Preparation Parametric Comparison and Performance Evaluation of FRP and HDPE Type Biogas Digesters

Rishi Pareek and Hemant J. Nagarsheth

***Abstract*—This paper reports a systematic study regarding comparison of construction material of biogas digester. Indian government as per data is promoting the use of domestic biogas plant in rural and urban areas of country. In the current scenario prefabricated biogas plants (PB) are rather preferred over the tradition cement concrete plants .Basically two main types of digesters are available in the market made of High-Density Polyethylene (HDPE) and Fiber Reinforced Plastic (FRP).In the present work analysis has been done practically on the digesters to depict the material type which serves the purpose efficiently. Various parameters and tests such as tensile test, strength to weight ratio and temperature retaining capability of material were considered during the research work. Three specimen of variable thickness were taken under consideration for tensile test according to ASTM Standard D 638. Highest peak load of 2441.9 N with elongation of 7.9 mm was obtained for FRP Specimen of 4mm thickness. Strength to weight ratio of FRP material with thickness of 2.7mm was at the higher side giving value of 6.06 Temperature retaining capability serves better platform in case of FRP material which further helps in growth of methanogens and hence biogas production. The outcome of the present work suggests the use of FRP tanks in place of cement, HDPE and other materials for the production of biogas.**

***Index Terms*—Biogas digester, FRP, HDPE.**

I. Introduction

In recent years, biogas technology has been elevated worldwide as a result of encouraged use of Alternative energy resources for various applications. Its use has led to the recognition of the many benefits of domestic biogas. In context to India, Ministry of New and Renewable Energy has implemented the National Biogas and Manure Management Programme (NBMMP) in all the States and UTs of the country. About 47.5 Lakh biogas plants have already been installed in the country upto 31st March, 2014. During the year 2014-15, a target of setting up 1, 10,000 biogas plants has been set [1].

The Biogas plant is the best option for households having organic raw material as an input for Biogas digester, to become self- dependent for cooking gas and highly organic enriched bio-fertilizer. It provides the solution to protect the households from the problems of indoor air pollution generated as a result of burning of wood or cow dung cake and while saving on cost of refilling of LPG cylinders.

Various researchers have done work on production of biogas, including the design, development and construction of prefabricated Biogas digesters. Basically Biogas digesters are bifurcated into large scale (Communal) digesters having capacity greater than 25 m3 and individual small scale biogas digester with capacity less than 6m3. One approach of improving energy access is to establish demand-side indicators for improved monitoring and evaluation of existing biogas schemes and their adoption and use at the community level [2]. Community-level biogas initiatives are currently absent in developing country like India [3]. Most domestic biogas digesters in developing regions are constructed onsite and made of bricks and concrete. The poor construction of digesters, however, may cause leakages after a short period of operation. Once broken, digesters cannot be repaired easily for normal operation.

Moreover, construction is often time consuming, lasting for as long as several months [4] because of a dependency on weather conditions. Appropriate plant models are required to be adapted to various geological, topographical, and climate conditions. The frequently chosen materials for prefabricated biogas digesters are listed below in the Table I [5].

TABLE I: Materials for Prefabricated Biogas Digesters [5]

Type	Materials
BD (Bag type Digester)	For example: PVC (polyvinyl chloride, sometimes called geo - membrane) , PE (polyethylene), PAMM (polymethyl methacrylate), LDPE (low-density polyethylene), and neoprene
CMD (Composite Material Digester)	For example: FRP, hard PVC, ABS (acrylo nitrile butadiene styrene, polypropylene, HDPE, LLDPE (linear low — density polyethylene),
Ferro-or bamboo and cement	Cement and wire mesh or bamboo

Focusing on small scale domestic digester this paper reports the systematic study and parametric comparison of most commonly used material for domestic small scale biogas digester i.e. HDPE type biogas digesters and FRP (Fiber Reinforced Plastic) biogas digester. Various parameters are taken under consideration while comparing the specimen like tensile strength, peak load bearing capacity, temperature retaining ability, production of biogas and economical aspect. The present work is taken up to try a material in place of HDPE worth to be used for development of small domestic prefabricated biogas digester.

II. Methodology and Experimentation

Experiments were performed comparing FRP and HDPE material on the basis of load bearing capacity in reference to elongation, stress & strain graphs to portray ultimate tensile strength , weight to strength ratio of each specimen. Also literature survey for the life, reparability and ease of manufacturing was accounted as a part of research work.

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Rishi Pareek and Hemant J. Nagarsheth are with the Departement of Mechanical Engineering, S. V. National Institute of Technology, Surat, Gujarat, India (e-mail: rishi.pareek@outlook.com, hemantnagarsheth@gmail.com).

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A. Tensile Test of Specimen

Tensile test was conducted to evaluate the stress-strain graphs, ultimate tensile strength and peak load with elongation of FRP and HDPE material used for manufacturing domestic prefabricated biogas plants. Tensile Testing was done considering ASTM standard test method for tensile properties of plastics and reinforced composite designation: D 638 - 02a. Specimens as shown in Fig. 2 were machined according to the D 638 ASTM standard Type 1 dimensions as shown in Fig. 1.

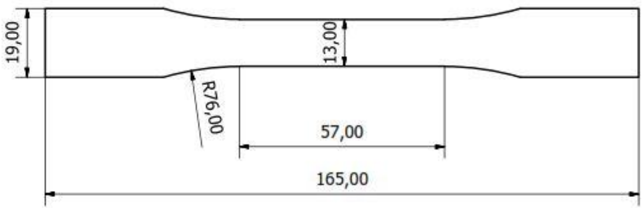

Fig. 1. ASTM standard test specimen D638 2D sketch (dimensions in mm).

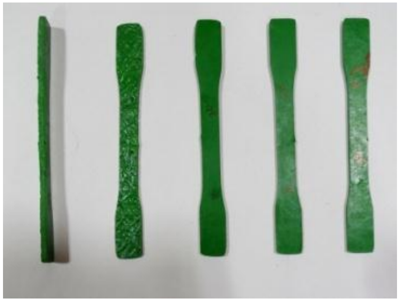
Fig. 2. Photo of specimen obtained after water jet machining.

Experiments were carried out for tensile strength of HDPE and FRP material considering various samples as specified in the Table II.

TABLE II: SPECIMEN NOTATION

Material	Thickness	Notation
FRP	2.7mm	F2.7
FRP	3.1mm	F3.1
FRP	4mm	F4.0
HDPE	3.7mm	H3.7


Fig. 3. Photo of Tensometer with FRP and HDPE specimen.

Tenso-meter attached with load cell of 20050 N was used considering test speed of 10 mm / min. Grippers were adjusted and specimen was allowed to rest between grippers as shown in Fig. 3, at standard length according to ASTM standards. After the completion of tensile test graphs were plotted between load vs. displacement and stress vs. strain. Fig. 4-Fig. 7, show the plot between load and displacement of all four specimens respectively.

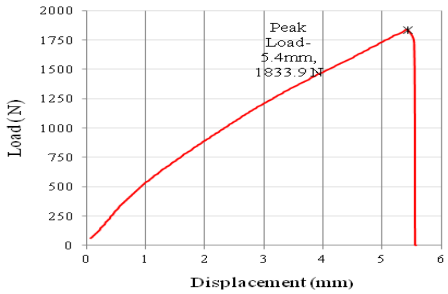

Fig. 4. Load vs. displacement for FRP – F2.7.

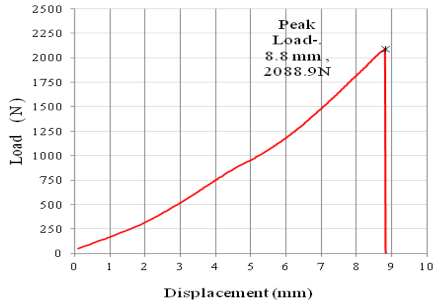

Fig. 5. Load vs. displacement for FRP – F3.1.

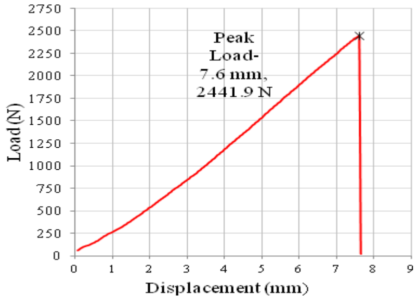

Fig. 6. Load vs. displacement for FRP – F4.0.

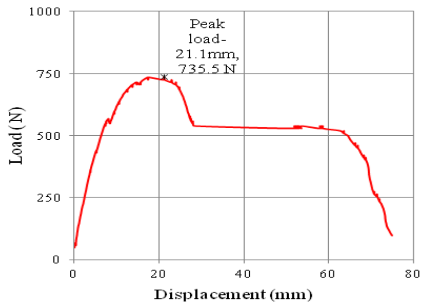

Fig. 7. Load vs. displacement graph.

After plotting curves between load vs. Displacement, readings of stress and strain were obtained during the experimentation and graphs were plotted shown in Fig. 8-Fig. 11 for all four specimen F2.7, F3.1, F4.0, HDPE 3.7 respectively.

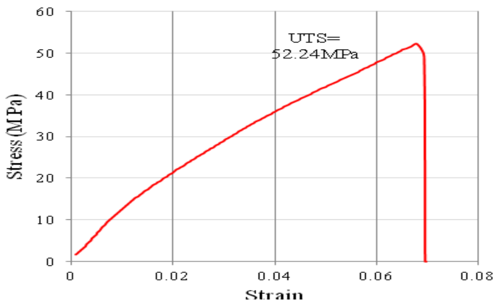

Fig. 8. Stress vs. strain graph for FRP - F2.7.

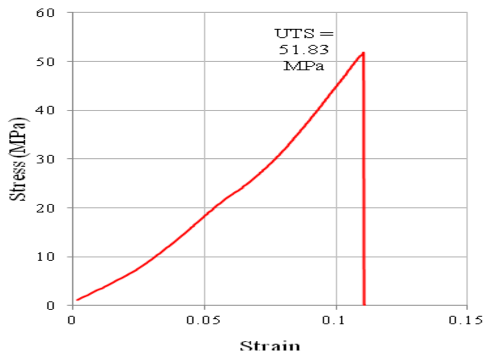

Fig. 9. Stress vs. strain graph for FRP - F3.1.

As peak load with the elongation was labelled in load vs. displacement graph, in the same way UTS (Ultimate Tensile Strength) points were also shown in stress- strain curve. These points denote the maximum stress that a specimen can withstand while being stretched or pulled before failing or breaking.

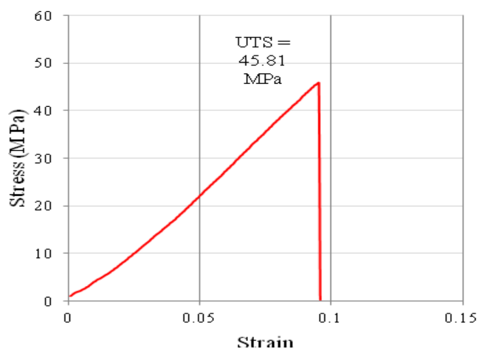

Fig. 10. Stress vs. strain graph for FRP – F4.0.

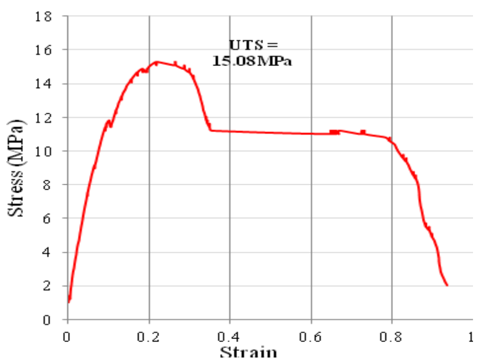

Fig. 11. Stress vs. strain graph for (HDPE - H3.7).

B. Strength-to-Weight Ratio

Strength-to-weight ratio is a material's strength in relation to the self weight of the specimen. Some materials are very impregnable and heavy such as steel, other materials can be strong and light, such as bamboo poles. Composite materials can be designed to bridge the gap and serve both strong and light. This property makes composites suitable to build efficient and durable biogas digesters. Weight of specimen were taken on highly precise lab balance Make: Mettler Toledo, model ME 204.

Each specimen precisely weighed on the machine as shown in Fig. 12 and readings were noted down for further analysis. Strength to weight ratio was calculated as tabulated below in the Table III and also graphically representation is shown in Fig. 13.

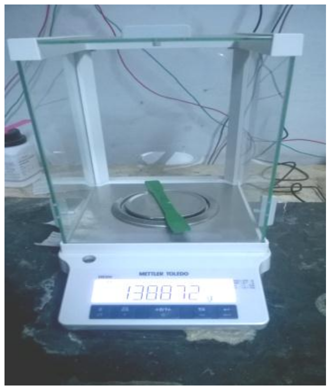

Fig. 12. Photograph of FRP specimen on weighing scale.

TABLE III: ULTIMATE TENSILE STRENGTH AND WEIGHT RATIO OF SPECIMEN

Material	Notation	UTS (MPa)	Weight (Grams)	Strength/Weight ratio
FRP	F2.7	52.24	8.6171	6.062364
FRP	F3.1	51.83	13.8872	3.732214
FRP	F4.0	45.81	14.5431	3.149947
HDPE	H3.7	15.08	16.1933	0.931249

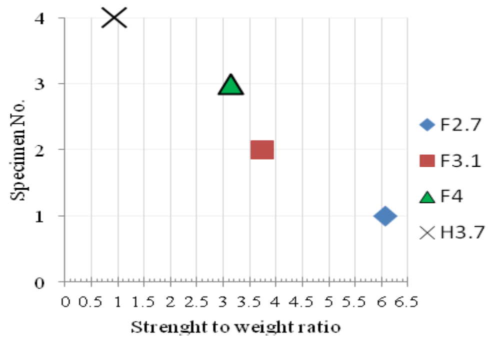

Fig. 13. Point graph showing strength to weight ratio.

C. Temperature Retaining Capability

One of the important and difficult parameters to preserve within optimized limits in domestic biogas digesters is the temperature. It is well demonstrated by researchers that breakdown of organic matter in slurry stores increases with temperature [6]. Few studies portray that Methanogens are active, even at a very low temperature [7]-[11]. According to some observations, the amount of biogas produced by high temperature 20° to 45 ℃ (mesophilic) and low HRT (Hydraulic Retention Time) is comparably on higher side to the biogas produced with low temperature (psycrophilic) and high HRT [7]. People living in mountain valleys or outside of tropical regions suffer from low digestion rates in turn low biogas production during the winter season, when the temperature drops below 15 ℃ [8]. The temperature in the digesters in winter is likely to be affected by a range of different factors, but basic factor considered by researchers are air temperature, degree of heat exchange between the digester and the air, soil temperature, temperature of inflowing slurry, temperature of the water mixed with raw material to make slurry [9]. It is well-known that the thermophilic temperatures (41 °and 122 ℃) are more efficient than the mesophilic in terms of retention time, loading rate, and nominal biogas production but it needs a higher energy input, more expensive technology, and greater sensitivity to operating and environmental variables, which make the process more problematic than mesophilic digestion [10]. Low temperature has a deleterious effect on methanogenesis, which is the main process for generation of biogas and can cause decreased gas yields and digester failure [11].

The economical solution here can be suggested to make the biogas digester with material such as FRP so as to retain the inside temperature of digester. To compare the temperature retaining capability of FRP material tanks and HDPE tanks, temperature readings inside biogas digester were taken (Fig. 14) for continuous 10 days in context to ambient temperature. Graph plotted with the help of reading taken is portrayed further in Fig. 15.

Fig. 14. Photograph of probe thermometer employed to obtain inside temperature of digester.

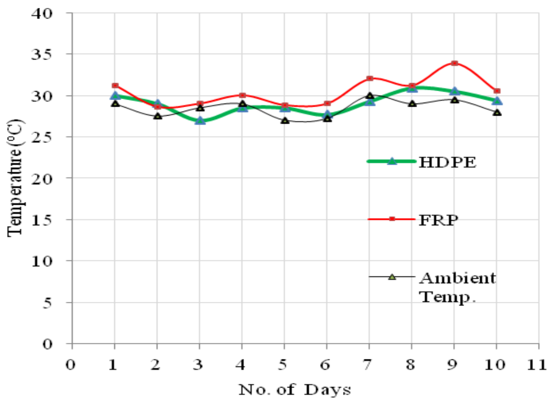

Fig. 15. Inside temperature of FRP and HDPE biogas digester.

D. Long-Term Performance and on Site Structural Reparability

FRP storage tanks for liquids are ideal application of FRP using corrosion and solvent resistant resins. These tanks are easy to install, more economical than the conventional materials like HDPE, and they have better service life. Researchers visualize that within a few years large number of tanks, starting from municipal water tanks to large petrochemical tanks, will be built with FRP composites [12].

FRP composites are ideally suited as quick and effective structural repair tool because of their lightweight, high strength and corrosion resistance. FRP digester can be easily and quickly repaired on site where as it is not possible in case of HDPE tank. One has to again send back HDPE tank to the manufacturer to accomplish remoulding process which in turn is too much time consuming and expensive. There are several other advantages also which make FRP Digester much suitable for the use of Production of Biogas. FRP Digester can be custom made as per the requirement due to their simple manufacturing process and number of resins and variable thickness glass fibre available in market as compared to HDPE [13]. FRP strengthening and reinforcing can be applied to concrete and masonry structural elements to resist loads from wind, soil pressure, increased/super imposed framed level loading, fluid pressure [14].

III. Results and Discussions

The analysis exposes several important relations among load applied with elongation, stress–strain curves, strength to weight ratio and temperature retaining capability of both the materials when used for biogas digester. Tensile test results clearly portray the emphasis towards use of FRP material over HDPE in construction of prefabricated biogas plants.

A. Tensile Test of Specimen

It can be suggested from the graphs depicted (Fig. 4-Fig. 7) during tensile test to use FRP material due to high load bearing capacity with low elongation. Table IV below shows the comparison of peak load and elongation of all specimens during tensile testing.

TABLE IV: Results of Peak Load and Elongation

Specimen	Peak Load (N)	Elongation (mm)
F2.7	1833.9	5.4
F3.1	2088.9	8.8
F4.0	2441.9	7.6
H3.7	735.5	21.1

Maximum peak load was observed during tensile test of specimen F4.0 with the elongation of 7.6mm which is around 3 times on higher side if compared with the peak load of HDPE specimen H3.7.

It can be suggested with the help of above observation that FRP provided higher peak load value for even lower thickness when compared to the HDPE material which is again another reason to use it as construction material for biogas digester.

B. Strength-to-Weight Ratio

Another parameter considered during the research work and experimentation was Ultimate Tensile Strength of the test specimen. Table III clearly portray that the FRP specimen F4.0 leads 3 times in UTS readings if compared to HDPE specimen H3.7which again supports the use of FRP for making prefabricated biogas digester. It can be observed in Fig. 13 that higher value of UTS for FRP further gives better results for strength to weight ratio. Maximum value of strength to weight ratio is observed with FRP specimen F2.7 of 6.06, which is far better if compared to 0.93 for HDPE material specimen H3.7.

From the above observation it can be seen that FRP can be used in place of HDPE. It is lighter in weight with good ultimate tensile strength of 45.81 Mpa for sample F4.0 as compared to 15.08 Mpa of HDPE sample H3.7. This observation shows the usability and ease to use FRP as it would serve lighter in weight with more strength, hence helpful in installation and transportation.

C. Temperature Retaining Capability

Most important factor to be considered while working with the biogas production is the temperature at which fermentation takes place inside biogas digester. It can be mentioned referring Fig. 15 that FRP serves better temperature retaining ability if compared to HDPE material. Maximum temperature gained inside FRP biogas digester was 33.9^{o}C at ambient temperature of 29.5^{o}C, at same condition HDPE digester is showing 30.5^{o}C temperature inside biogas digester. Graph in Fig. 15 clearly shows that at different ambient temperature FRP material retains higher temperature as compared to HDPE which further supports the quality and production of biogas.

IV. Conclusions

FRP digesters are considered an appropriate technology compared to HDPE digesters in expanding use of biogas as an alternate energy resources in developing countries like India. Advantages, such as highly adaptable to design change and high strength to weight ratio compared to HDPE make FRP much reliable as a construction material for biogas digester.

Former advantage to focus the use of FRP can be suggested as the temperature retaining capability, which is the important parameter in the growth of methanogen bacteria and in turn accelerate the biogas production.

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Rishi Pareek is pursuing his Ph.D. degree in the Mechanical Engineering Department at Sardar Vallabhbhai National Institute of Technology, Surat, Gujarat, India. He has been awarded the M.Tech degree in mechanical in 2012 with distinction from S.V. National Institute of Technology. His major field of study includes alternative energy recourses, biomass and biofuels, application of biogas in I.C. engine.

He had worked with Maruti Suzuki Joint Venture Company which located in Gurgaon, Haryana, India in the Department of Quality System and Quality Assurance. He also has presented and published two research papers in international conferences.

Mr. Pareek is also a member of Institute of Industrial Engineers, life time member of Indian Society of Technical Education, life time member of Indian Society of Mechanical Engineers, associate member of the Institution of Engineers (India) and life time member of Indian Biogas Association.

Hemant J. Nagarsheth currently serving as a professor and the head of the Department in Mechanical Engineering, Sardar Vallabhbhai National Institute of Technology, Surat , Gujarat, India. He has completed his Ph.D degree in 2006 and the M.tech degree in 1987 from S.V. National Institute of Technology. He has been awarded the bachelor degree of engineering from Bombay University in 1978. His research interest includes automobile engineering, robotics and bio-mechanic.

He had also served in various renowned industries namely Himpson Textile Ltd. located in Gujarat, Premier Automobiles Ltd., Crompton Greeaves Ltd., New Standard Engineering located in Mumbai. In acedamic field, he had also served in the Government Engineering College located in Surat, Gujarat, India and S.V. National Institute of Technology, Surat, Gujarat, India. He has more than 15 publications in various international and national journals and conferences.

Dr. Nagarsheth holds the lifetime membership of Indian Society of Technical Education and the Indian Biogas Association.

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