vehicle with 37 liters capacity was 1172.16 MJ. It implies that more cylinders are to be used in the vehicle. After the calculation of energy content, the total weight analysis was carried out by adding the mass of the biosyngas to the mass of the empty cylinder, which comes out to be 26.5 kg for the stainless steel and 8.24 kg for Composite Material (E-Glass Epoxy UD) for 20 litres of volume capacity at 50 bar of gas pressure.
3) The different layouts were prepared for placing the biosyngas cylinder in the boot space of the selected vehicle, Maruti Suzuki Swift. It was found that the three-cylinders arrangement is more convenient and stable as the 3rd cylinder was placed above and in between the two-cylinder, which gives it more stability. The total weight of three filled gas cylinder arrangements was found 79.5 kg for Stainless Steel and 31.02 kg for Composite Material (E-Glass Epoxy UD). Hence, composite material (E-Glass Epoxy UD) is

preferred over SS for storage of biosyngas and for placing it in the boot of the vehicle.

The composite material is corrosion-resistant, light in weight, and also the cylinder can withstand the desired pressure and temperature for various applications when compared with Stainless Steel material. As per the desired gas pressure and availability of the space for placing the cylinders, the specific layout selection can be customized according to the need of the customers. The experimental study on biosyngas compression above 50 bar would reveal more options for biosyngas storage at a higher pressure and more energy content in the fuel tank.

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